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SRC BURN TEST IN 700-hp OIL-DESIGNED BOILER
Boiler Emission Report
Final Technical Report

September 1983

Work Performed Under Contract No. AC05-78OR03054

WFI Sciences Company
Coraopolis, Pennsylvania

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy



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FINAL TECHNICAL REPORT:
SRC BURN TEST IN 700-hp OIL-DESIGNED BOILER.
ANNEX VOLUME C:
BOILER EMISSION REPORT

Prepared by

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under subcontract to

INTERNATIONAL COAL REFINING COMPANY
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for the

UNITED STATES DEPARTMENT OF ENERGY
Office of Solvent-Refined Coal Products
under Contract DE-AC05-78-OR0-3054

SRC TEST BURN PROGRAM
WHEELABRATOR-FRYE INC.
SUMMARY

The International Coal Refining Company (ICRC) is under contract from the Department of Energy (DOE) to study the technical feasibility and marketing potential of solvent-refined coal (SRC) fuels for oil-fired boiler applications. The technical aspects of the boiler fuel system conversion, combustion performance, and emission control system performance were studied through an SRC combustion test program, conducted at the Pittsburgh Energy Technology Center (PETC). Testing was conducted on the 700-hp watertube industrial boiler, designed for oil firing. Base-line data was collected by firing No. 6 fuel oil. Feasibility data were obtained by firing three types of SRC fuels: Pulverized SRC Solids, SRC Residual Oil, and SRC-Water Slurry.

The scope of work performed by the Air Pollution Control (APC) Division of Wheelabrator-Frye Inc. (WFI) and WFI Sciences was as follows: (1) provide mobile electrostatic precipitator (ESP); (2) operate and maintain the ESP; (3) provide a report on evaluation of ESP performance; (4) provide a reverse air pilot filter (PF); (5) operate and maintain the PF; (6) provide a report on evaluation of the PF performance; (7) provide equipment and personnel for assessment of particulate mass emissions at the ESP inlet and outlet and boiler outlet; (8) provide a report on particulate mass emissions data; (9) provide equipment and personnel for determination of particulate mass emissions from the existing pulse-jet baghouse (PJ); and (10) provide a report on the PJ mass emissions.

Results from the ESP evaluation report indicate that the fly ash from combustion of all three SRC fuels is easily removable by a conventional dry ESP. A relatively small collecting area is needed to collect the fly ash, but rapping reentrainment may necessitate a larger box. The pilot ESP was not set up to minimize rapping reentrainment, which was evident during the test program. Full-size units can be designed to minimize rapping reentrainment by varying the number of ESP fields, by minimizing plate height, and by using a low rapping intensity.

Results from the fabric filter feasibility evaluation report indicate that the particulate emissions from SRC fuels combustion were successfully controlled to less than $0.01 \text{ lb}/10^6 \text{ Btu}$, well within the particulate emission limit of the Federal Environmental Protection Agency (EPA) New Source Performance Standard (NSPS) of $0.03 \text{ lb}/10^6 \text{ Btu}$ for electric utility steam-generating units. The amount of controlled particulate emissions from the SRC fuels combustion was equal to or less than the controlled particulate emissions from the No. 6 fuel oil combustion. Thus, the SRC Test Burn Program clearly established that the conventional fabric filters make a feasible control device for emissions from SRC-fuel-fired boilers.

Results from the boiler emission report show that the uncontrolled particulate emissions averaged $0.92 \text{ lb}/10^6 \text{ Btu}$ for SRC Solids, $0.20 \text{ lb}/10^6 \text{ Btu}$ for SRC Residual Oil, and $0.91 \text{ lb}/10^6 \text{ Btu}$ for SRC-Water Slurry.

A detailed review of the findings of ESP and Fabric Filter studies is provided in the reports submitted by Wheelabrator-Frye Inc. and WFI Sciences for the SRC Test Burn Program.

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I. EXECUTIVE SUMMARY

The Solvent-Refined Coal (SRC) test burn program was conducted at the Pittsburgh Energy Technology Center (PETC) located in Bruceton, Pa. One of the objectives of the study was to determine the feasibility of burning SRC fuels in boilers set up for fuel oil firing and to characterize emissions. Testing was conducted on the 700-hp oil-fired boiler used for research projects. No. 6 fuel oil was used for baseline data comparison, and the following SRC fuels were tested: SRC Fuel (pulverized SRC), SRC Residual Oil, and SRC-Water Slurry.

Uncontrolled particulate emission rates averaged $0.9243 \text{ lb}/10^6 \text{ Btu}$ for SRC Fuel, $0.1970 \text{ lb}/10^6 \text{ Btu}$ for SRC Residual Oil, and $0.9085 \text{ lb}/10^6 \text{ Btu}$ for SRC-Water Slurry. On a $\text{lb}/10^6 \text{ Btu}$ basis, emissions from SRC Residual Oil averaged 79 and 78%, respectively, lower than the SRC Fuel and SRC-Water Slurry. The lower SRC Residual Oil emissions were due, in part, to the lower ash content of the oil and more efficient combustion. The SRC Fuel had the highest emission rate, but only 2% higher than the SRC-Water Slurry.

Each fuel type was tested under variable boiler operating parameters to determine its effect on boiler emissions. The program successfully demonstrated that the SRC fuels could be burned in fuel oil boilers modified to handle SRC fuels.

This report details the particulate emission program and results from testing conducted at the boiler outlet located before the mobile precipitator take-off duct. The sampling method was EPA Method 17, which uses an in-stack filter.

II. SUMMARY OF RESULTS

Table 1 summarizes particulate emissions data from the boiler outlet sampling location. The data represent the arithmetic mean average of all the tests conducted during each fuel burn. The particulate concentrations and emission rates are presented in both metric and English units. The concentrations and emission rates of particulates were based on filterable particulate matter and exclude any condensable particulate fractions. Southern Research Institute (SoRI) and WFI jointly decided to exclude particulate condensibles, in order to reduce the turnaround time between tests.

All of the results for each fuel burn are presented in detail in Section V, Results. No tests were performed for the base-line oil testing.

Table 1
Boiler Emission Summary

TEST DATES	NO. OF TESTS	FUEL TYPE	PARTICULATE EMISSION DATA							
			CONCENTRATION				EMISSION RATE			
			^a mg/M ³	^b Gr/ACF	^c mg/M ³	^d Gr/DSCF	^e kg/HR	^f Lb/HR	^g ng/J	^h LB/10 ⁶ BTU
10/29/82 through 11/19/82	19	Pulverized SRC	518	0.2263	1,063	0.4645	11.4	25.2	397.4	0.9243
12/8/82 through 12/17/82	21	SRC Residual	133	0.0607	269	0.1175	2.3	5.2	84.7	0.1970
1/5/83 through 1/14/83	15	SRC Water Slurry	581	0.2538	1,218	0.5322	11.3	24.8	390.6	0.9085

- a milligrams per cubic meter
- b grains per actual cubic feet
- c milligrams per standard cubic meter
- d grains per dry standard cubic feet
- e kilograms per hour
- f pounds per hour
- g nanograms per joule of heat input
- h pounds per million BTU of heat input

III. INTRODUCTION

From October 29, 1982 through January 14, 1983, particulate emission testing was conducted by WFI Sciences' field crew on the 700-hp boiler at the Pittsburgh Energy Technology Center (PETC) in Bruceton, Pa. The testing was conducted as part of International Coal Refining Company's (ICRC) SRC-I combustion research project. The main objective of the program was to acquire SRC-I combustion characteristics in the 700-hp oil-designed boiler for a data base line to use for optimization and utilization of the SRC fuels on utility-sized boilers.

During the SRC Fuel, SRC Residual Oil, and SRC Water-Slurry fuel burns, particulate emission testing was conducted at the boiler outlet located before the mobile electrostatic precipitator (ESP) takeoff. All of the boiler operating parameters were designated and monitored by Southern Company Services, Inc. This report details the particulate loading data for the boiler outlet and the sampling methodology used.

IV. PROCEDURES AND METHODOLOGY

Boiler Outlet

At the boiler outlet, sampling was conducted in two ports, located 90° apart in the 24-in. inner diameter (i.d.) circular duct (see Figures 1 and 2). The sampling train (see Figure 3) consisted of a stainless steel nozzle; an in-stack alundum thimble; a heated stainless steel probe; an out-of-stack, heated, 47-mm fiberglass filter; a sample line; a condenser; and a silica gel holder. A meter box containing a pump, calibrated dry gas meter, orifice, and inclined manometer followed the sampling train.

Sampling Procedure

All sampling trains were set up and run according to EPA Reference Method 17. Prior to testing, the train was assembled using tared filter media and then leak-checked at 15-in. Hg vacuum. After the train was found to be leak-free, ice was placed around the condenser to keep the sample gases below 68°F during the tests. The probe was then placed and the pressure differential (ΔP) recorded. The orifice differential (ΔH), required to maintain an isokinetic rate of $100 \pm 10\%$, was then calculated using isokinetic sampling equations. This was done at each sample point. At the conclusion of the test, the sampling train was leak-checked at the highest vacuum attained during the test run.

Sample Recovery

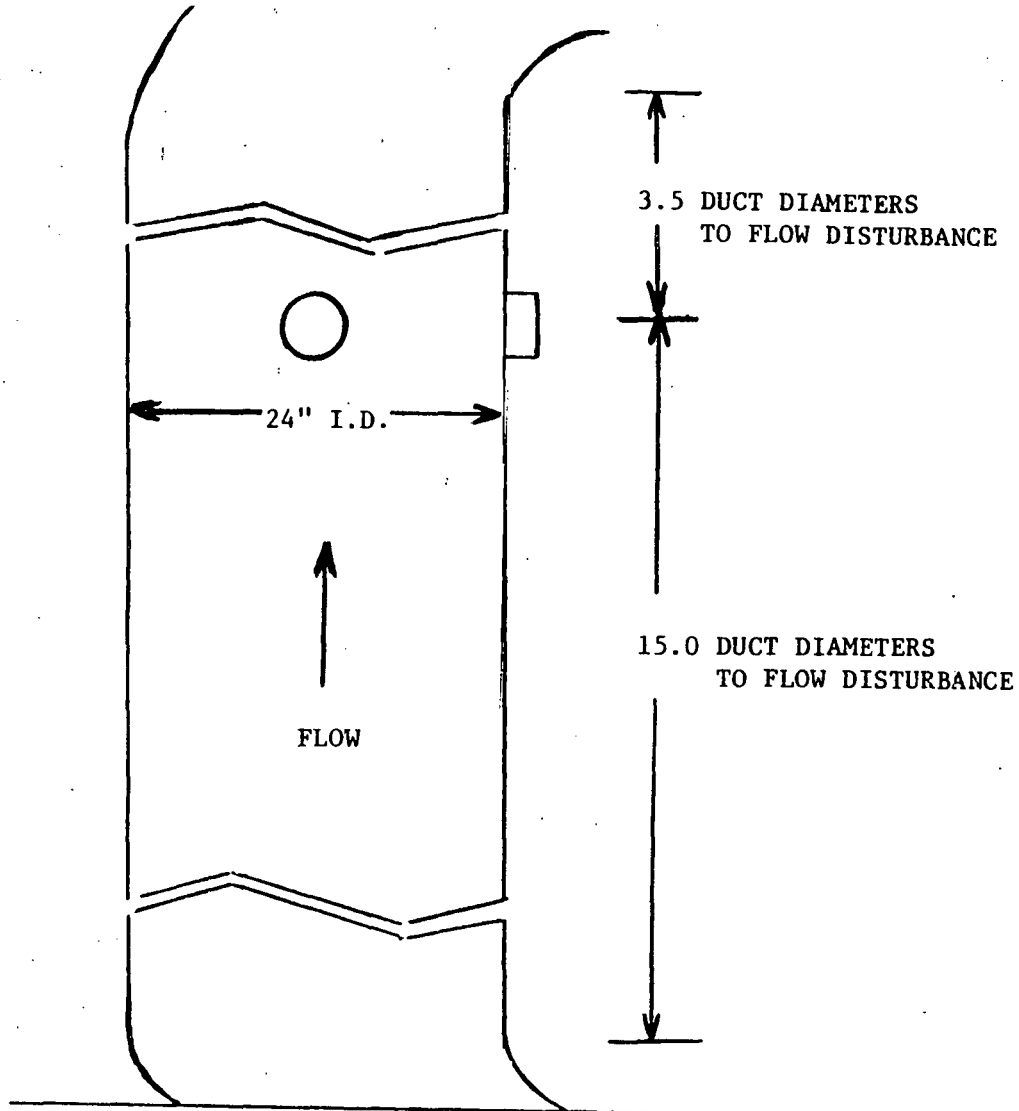
At the end of the test run, the sampling train was removed from the stack, leak-checked, and moved to the cleanup area. The sample fractions were recovered as follows:

No. 1. The alundum thimble was removed from its holder, capped, and placed in its identified container and labeled.

No. 2. The 47-mm fiberglass backup filter was removed from its holder and placed along with any loose filter fibers into its identified container and labeled.

Figure 1

Boiler Outlet Sample Location



2 SAMPLE PORTS

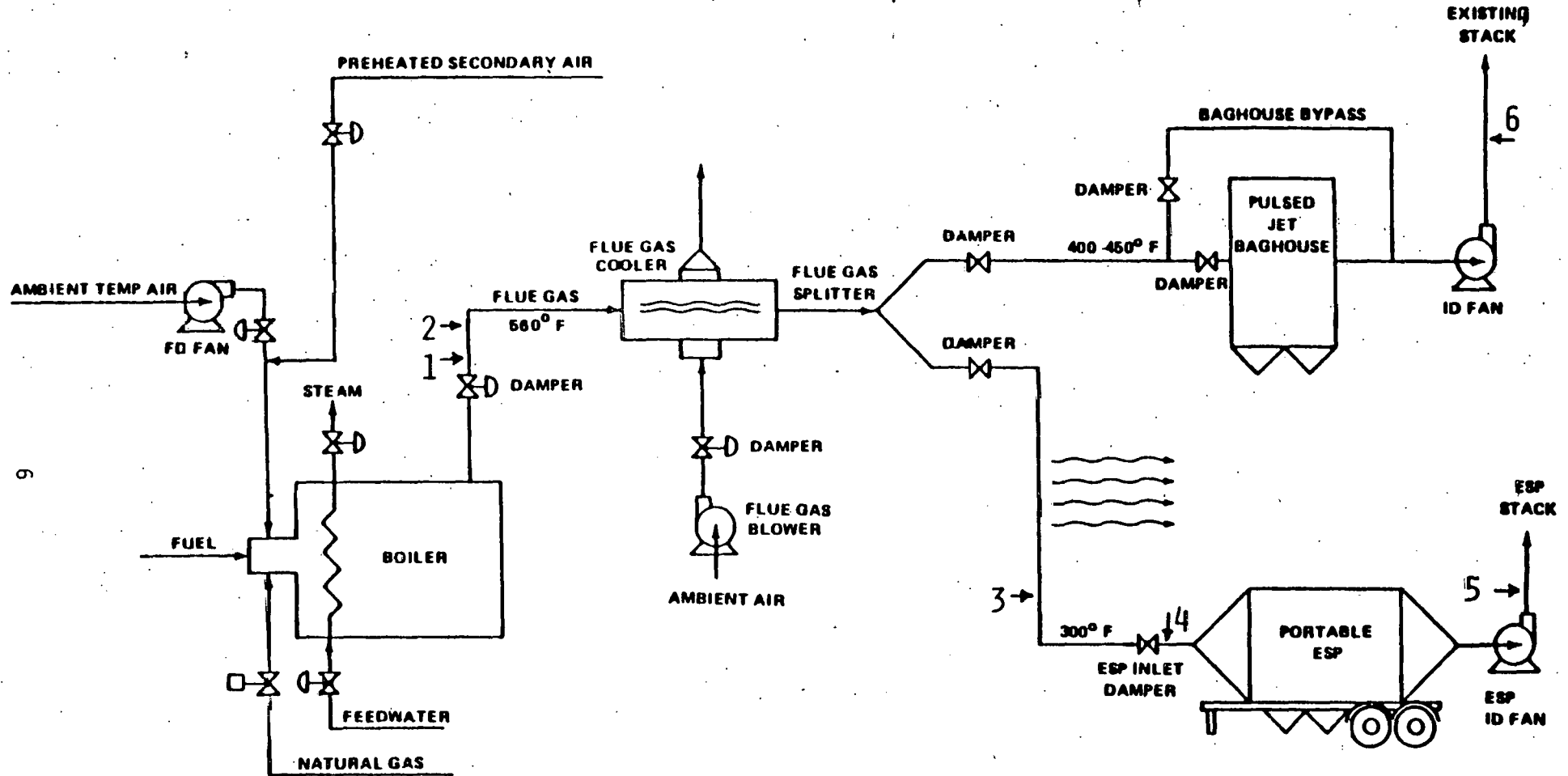
24" DUCT DIAMETER

12 TOTAL SAMPLE POINTS

6 PER PORT

TRAVERSE POINT	PERCENT OF DUCT DIAMETER
1	4.4
2	14.6
3	29.6
4	70.4
5	85.4
6	95.6

Figure 2
Boiler Outlet Sample Location



FLUE GAS SAMPLING SITES

<u>NO.</u>	<u>NAME</u>
1	BOILER OUTLET (GE)
2	BOILER OUTLET (WFI SC.)
3	INLET TO REVERSE AIR PILOT FILTER
4	ESP INLET
5	ESP OUTLET
6	PULSE JET BAGHOUSE STACK

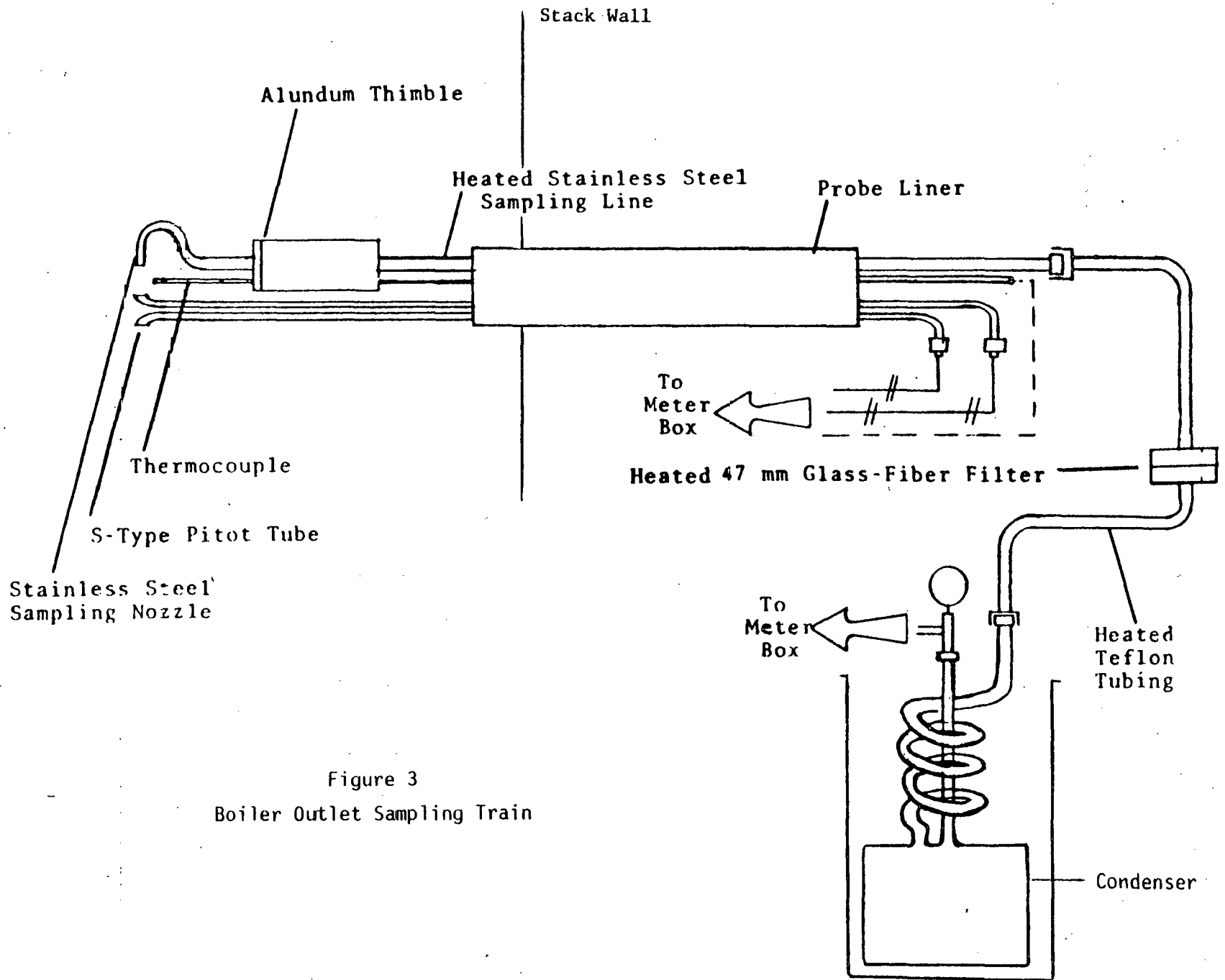


Figure 3
Boiler Outlet Sampling Train

No. 3. The nozzle and probe sample was recovered by rinsing with acetone from a wash bottle and brushing. The nozzle and probe were rinsed until no particles were visible in the rinse. The sample was stored in a polyethylene sample bottle and labeled.

No. 4. An acetone blank was taken.

No. 5. The condensate in the condenser was measured to the nearest milliliter and discarded.

No. 6. The silica gel was weighed to the nearest 0.5 g and discarded.

Sample Analysis

No. 1. The alundum thimble was dried in an oven at 105°C for 2 to 3 hr, cooled in a desiccator, and weighed to a constant weight.

No. 2. The 47-mm fiberglass backup filter was dried in an oven at 105°C for 2 to 3 hr, cooled in a desiccator, and weighed to a constant weight.

No. 3. The acetone nozzle rinse was measured, transferred to a tared 250-mL beaker, evaporated to dryness, desiccated for 24 hr, and weighed to a constant weight.

No. 4 (Acetone Blank). The acetone blank was treated in the same manner as the nozzle rinse. A correction was then made in the rinse sample to account for any acetone contamination.

V. RESULTS

Table 2 summarizes the boiler outlet sampling data, including sample times, gas sample volumes, and isokinetic sampling rates. These data are integrated by the fuel burn type. Table 3 presents the flue gas parameters including % CO₂, % O₂, % moisture, and gas flow rates. Table 4 presents the particulate emission data, including particulate concentrations and emission rates. All tables present parameters in both metric and English units, where applicable. Table 5 summarizes the loss on ignition (L.O.I.) data for the particulate samples taken, and Table 6 lists fuel and flue gas analyses for each of the SRC fuels. Results are discussed in Section VI.

Table 2

Boiler Outlet Sampling Data: SRC Fuel Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	SAMPLE TIME			GAS SAMPLE VOLUME		ISOKINETIC ^c SAMPLING RATE %
			24 Hr. Clock		Total Test Time-Min.	a M ³	b DSCF	
			Start	Finish				
10-29-82	BO-1	1029-1*	11:21	13:13	120	1.638	57.857	79.3
10-29-82	BO-2	1029-2*	18:43	20:12	120	1.496	52.810	68.2
11-1-82	BO-3	1101-1*	13:50	15:56	120	2.122	74.926	106.3
11-1-82	BO-4	1101-2*	17:31	20:06	120	2.264	79.954	103.9
11-3-82	BO-5	1103-1*	15:58	17:31	84	1.560	55.087	99.7
11-4-82	BO-6	1104-1*	11:51	13:55	120	2.248	79.387	95.5
11-15-82	BO-7	1115-1*	8:58	11:01	120	2.264	79.937	101.7
11-15-82	BO-8	1115-2*	18:00	19:54	107	2.037	71.942	95.3
11-16-82	BO-9	1116-1*	9:03	11:07	120	2.380	84.036	105.2
11-16-82	BO-10	1116-2*	16:38	17:03	25	0.525	18.530	94.9
11-16-82	BO-11	1116-3*	18:43	19:26	43	0.919	32.463	96.5
11-17-82	BO-12	1117-1*	8:50	10:54	120	2.515	88.818	103.6
11-17-82	BO-13	1117-2*	14:44	16:51	120	2.513	88.724	100.5
11-18-82	BO-14	1118-1*	14:22	16:25	120	2.409	85.059	98.6
11-18-82	BO-15	1118-2*	17:02	19:07	120	2.572	90.806	97.1
11-19-82	BO-16	1119-1*	8:37	10:34	120	2.356	83.208	99.4
11-19-82	BO-17	1119-1*	11:53	12:01	8	0.135	4.909	86.1
11-19-82	BO-18	1119-2*	12:41	14:47	120	2.314	81.727	98.3
11-19-82	BO-19	1119-3*	15:46	17:52	120	2.461	86.913	96.8

* steady state test

a cubic meters at standard conditions (20°C and 760 mm Hg)

b dry standard cubic feet at standard conditions (68°F and 29.92" Hg)

c % isokinetic = $\frac{\text{velocity of gases entering nozzle}}{\text{velocity of approaching stack gases}} \times 100$

Table 2 (Continued)

Boiler Outlet Sampling Data: SRC Residual Oil Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	SAMPLE TIME			GAS SAMPLE VOLUME		ISOKINETIC SAMPLING RATE %
			24 Hr. Clock		Total Test Time-Min.	M ³	DSCF	
			Start	Finish				
12-8-82	B0-20	1208-1**	10:22	12:31	120	1.985	70.103	104.5
12-8-82	B0-21	1208-2**	14:58	17:04	120	1.888	66.663	103.2
12-9-82	B0-22	1209-1**	9:00	11:07	120	2.231	78.768	102.4
12-9-82	B0-23	1209-2**	13:23	15:30	120	2.199	77.668	102.8
12-10-82	B0-24	1210-1*	11:49	13:56	120	2.001	70.670	104.4
12-10-82	B0-25	1210-2*	14:27	17:19	120	2.051	72.440	107.1
12-13-82	B0-26	1213-1*	11:06	13:14	121	1.980	69.903	105.2
12-13-82	B0-27	1213-2*	14:13	16:23	120	1.943	68.596	102.8
12-14-82	B0-28	1214-1*	9:00	11:09	120	1.922	67.879	103.7
12-14-82	B0-29	1214-2*	12:00	14:07	120	1.971	69.588	105.2
12-14-82	B0-30	1214-2*	15:30	17:40	120	1.944	68.656	103.4
12-15-82	B0-31	1215-1*	8:58	11:04	120	1.972	69.653	105.3
12-15-82	B0-32	1215-2*	11:34	13:41	120	1.951	68.879	102.6
12-15-82	B0-33	1215-2*	14:15	16:22	120	1.964	69.365	103.7
12-15-82	B0-34	1215-3**	17:10	18:14	60	0.910	32.126	106.7
12-16-82	B0-35	1216-1*	8:34	10:40	120	1.954	68.998	103.3
12-16-82	B0-36	1216-2*	11:15	13:20	120	1.923	67.892	102.6
12-16-82	B0-37	1216-3**	16:00	18:05	120	2.150	75.928	101.0
12-17-82	B0-38	1217-1*	9:21	11:28	120	1.934	68.304	102.8
12-17-82	B0-39	1217-1*	11:52	13:57	120	1.919	67.776	101.1
12-17-82	B0-40	1217-2*	14:33	16:38	120	1.923	67.902	103.4

* steady state test

** parametric test

Table 2 (Continued)
 Boiler Outlet Sampling Data: SRC-Water Slurry Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	SAMPLE TIME			GAS SAMPLE VOLUME		ISOKINETIC SAMPLING RATE %
			24 Hr. Clock		Total Test Time-Min.	M ³	DSCF	
			Start	Finish				
1-5-83	BO-41	0105-1**	10:24	12:34	120	2.108	74.438	98.0
1-6-83	BO-42	0106-1**	8:39	10:49	120	2.117	74.763	100.2
1-7-83	BO-43	0107-1**	9:01	10:31	84	1.393	49.194	99.2
1-7-83	BO-44	0107-1**	11:16	12:45	84	1.360	48.028	97.6
1-7-83	BO-45	0107-2**	15:31	16:46	60	0.966	34.121	101.5
1-10-83	BO-46	0110-1**	8:50	10:59	120	2.086	73.676	95.5
1-10-83	BO-47	0110-2**	12:53	15:27	123	2.144	75.694	94.4
1-11-83	BO-48	0111-1*	8:48	10:54	120	2.121	74.911	112.0
1-11-83	BO-49	0111-2*	11:31	13:38	120	2.015	71.146	103.5
1-12-83	BO-50	0112-1*	8:57	11:02	120	1.956	69.059	99.8
1-12-83	BO-51	0112-2*	12:10	14:15	120	1.970	69.570	102.6
1-13-83	BO-52	0113-1*	8:07	10:13	120	1.994	70.410	100.4
1-13-83	BO-53	0113-2*	10:45	12:51	120	1.953	68.962	98.9
1-14-83	BO-54	0114-1*	8:22	10:28	120	1.889	66.695	103.8
1-14-83	BO-55	0114-2*	11:13	13:20	120	1.926	68.029	96.8

* steady state test
 ** parametric test

Table 3
Boiler Outlet Flue Gas Data: SRC Fuel Testing Series

DATE	WFI TEST NO.	BOILER TEST NO.	PERCENT			PERCENT MOISTURE BY VOLUME	GAS DENSITY		STATIC PRESSURE		STACK TEMP.		GAS VELOCITY		GAS FLOW RATES			
			By Volume	Excess	Air		a	b	c	d	e	f	g	h	i	j	k	l
			CO ₂	O ₂			kg/m ³	lb/ft ³	G/cm ²	IN. HG	°C	°F	cm/SEC	FPM	ACFM	ACFM	DSCFM	DSCFM
10-29-82	BO-1	1029-1	14.6	4.4	25.9	5.6	.628	.0392	-23.6	-9.3	280	537	1,895	3,731	332	11,721	158	5,591
10-29-82	BO-2	1029-2	13.6	6.0	39.4	6.4	.613	.0383	-18.8	-7.4	291	556	2,062	4,060	361	12,755	168	5,931
11-1-82	BO-3	1101-1	12.8	5.0	29.9	6.2	.639	.0399	-19.3	-7.6	265	510	1,759	3,462	308	10,870	150	5,298
11-1-82	BO-4	1101-2	12.3	5.9	37.6	6.7	.628	.0392	-20.8	-8.2	273	523	1,994	3,925	349	12,325	167	5,888
11-3-82	BO-5	1103-1	12.6	5.6	35.0	6.2	.612	.0382	-17.8	-7.0	287	549	2,096	4,127	367	12,958	171	6,047
11-4-82	BO-6	1104-1	13.2	5.4	33.6	5.3	.644	.0402	-19.5	-7.7	262	503	2,099	4,132	367	12,974	181	6,387
11-15-82	BO-7	1115-1	12.2	6.4	42.4	6.0	.647	.0404	-21.1	-8.3	262	503	1,967	3,873	344	12,167	171	6,024
11-15-82	BO-8	1115-2	11.2	7.0	47.9	5.5	.645	.0403	-20.5	-8.1	263	506	2,109	4,152	369	13,043	184	6,488
11-16-82	BO-9	1116-1	12.0	6.8	46.4	5.6	.647	.0404	-20.8	-8.2	261	502	1,992	3,922	349	12,320	173	6,119
11-16-82	BO-10	1116-2	12.0	6.8	46.4	3.7	.647	.0404	-19.0	-7.5	265	510	2,311	4,549	405	14,291	203	7,175
11-16-82	BO-11	1116-3	11.0	7.8	57.2	5.7	.634	.0396	-18.5	-7.3	269	517	2,382	4,689	417	14,732	204	7,194
11-17-82	BO-12	1117-1	11.8	8.0	60.7	5.8	.641	.0400	-20.0	-7.9	266	511	2,162	4,256	379	13,371	186	6,567
11-17-82	BO-13	1117-2	11.8	6.8	46.3	6.4	.647	.0404	-20.5	-8.1	258	497	2,209	4,348	387	13,658	191	6,762
11-18-82	BO-14	1118-1	10.8	8.0	59.5	6.5	.647	.0404	-15.2	-6.0	260	500	2,155	4,243	377	13,331	187	6,608
11-18-82	BO-15	1118-2	11.8	7.0	48.5	5.5	.634	.0396	-12.7	-5.0	276	529	2,377	4,680	416	14,702	203	7,167
11-19-82	BO-16	1119-1	13.0	6.6	45.1	6.4	.658	.0411	-20.8	-8.2	253	488	2,071	4,077	363	12,807	182	6,413
11-19-82	BO-17	1119-1	13.0	6.6	45.1	7.1	.636	.0397	-20.5	-8.1	270	518	2,200	4,331	385	13,608	185	6,551
11-19-82	BO-18	1119-2	11.4	7.0	48.1	6.8	.650	.0406	-19.5	-7.7	254	490	2,072	4,079	363	12,815	180	6,369
11-19-82	BO-19	1119-3	11.4	7.0	48.1	6.1	.628	.0392	-19.8	-7.8	275	528	2,267	4,462	389	13,746	195	6,882

a kilograms per cubic meter
b pounds per cubic feet
c grams per square centimeter
d inches of water
e degrees centigrade
f degrees fahrenheit

g centimeters per second
h feet per minute
i actual cubic meters per minute
j actual cubic feet per minute
k dry standard cubic meters per minute
at 68°F and 29.92" Hg
l dry standard cubic feet per minute
at 68°F and 29.92" Hg

Table 3 (Continued)
Boiler Outlet Flue Gas Data: SRC-Water Slurry Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	PERCENT			PERCENT MOISTURE BY VOLUME	GAS DENSITY		STATIC PRESSURE		STACK TEMP		GAS VELOCITY		GAS FLOW RATES			
			By Volume CO ₂	Excess O ₂	Air		Kg/M ³	Lb/FT ³	G/cm ²	IN. WG	°C	°F	cm/SEC	FFM	ACFM	ACFM	DSCFM	DSCFM
1-5-83	BO-41	0105-1	14.4	3.4	18.6	10.7	.658	.0411	-17.2	-6.8	248	478	1944	3826	341	12,043	165	5,835
1-6-83	BO-42	0106-1	14.0	4.1	23.4	11.3	.647	.0404	-22.6	-8.9	247	476	1946	3831	341	12,060	162	5,731
1-7-83	BO-43	0107-1	14.0	3.6	19.8	11.3	.657	.0410	-22.6	-8.9	235	455	1823	3588	320	11,294	154	5,440
1-7-83	BO-44	0107-1	13.8	4.0	22.6	10.7	.639	.0399	-22.6	-8.9	250	482	1848	3638	324	11,452	153	5,397
1-7-83	BO-45	0107-2	14.8	3.0	16.0	10.7	.639	.0399	-24.4	-9.6	250	483	1774	3492	311	10,994	146	5,163
1-10-83	BO-46	0110-1	14.0	5.0	30.5	10.7	.645	.0403	-13.7	-5.4	249	480	2009	3954	352	12,449	168	5,919
1-10-83	BO-47	0110-2	13.2	4.0	22.4	10.5	.631	.0394	-13.7	-5.4	259	499	2076	4087	364	12,867	170	6,009
1-11-83	BO-48	0111-1	13.0	4.0	22.3	10.1	.631	.0394	-23.3	-9.2	252	485	1767	3478	310	10,950	145	5,134
1-11-83	BO-49	0111-2	14.0	4.0	22.7	12.2	.633	.0395	-23.6	-9.3	249	483	1847	3636	324	11,446	149	5,279
1-12-83	BO-50	0112-1	13.8	4.0	22.6	10.5	.684	.0427	-6.8	-2.7	228	443	1697	3340	298	10,516	150	5,314
1-12-83	BO-51	0112-2	14.8	3.6	20.1	11.8	.653	.0408	-6.3	-2.5	251	484	1762	3469	309	10,921	147	5,204
1-13-83	BO-52	0113-1	14.0	4.0	22.7	9.8	.644	.0402	-24.1	-9.5	253	488	1822	3587	320	11,291	152	5,385
1-13-83	BO-53	0113-2	13.5	4.3	24.7	11.8	.649	.0405	-23.8	-9.4	243	470	1816	3575	319	11,255	151	5,350
1-14-83	BO-54	0114-1	13.4	4.2	23.9	11.6	.665	.0415	-6.8	-2.7	233	451	1630	3208	286	10,099	140	4,935
1-14-83	BO-55	0114-2	13.6	3.8	21.1	11.4	.653	.0408	-6.1	-2.4	243	470	1815	3574	319	11,253	153	5,397

Table 3 (Continued)
Boiler Outlet Flue Gas Data: SRC Residual Oil Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	PERCENT By Volume Excess			PERCENT MOISTURE BY VOLUME	GAS DENSITY		STATIC PRESSURE		STACK TEMP		GAS VELOCITY		GAS FLOW RATES			
			CO ₂	O ₂	Air		Kg/M ³	Lb/FT ³	G/cm ²	IN. WG	°C	°F	cm/SEC	FPM	ACFM	ACFM	DSCMM	DSCFM
12-8-82	BO-20	1208-1	15.4	3.2	17.5	9.5	.689	.0430	-25.6	-10.1	235	455	1,635	3,219	287	10,130	146	5,149
12-8-82	BO-21	1208-1	15.4	2.6	13.6	9.8	.666	.0416	-26.1	-10.3	250	483	1,627	3,203	285	10,080	140	4,957
12-9-82	BO-22	1209-1	13.0	4.8	28.4	9.3	.668	.0417	-24.6	- 9.7	240	465	1,907	3,755	335	11,820	167	5,902
12-9-82	BO-23	1209-2	13.6	5.4	33.8	8.6	.674	.0421	-24.6	- 9.7	239	463	1,855	3,652	325	11,493	164	5,801
12-10-82	BO-24	1210-1	14.8	3.2	17.3	10.1	.655	.0409	-25.9	-10.2	244	471	1,733	3,411	304	10,736	147	5,194
12-10-82	BO-25	1210-2	15.0	3.0	16.1	9.7	.657	.0410	-25.9	-10.2	235	455	1,695	3,336	297	10,500	147	5,192
12-13-82	BO-26	1213-1	15.0	3.2	17.4	10.0	.671	.0419	-18.3	- 7.2	239	462	1,648	3,245	289	10,213	143	5,059
12-13-82	BO-27	1213-2	14.8	3.4	18.7	10.1	.623	.0389	-18.3	- 7.2	241	466	1,679	3,306	295	10,406	145	5,121
12-14-82	BO-28	1214-1	14.7	3.8	21.4	10.3	.657	.0410	-26.4	-10.4	243	470	1,676	3,300	294	10,385	142	5,024
12-14-82	BO-29	1214-2	14.6	3.4	18.6	9.6	.653	.0408	-25.9	-10.2	247	476	1,691	3,328	297	10,474	144	5,076
12-14-82	BO-30	1214-2	14.4	4.1	23.5	10.1	.657	.0410	-25.6	-10.1	243	470	1,694	3,335	297	10,497	144	5,094
12-15-82	BO-31	1215-1	14.0	4.0	22.7	10.1	.660	.0412	-25.9	-10.2	239	463	1,676	3,300	294	10,385	144	5,076
12-15-82	BO-32	1215-2	14.4	3.6	19.9	9.8	.669	.0418	-25.6	-10.1	233	452	1,676	3,299	294	10,382	146	5,153
12-15-82	BO-33	1215-2	14.8	3.2	17.3	10.3	.653	.0408	-25.6	-10.1	245	474	1,721	3,388	302	10,662	145	5,134
12-15-82	BO-34	1215-3	14.4	3.4	18.6	12.1	.658	.0411	-38.1	-15	231	448	1,554	3,060	273	9,631	131	4,620
12-16-82	BO-35	1216-1	12.0	6.4	42.3	9.8	.645	.0403	-24.6	- 9.7	244	472	1,715	3,377	301	10,628	145	5,124
12-16-82	BO-36	1216-2	14.2	4.2	24.2	9.9	.645	.0403	-24.6	- 9.7	248	479	1,716	3,378	301	10,630	144	5,088
12-16-82	BO-37	1216-2	14.0	4.0	22.7	9.3	.657	.0410	-21.3	- 8.4	242	468	1,904	3,748	334	11,796	163	5,767
12-17-82	BO-38	1217-1	15.8	3.0	16.3	9.7	.700	.0437	- 1.5	- 0.6	227	441	1,595	3,140	280	9,882	144	5,099
12-17-82	BO-39	1217-1	14.2	4.0	22.7	9.9	.692	.0432	- 1.8	- 0.7	229	445	1,620	3,190	284	10,039	146	5,146
12-17-82	BO-40	1217-2	15.4	2.8	14.9	10.2	.698	.0436	- 2.0	- 0.8	227	440	1,585	3,120	278	9,818	143	5,039

Table 4

Boiler Outlet Particulate Emission Data: SRC Fuel Testing Series

DATE	WPI TEST NO.	BOILER TEST NO.	TOTAL COLLECTED MASS G ^a	PARTICULATE CONCENTRATION				PARTICULATE EMISSION RATES			
				^b mg M ³	^c Gr/ACF	^d mg M ³	^e Gr/DSCP	^f Kg/HR	^g Lb/HR	^h ng/J	ⁱ Lb/10 ⁶ BTU
10-29-82	BO-1	1029-1	3.0683	891	0.3896	1,869	0.8167	17.8	39.2	613.6	1.4270
10-29-82	BO-2	1029-2	1.6300	506	0.2210	1,087	0.4753	11.0	24.2	395.5	0.9197
11-1-82	BO-3	1101-1	2.5571	586	0.2562	1,202	0.5255	10.8	23.9	407.0	0.9466
11-1-82	BO-4	1101-2	2.4380	513	0.2243	1,074	0.4696	10.7	23.7	388.1	0.9025
11-3-82	BO-5	1103-1	1.8946	566	0.2473	1,212	0.5297	12.5	27.5	429.2	0.9981
11-4-82	BO-6	1104-1	2.3485	513	0.2243	1,042	0.4556	11.3	24.9	364.3	0.8473
11-15-82	BO-7	1115-1	2.4053	525	0.2294	1,060	0.4634	10.9	24.0	396.1	0.9213
11-15-82	BO-8	1115-2	1.5165	369	0.1615	743	0.3246	8.2	18.1	289.5	0.6733
11-16-82	BO-9	1116-1	1.7852	372	0.1625	749	0.3272	7.8	17.2	287.6	0.6689
11-16-82	BO-10	1116-2	0.4689	448	0.1957	892	0.3897	10.9	24.0	342.6	0.7967
11-16-82	BO-11	1116-3	0.6719	356	0.1557	729	0.3187	8.9	19.7	301.6	0.7015
11-17-82	BO-12	1117-1	2.1958	428	0.1871	871	0.3808	9.7	21.5	365.8	0.8507
11-17-82	BO-13	1117-2	2.7683	544	0.2379	1,099	0.4805	12.6	27.9	422.4	0.9824
11-18-82	BO-14	1118-1	1.9844	407	0.1781	822	0.3593	9.2	20.4	345.3	0.8030
11-18-82	BO-15	1118-2	2.2705	429	0.1877	881	0.3851	10.7	23.7	343.4	0.7986
11-19-82	BO-16	1119-1	2.0918	444	0.1939	886	0.3872	9.7	21.3	335.6	0.7806
11-19-82	BO-17	1119-1	0.3333	1,151	0.5029	2,390	1.0447	26.7	58.8	905.7	2.1063
11-19-82	BO-18	1119-2	1.8536	398	0.1738	800	0.3498	8.7	19.1	311.9	0.7254
11-19-82	BO-19	1119-3	1.9355	393	0.1717	784	0.3429	9.2	20.3	305.8	0.7113

a grams
b milligrams per cubic meter
c grains per actual cubic feet
d milligrams per standard cubic meter
e grains per dry standard cubic feet
at 68° F and 29.92" Hg

f kilograms per hour
g pound per hour
h nanograms per joule
i pounds per million BTU's of
heat input

Table 4 (Continued)

Boiler Outlet Particulate Emission Data: SRC Residual Oil Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	TOTAL COLLECTED MASS G	PARTICULATE CONCENTRATION				PARTICULATE EMISSION RATES			
				mg/M ³	Gr/ACF	mg/M ³	Gr/DSCF	Kg/HR	Lb/HR	ng/J	Lb/10 ⁶ BTU
12-8-82	BO-20	1208-1	0.7887	202	0.0881	396	0.1733	3.5	7.7	121.0	0.2815
12-8-82	BO-21	1208-2	0.7080	184	0.0804	374	0.1636	3.2	7.0	110.5	0.2570
12-9-82	BO-22	1209-1	0.6397	143	0.0625	286	0.1251	2.9	6.3	96.1	0.2235
12-9-82	BO-23	1209-2	0.4306	99	0.0431	195	0.0854	1.9	4.2	68.1	0.1584
12-10-82	BO-24	1210-1	0.4194	101	0.0442	209	0.0914	1.9	4.1	63.8	0.1484
12-10-82	BO-25	1210-2	0.5417	130	0.0569	263	0.1152	2.3	5.1	79.5	0.1850
12-13-82	BO-26	1213-1	0.3682	92	0.0402	185	0.0811	1.6	3.5	56.7	0.1318
12-13-82	BO-27	1213-2	0.3521	89	0.0389	181	0.0790	1.6	3.5	55.8	0.1299
12-14-82	BO-28	1214-1	0.6138	154	0.0674	319	0.1393	2.7	6.0	100.7	0.2342
12-14-82	BO-29	1214-2	0.5860	144	0.0629	297	0.1297	2.5	5.6	91.6	0.2131
12-14-82	BO-30	1214-2	0.5389	134	0.0587	277	0.1209	2.4	5.3	89.0	0.2069
12-15-82	BO-31	1215-1	0.5099	126	0.0551	258	0.1127	2.2	4.9	82.5	0.1918
12-15-82	BO-32	1215-2	0.3995	101	0.0443	204	0.0893	1.8	3.9	63.8	0.1484
12-15-82	BO-33	1215-2	0.4850	119	0.0519	246	0.1077	2.1	4.7	75.2	0.1750
12-15-82	BO-34	1215-3	0.3926	207	0.0903	431	0.1882	3.4	7.5	132.9	0.3092
12-16-82	BO-35	1216-1	0.5420	133	0.0583	277	0.1210	2.4	5.3	103.1	0.2398
12-16-82	BO-36	1216-2	0.5715	142	0.0620	296	0.1296	2.5	5.6	96.0	0.2233
12-16-82	BO-37	1216-2	0.3061	69	0.0304	142	0.0621	1.4	3.1	45.4	0.1056
12-17-82	BO-38	1217-1	0.4983	133	0.0580	257	0.1123	2.2	4.9	77.6	0.1805
12-17-82	BO-39	1217-1	0.5060	135	0.0589	263	0.1150	2.3	5.1	84.1	0.1956
12-17-82	BO-40	1217-2	0.5505	147	0.0641	286	0.1249	2.4	5.4	85.3	0.1984

Table 4 (Continued)
 Boiler Outlet Particulate Emission Data: SRC-Water Slurry Firing Series

DATE	WFI TEST NO.	BOILER TEST NO.	TOTAL COLLECTED MASS G	PARTICULATE CONCENTRATION					PARTICULATE EMISSION RATES		
				mg/M ³	Gr/ACF	mg/M ³	Gr/DSCF	Kg/HR	Lb/HR	mg/J	Lb/10 ⁶ BTU
1-5-83	BO-41	0105-1	2.5523	585	0.2558	1208	0.5280	12.0	26.4	375.3	0.8727
1-6-83	BO-42	0106-1	2.4044	538	0.2354	1133	0.4953	11.0	24.4	366.7	0.8527
1-7-83	BO-43	0107-1	1.6767	578	0.2528	1201	0.5248	11.1	24.5	377.4	0.8776
1-7-83	BO-44	0107-1	2.0396	705	0.3082	1496	0.6539	13.7	30.3	481.1	1.1188
1-7-83	BO-45	0107-2	1.2232	593	0.2593	1263	0.5521	11.1	24.5	383.6	0.8921
1-10-83	BO-46	0110-1	3.0508	694	0.3032	1459	0.6377	14.7	32.4	498.8	1.1601
1-10-83	BO-47	0110-2	2.6353	573	0.2503	1227	0.5362	12.6	27.7	394.6	0.9177
1-11-83	BO-48	0111-1	2.4096	531	0.2323	1133	0.4954	9.9	21.8	364.6	0.8479
1-11-83	BO-49	0111-2	2.8080	641	0.2802	1391	0.6079	12.5	27.5	447.4	1.0404
1-12-83	BO-50	0112-1	2.3868	615	0.2690	1218	0.5323	11.0	24.3	391.7	0.9109
1-12-83	BO-51	0112-2	2.0913	505	0.2206	1059	0.4629	9.4	20.7	332.8	0.7740
1-13-83	BO-52	0113-1	1.9381	463	0.2022	970	0.4239	8.9	19.6	312.0	0.7256
1-13-83	BO-53	0113-2	2.0331	494	0.2158	1039	0.4540	9.5	20.9	340.2	0.7912
1-14-83	BO-54	0114-1	2.3217	599	0.2619	1227	0.5361	10.3	22.7	399.2	0.9285
1-14-83	BO-55	0114-2	2.3970	595	0.2602	1241	0.5426	11.4	25.1	394.7	0.9179

Table 5
Boiler Outlet Loss on Ignition Data

<u>SRC SOLIDS TESTING SERIES</u>			<u>SRC RESIDUAL OIL FIRING SERIES</u>			<u>SRC SLURRY FIRING SERIES</u>		
DATE	TEST #	L.O.I.	DATE	TEST #	L.O.I.	DATE	TEST #	L.O.I.
10-29-82	BO-1	95.4	12-8-82	BO-20	88.5	1-5-83	BO-41	75.5
10-29-82	BO-2	90.5	12-8-82	BO-21	90.1	1-6-83	BO-42	71.6
11-1-82	BO-3	93.9	12-9-82	BO-22	82.5	1-7-83	BO-43	70.0
11-1-82	BO-4	93.3	12-9-82	BO-23	74.0	1-7-83	BO-44	71.2
11-3-82	BO-5	78.6	12-10-82	BO-24	82.9	1-7-83	BO-45	64.9
11-4-82	BO-6	90.1	12-10-82	BO-25	81.4	1-10-83	BO-46	69.5
11-15-82	BO-7	92.8	12-13-82	BO-26	79.6	1-10-83	BO-47	68.7
11-15-82	BO-8	89.8	12-13-82	BO-27	77.7	1-11-83	BO-48	63.2
11-16-82	BO-9	92.6	12-14-82	BO-28	87.5	1-11-83	BO-49	65.4
11-16-82	BO-10	92.2	12-14-82	BO-29	87.4	1-12-83	BO-50	69.1
11-16-82	BO-11	92.5	12-14-82	BO-30	86.5	1-12-83	BO-51	64.8
11-17-82	BO-12	90.5	12-15-82	BO-31	86.1	1-13-83	BO-52	70.0
11-17-82	BO-13	94.1	12-15-82	BO-32	88.3	1-13-83	BO-53	71.4
11-18-82	BO-14	77.5	12-15-82	BO-33	86.1	1-14-83	BO-54	74.2
11-18-82	BO-15	87.2	12-15-82	BO-34	91.1	1-14-83	BO-55	81.1
11-19-82	BO-16	88.2	12-16-82	BO-35	87.5			
11-19-82	BO-17	93.7	12-16-82	BO-36	88.7			
11-19-82	BO-18	84.7	12-16-82	BO-37	87.5			
11-19-82	BO-19	83.8	12-17-82	BO-38	88.2			
			12-17-82	BO-39	79.2			
			12-17-82	BO-40	70.0			

A percent wt. lost L.O.I. @ 750°C

Table 6
Analyses of Fuel and Flue Gas Data

ANALYTICAL RESULTS	TYPE OF TESTS	NO. 6 FUEL OIL				SRC				SRC RESIDUAL OIL				SRC SLURRY			
		Parametric		Steady State		Parametric		Steady State		Parametric		Steady State		Parametric		Steady State	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
FUEL ANALYSIS																	
Ultimate Analysis																	
Hydrogen	X	11.18 - 12.02	10.46 - 14.42	6.18 - 6.25	5.70 - 6.34	7.97 - 8.14	7.81 - 8.11	7.77 - 7.85	7.58 - 7.77								
Carbon	X	81.69 - 83.61	80.20 - 85.71	86.20 - 86.41	84.52 - 86.52	85.18 - 87.00	85.66 - 87.02	86.26 - 87.37	87.65 - 88.09								
Nitrogen	X	0.21 - 0.26	0.16 - 0.27	1.93 - 1.97	1.74 - 2.08	1.23 - 1.35	1.19 - 1.36	1.16 - 1.29	1.16 - 1.28								
Sulfur	X	0.63 - 0.68	0.50 - 0.71	0.82 - 0.93	0.88 - 1.03	0.40 - 0.49	0.42 - 0.57	0.69 - 0.71	0.65 - 0.70								
Oxygen	X	4.22 - 5.36	0.35 - 8.36	4.17 - 4.36	4.02 - 6.11	3.13 - 5.30	3.02 - 4.73	32.38 - 33.47	31.91 - 32.57								
Ash	X	0.07 - 0.14	0.07 - 0.19	0.36 - 0.42	0.03 - 0.52	0.04 - 0.08	0.02 - 0.11	0.38 - 0.55	0.27 - 0.49								
Moisture	X	5.8 - 7.8	3.0 - 6.7	0.37 - 0.38	0.42 - 0.66	0.18 - 1.32	0.23 - 1.32										
Heating Value	BTU/Lb	17404 -17556	17421 -18168	15781 -15789	15686 -15852	16678 -16817	16601 -16808	10384 -10627	10512 -10632								
Specific Gravity @ 75°		0.9467															
Solids Particle Size Consist(-200 Mesh)	X			96	90 - 100			87 - 91	88 - 91								
SRC-1 Concentration	X							65.3 - 66.4	66.5 - 66.7								
FLUE GAS ANALYSIS																	
O ₂	X	0.6 - 5.1	2.3 - 2.5	3.1 - 5.4	2.7 - 6.5	0.4 - 4.4	2.4 - 2.7	2.1 - 4.0	3.0 - 3.1								
CO ₂	X	11.8 - 15.4	13.3 - 13.8	12.8 - 14.7	11.7 - 15.1	13.8 - 16.7	14.6 - 14.9	14.0 - 16.0	14.7 - 15.2								
CO	ppm	22 - 190	20 - 48	70 - 370	30 - 313	25 - 123	29 - 49	51 - 280	60 - 87								
SO ₂	ppm	445 - 560	378 - 533	566 - 667	499 - 674	315 - 409	345 - 391	714 - 797	621 - 752								
	Lb/MBTU	0.90 - 0.97	0.69 - 1.00	1.26 - 1.29	1.17 - 1.36	0.59 - 0.71	0.65 - 0.73	1.38 - 1.47	1.20 - 1.47								
NO _x	ppm	202 - 241	167 - 239	402 - 494	447 - 950	468 - 533	427 - 542	321 - 440	334 - 409								
	Lb/MBTU	0.25 - 0.34	0.22 - 0.32	0.56 - 0.80	0.63 - 1.54	0.57 - 0.76	0.56 - 0.74	0.41 - 0.65	0.47 - 0.56								
HC	ppm	0.2 - 2.0	0.2 - 1.0	1 - 2	1 - 2	0.2 - 0.8	0.3 - 0.8	1	1 - 2								
Opacity	X	1 - 6	1 - 10	15 - 48	11 - 44	6 - 17	3 - 10	10 - 14	11 - 12								
PARTICULATE EMISSIONS																	
Mass Emission Rate	Lb/Hr	0.60 - 1.15	0.50 - 1.11	28.5 - 35.5	17.5 - 34.1	2.4 - 6.5	2.46 - 5.21	23.36 - 31.75	19.31 - 25.74								
Emission Rate Heat Input Basis	Lb/MBTU	0.02 - 0.04	0.02 - 0.04	1.07 - 1.26	0.66 - 1.25	0.09 - 0.24	0.09 - 0.20	0.86 - 1.15	0.74 - 1.00								
Carbon Content (LOI)	X	24.9 - 72.5	26.6 - 47.1	60.9 - 93.3	41.3 - 95.1	50.8 - 88.7	58.4 - 89.5	67.4 - 71.2	63.8 - 74.9								

VI. DISCUSSION OF RESULTS

The current New Source Performance Standard (NSPS) for particulate emissions from electric utility steam-generating units modified or constructed after September 18, 1978 with a minimum heat input of 250 million Btu/hr is $0.03 \text{ lb}/10^6 \text{ Btu}$. Based on boiler emissions measured during the test program, the SRC Fuel averaged $0.9243 \text{ lb}/10^6 \text{ Btu}$ for uncontrolled particulate emissions. In order to meet the NSPS, a particulate emission control system with a collection efficiency of 96.7% would be required. Particulate emissions from firing the SRC Residual Oil averaged $0.1970 \text{ lb}/10^6 \text{ Btu}$, which would require a control system with a collection efficiency of 84.8%. Finally, the SRC-Water Slurry emissions averaged $0.9085 \text{ lb}/10^6 \text{ Btu}$, which would require a control system with an efficiency of 96.7%.

For each fuel, the boiler operational parameters were monitored and maintained at similar predetermined conditions to eliminate any bias in emissions due to boiler operation. Among the three SRC fuels tested, the SRC Residual Oil produced the lowest particulate emissions, partly because of its lower ash content and superior combustion properties. On a $\text{lb}/10^6 \text{ Btu}$ basis, particulate emissions from SRC Residual Oil averaged 79 and 78% lower than the SRC Fuel and SRC-Water Slurry, respectively. The SRC Fuel produced the highest particulate emissions of the three SRC fuels, but the amount averaged only 2% higher than the SRC Water-Slurry emissions.

During the SRC Fuel burn, emission rates from several tests were considered outliers, when compared with the average series emission rates. Tests B0-8 and B0-9 were 27 and 28% lower, respectively, compared to the series average of $0.9243 \text{ lb}/10^6 \text{ Btu}$. Test B0-17 was 128% higher than average; however, there were boiler problems during this test and it was aborted after 8 min into the run. Because there were no apparent problems with the test procedures or analysis, these emission variations were probably due to variations in boiler conditions.

During the SRC Residual Oil series, Tests B0-20 and B0-34 had emission rates that were 43 and 57% higher, respectively, than the

series average of 0.1970 lb/10⁶ Btu. Also, emission rates from tests B0-26 and B0-27 were 33 and 34%, respectively, lower than the series average. Apparently, these tests were also outliers due to variation in boiler conditions.

The loss on ignition (L.O.I.) data averaged 93.9, 94.3, and 70.0 for the SRC Fuel, SRC Residual Oil, and SRC-Water Slurry, respectively

VII. NOMENCLATURE AND CALCULATIONS

NOMENCLATURE

Symbol	Units	Description	Symbol	Units	Description
(a)	Percent	Column identification for traverse point distance on circular stack or duct	IB	-----	Ice bath
(a)	In. H ₂ O	Column identification for ΔP	IMP	-----	Impinger
A, B, C, &c	-----	Port identification	b	-----	Constant
acf	Ft ³	Actual cubic feet: volume of gas sampled at dry test meter temperature, pressure, and moisture	v _{CM2}	-----	Velocity correction for molecular weight
ACF	Ft ³	Actual volume of gas sampled at stack conditions	v _F	-----	Flow correction
ACFM	Ft ³ /Min	Gas volumetric flow rate at stack conditions	k _I	-----	Isokinetic sampling correction excluding pressure correction
A _n	Ft ²	Actual nozzle opening area	k _I	-----	Isokinetic sampling correction including pressure correction
A _s	Ft ²	Area of duct or stack	k _T	-----	Isokinetic meter temperature correction
(b)	In.	Column identification for (a) expressed in inch units	k _w	-----	Isokinetic moisture correction
(b)	-----	Column identification for k _I	k _{moisture}	-----	Velocity correction for moisture
(c)	In.	Column identification for probe marking distance, decimal and nearest 1/4 inch	k _p	-----	Pitot tube constant
C	ml	Liquid moisture volume condensed in condenser/impinger and desiccant together	k _p	-----	Velocity correction for static pressure
CM	Ft ³	Moisture volume in gas phase, metered through dry test meter at STP	k _{pressure}	-----	Isokinetic orifice constant
CND	-----	Condenser	v _P	-----	Isokinetic stack temperature correction
CP	Ft ³	C expressed as gas-phase moisture at STP	k _s	-----	Moisture in dry test meter gas (by volume)
CT	Ft ³	Total gas-phase moisture volume at STP	W	Percent	Moisture in dry test meter gas (by volume)
D	Lb/Ft ³	Density of wet stack gas	W _m	Lb/Lb Mole	Molecular weight at meter conditions
D _n	In.	Actual nozzle diameter	W _s	Lb/Lb Mole	Molecular weight at stack conditions
D _N	In.	Calculated nozzle diameter	W _{dry}	Lb/Lb Mole	Molecular weight of dry stack gas
D _s	Ft.	Diameter of stack or duct	W _{wet}	Lb/Lb Mole	Molecular weight of wet stack gas
D _{s'}	In.	Diameter of stack or duct	N	-----	Number of points to be traversed
DTM _F	Ft ³	Final dry test meter gas volume reading	N, S, E, W	-----	Directions: north, south, east, and west, respectively
DTM _I	Ft ³	Initial dry test meter gas volume reading	AP	In. H ₂ O	Velocity of stack gas
EPA	-----	Federal Environmental Protection Agency	P _A	In. Hg	Ambient, barometric pressure
EQN	-----	Equation	P _s	In. H ₂ O	Static pressure of stack gas (P _s may be In. Hg; check pertinent equation)
FH	-----	Filter holder	Q	Ft ³ /Min	Stack gas sampling rate
GBS	-----	Greenburg-Smith	SB	-----	Sample box
Gr/ACF	Grains Per Ft ³	Mass of particulate matter in grains per one cubic foot of sampled gas at stack conditions	SCF	Ft ³	Gas volume at 68°F 29.92 in. Hg
Gr/SDCF	Grains Per Ft ³	Mass of particulate matter in grains per one cubic foot of sampled gas at standard dry conditions	SCGF	Ft ³	SCF gas volume without any moisture
H	In.	Measure of wall thickness and probe holder length together	SCCFM	Ft ³ /Min	Gas volumetric flow rate at standard conditions
ΔH	In. H ₂ O	Orifice differential indicating the sampling train flow rate	STD	-----	Standard conditions: 68°F and 29.92 In. Hg
H _v	-----	Velocity correction factor	t	Minutes	Actual sampling time
H ₂ O	-----	Water or moisture	t _A	°F	Ambient, dry bulb temperature
ΔH ₂ O	Percent	Moisture content of stack gas (by volume)	t _I	°F	Dry test meter inlet gas temperature
I	Percent	Isokinetic sampling rate	t _S	°F	Stack gas dry bulb temperature
			V _{act}	Ft/Min	Actual stack gas velocity at stack temperature, pressure, and moisture
			V _{ref}	Ft/Min	V _{act} as determined from partial traverse of the duct
			V _{std}	Ft/Min	Stack gas velocity corrected to 68°F to 29.92 In. Hg
			V _{uc}	Ft/Sec	Velocity from tables, uncorrected
			WT	Grams	Weight of particulate collected in sampling train
			Y	-----	DTM calibration factor

CALCULATION FORMULAS

- SCF** = 17.64 acf $\left[\frac{P_a + \Delta H/13.6}{460 + t_m} \right]$
- SDCF** = $\frac{SCF(100 - \%H_2O)}{100}$
- CP** = 0.0471 C
- CM** = $\frac{SCF(\%M)}{100}$
- CT** = CP + CM
- $\%H_2O$ = $\frac{100 CT}{SDCF + CT}$
- D** = 0.0458 MW_{wet} $\left[\frac{P_a + P_a/13.6}{460 + t_s} \right]$
- V_{act}** = $\frac{1097.8 k_p \sqrt{\Delta P}}{\sqrt{D}}$
- V_{std}** = 17.64 V_{ref} $\left[\frac{P_a + P_a/13.6}{460 + t_s} \right]$
- I** = $\frac{(SDCF + CT) 6000}{(t) (V_{std}) (60A_n)}$
- ACFM** = V_{act} (A_s)
- SDCFM** = 0.1764 (100 - %H₂O) $\left[\frac{P_a + P_a/13.6}{460 + t_s} \right]$ · ACFM
- Lb/Hr** = ACFM x Density x 60. (GAS FLOW RATE)
- Gr/SDCF** = $\frac{15.43 WP}{SDCF}$
- Gr/ACF** = 0.1764 (100 - %H₂O) $\left[\frac{P_a + P_a/13.6}{460 + t_s} \right]$ · Gr/SDCF
- Lb/10³Lb Dry Gas** = $\frac{55.04 Gr/SDCF}{MW_{dry}}$
- Lb/10³Lb Wet Gas** = $\frac{55.04 Gr/SDCF}{MW_{wet}} \times \left[\frac{100 - \%H_2O}{100} \right]$
- Lb/Hr** = 8.57 x 10⁻³ x Gr/SDCF x SDCFM. (EMISSION RATE)

Standard Conditions are 68°F and 29.92" Hg Barometric Pressure

ADDITIONAL NOMENCLATURE AND FORMULAS

<u>Symbol</u>	<u>Units</u>	<u>Description</u>
ZIL	Percent	In-Leakage to a Particular Unit
ZEA	Percent	Excess Air
E	Lb/10 ⁶ BTU	Pounds of Particulate Emissions Per Million BTU Heat Input
F	SDCF/10 ⁴ BTU	F-factor for Fossil Fuels: Coal-Anthracite - 101.4 Coal-Bituminous, Lignite - 98.2 Oil-Crude, Fuel - 92.2 Gas-Natural, Propane, Butane - 87.4

$$ZEA = \frac{100 \%O_2}{0.264 (100 - \%O_2 - \%CO_2) - \%O_2} \quad (\text{Exhaust Gas Concentrations}) \quad (\text{Assumes CO Negligible})$$

$$ZIL(O_2) = \frac{\%O_{2\text{out}} - \%O_{2\text{in}}}{20.9 - \%O_{2\text{out}}} \quad (100)$$

$$ZIL(CO_2 \ \& \ H_2O) = \left(\frac{\%In}{\%Out} - 1 \right) 100$$

$$ZIL(\text{temperature}) = \frac{t_{\text{out}} - t_{\text{in}}}{t_a - t_{\text{out}}} 100 \quad (\text{Well Insulated Units Only})$$

$$ZIL(\text{SDCFM}) = \left(\frac{\text{SDCFM}_{\text{out}}}{\text{SDCFM}_{\text{in}}} - 1 \right) 100$$

$$\text{Lb/SDCF} = \frac{\text{Gr/SDCF}}{7,000}$$

$$E = \text{Lb/SDCF} (F) \left(\frac{2,090}{20.9 - \%O_2} \right)$$

$$\%Wet = \%Dry \frac{100 - \%H_2O}{100}$$

Standard Conditions are 68°F and 29.92" Hg Barometric Pressure

CLASSIFICATION OF COLLECTED SAMPLES

Composite Particulate Matter

- Filterables (water insoluble)
- Water Soluble
- Organic Solvent Extractables

Condensables

- Filterables (Water insoluble)
- Water Soluble
- Organic Solvent Extractables

APPENDIX A

TEST METHODS, EQUIPMENT, AND CALIBRATIONS

Particulate Sampling

Figure A-1 is a schematic of the test equipment used to determine particulate emissions. Samples were extracted from the duct isokinetically by drawing the flue gas through a tapered, stainless steel nozzle and then through the collecting components. The nozzle was mounted adjacent to a pitot tube and thermocouple to allow simultaneous velocity measurement and sampling.

Before each test commenced, the complete sampling train was leak-tested by plugging the sampling nozzle, turning on the pump, and adjusting the pump bypass valve to a system vacuum of 15-in. Hg. The amount of inleakage was determined using the dry test meter. A maximum inleakage rate of 0.02 cfm is acceptable.

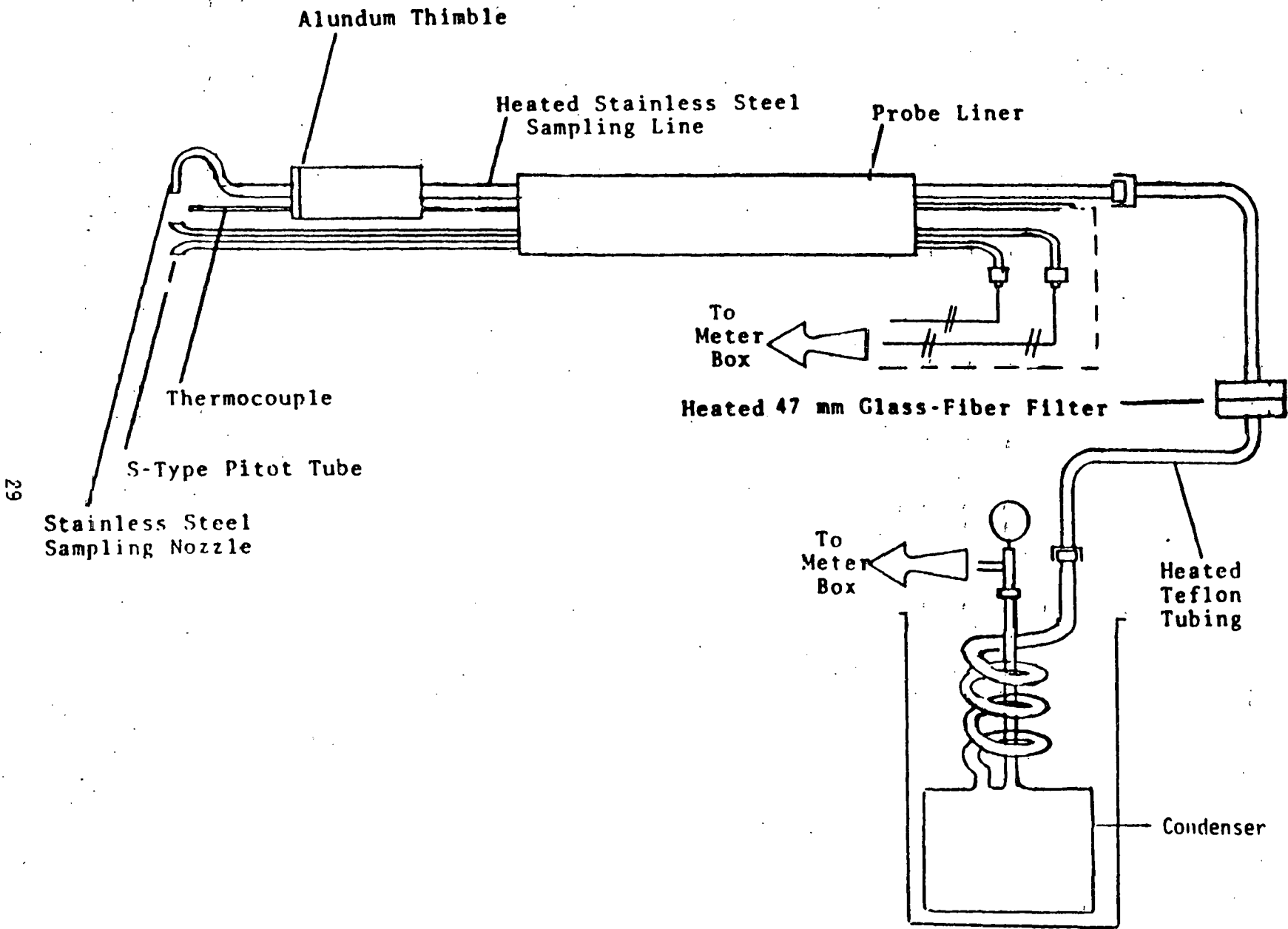
To start the test, the initial dry gas meter reading was recorded and the nozzle was placed at the first test point. The velocity pressure and temperature were then recorded, and an isokinetic flow rate was determined. The pump was then turned on and the flows adjusted using the orifice meter on the discharge side of the pump. Sampling was continued at this point for a specified time period; then the probe was moved to the next test point, where the same procedure was implemented. This was continued until all points of this port had been sampled. The sampling pump was then shut down, the probe was moved to the next port, and the test continued. Sampling was concluded when all points had been sampled.

The test train was dismantled and each collection component cleaned. Table A-1 summarizes the sample treatment and analysis.

Gas Analysis

During each test, an integrated gas sample was collected over a period of 10 to 15 min in a plastic sample bag. Each bag was then analyzed in duplicate for CO₂, O₂, and CO using an Orsat Analyzer, and the nitrogen content was then determined by difference.

Since the Orsat analysis gave results on a dry gas basis, the Orsat data and gas moisture data from the particulate tests were combined to give the wet gas composition, used to calculate the stack gas molecular weight on a wet gas basis.



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Figure A-1
Boiler Outlet Sampling Train

Table A-1 Analysis of Particulate Sample - Filter Sample

I. FILTER SAMPLE

1. Glass Fiber Sheet - 47 mm diameter circular
2. Glass Fiber Sheet - 4 inch diameter circular
3. Glass Fiber Sheet - 8 inch diameter circular
4. Glass Fiber Sheet - 8 inch x 10 inch rectangular
5. Glass Fiber Tube - 1 inch diameter x 8 inch long
6. Glass Fiber Thimble - 1 inch diameter x 4 inch long
7. Aluminum Thimble - 1 inch diameter x 4 inch long

II. PREFIELD PROCEDURE

1. Test filter is dried at 70°F and 105°C for two hours.
2. Test filter is desiccated at 70°F for two hours.
3. Test filter is tare weighed with an analytical balance.

III. FIELD PROCEDURE

1. Test filter is placed in a suitable container after being used in a test.
2. Test filter is weighed (as is) for preliminary weight.
3. Test filter is weighed (desiccated at 70°F) for preliminary particulate weight.
4. Test filter is weighed (after drying and desiccating) for preliminary particulate weight.

IV. POSTFIELD PROCEDURE

A. Composite Particulate Matter

1. Test filter is dried at 70°F and 105°C until particulate weight becomes constant.
2. Test filter is desiccated at 70°F for two hours.
3. Test filter is weighed with an analytical balance.
4. The difference between postfield and prefield weight of the filter is reported as composite particulate matter.

B. Water Soluble and Water Insoluble Particulate Matter

Water Insolubles

1. Test filter is washed with water.
2. The liquid is filtered with a tared lab filter which is also washed with water.
3. The test filter and the lab filter are dried at 105°C until particulate weight becomes constant.
4. The filters are desiccated at 70°F for two hours.
5. The filters are weighed with an analytical balance.
6. The difference between postfield weight and prefield weight of the test filter and the difference between the used weight and the tare weight of the lab filter are added together and the sum is reported as water insoluble particulate matter.

Water Solubles

7. The lab-filtered water washings of the test filter are collected in a tared beaker.
8. The liquid volume of the water washings is measured.
9. The pH of the liquid is measured.
10. The liquid is evaporated at 105°C until particulate weight becomes constant.
11. The beaker with particulate is desiccated at 70°F for two hours.
12. The beaker plus particulate is weighed with an analytical balance.
13. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross water soluble particulate matter.
14. Weight of the water soluble particulate matter in the equal amount of lab water is calculated for the blank correction.

NOTE: (IV) A. Water solubles, water insolubles, and organic solvent extractables are included but not identified.
 B. Organic solvent extractables are included but not identified.
 C. Water soluble: analysis may be bypassed. If so, follow the procedure by replacing "water" with the organic solvent used.

15. The gross water soluble particulate matter minus the blank correction is reported as net water soluble particulate matter.

C. Water Soluble, Water Insoluble, and Organic Solvent Extractable Particulate Matter

Water Insolubles

1. Test filter is washed with water and also with organic solvent.
2. The liquid is filtered with a tared lab filter which is also washed with water and the organic solvent.
3. The test filter and the lab filter are dried at 70°F and 105°C until particulate weight becomes constant.
4. The filters are desiccated at 70°F for two hours.
5. The filters are weighed with an analytical balance.
6. The difference between postfield weight and prefield weight of the test filter and the difference between the used weight and the tare weight of the lab filter are added together and the sum is reported as water insoluble particulate matter.

Separation

7. The lab-filtered washings are collected in a separatory funnel.
8. The water and the solvent are allowed to settle until distinctly clear and separate.
9. Additional solvent may be used to enhance the separation.
10. The water and the solvent liquids are collected in separate tared beakers.

Water Solubles

11. The liquid volume of the water portion is measured.
12. The pH of the liquid is measured.
13. The liquid is evaporated at 70°F and 105°C until particulate weight becomes constant.
14. The beaker with particulate is desiccated at 70°F for two hours.
15. The beaker plus particulate is weighed with an analytical balance.
16. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross water soluble particulate matter.
17. Weight of the water soluble particulate matter in the equal amount of lab water is calculated for the blank correction.
18. The gross water soluble particulate matter minus the blank correction is reported as net water soluble particulate matter.

Organic Solvent Extractables

19. The liquid volume of the solvent portion is measured.
20. The liquid is evaporated at 70°F and 105°C until particulate weight becomes constant.
21. The beaker with particulate is desiccated at 70°F for two hours.
22. The beaker plus particulate is weighed with an analytical balance.
23. The difference between the beaker plus particulate weight and the tared beaker weight reported as gross organic solvent extractable particulate matter.
24. Weight of the organic solvent extractable matter in the equal amount of the lab organic solvent is calculated for blank correction.
25. The gross organic solvent extractable particulate matter minus the blank correction is reported as net organic solvent extractable matter.

Table A-1 (Cont.) Analysis of Particulate Sample - Liquid Sample

I. LIQUID SAMPLE

A. Types of Liquid Sample

1. Nozzle Washings
2. Probe Washings
3. Cord Washings
4. Cyclone Washings
5. Filter Holder Washings
6. Impinger Liquid
7. Impinger Washings
8. Two or more of the above may be combined.

B. Types of Washing Fluid

1. Distilled Water
2. Acetone
3. Freon TF
4. Organic Solvent

C. Water Soluble, Water Insoluble, and Organic Solvent Extractable Particulate Matter

Water Insolubles

1. The liquid sample is filtered with a tared lab filter which is also washed with water and the organic solvent.
2. The lab filter is dried at 70°F and 105°C until particulate weight becomes constant.
3. The lab filter is desiccated at 70°F for two hours.
4. The lab filter is weighed with an analytical balance.
5. The difference between the used weight and the tare weight of the lab filter is reported as water insoluble particulate matter.

Separation

6. The lab-filtered liquid is collected in a separatory funnel.
7. The water and the solvent are allowed to settle until distinctly clear and separate.
8. Additional solvent may be used to enhance the separation.
9. A flame test or optical test may be performed to ascertain separation.
10. The water and the solvent liquids are collected in separate tared beakers.

Water Solubles

11. The liquid volume of the water portion is measured.
12. The pH of the liquid is measured.
13. The liquid is evaporated at 70°F and 105°C until particulate weight becomes constant.
14. The beaker with particulate is desiccated at 70°F for two hours.
15. The beaker plus particulate is weighed with an analytical balance.
16. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross water soluble particulate matter.
17. Weight of the water soluble particulate matter in the equal amount of the field water is calculated for the blank correction.
18. The gross water soluble particulate matter minus the blank correction is reported as net water soluble particulate matter.

Organic Solvent Extractables

19. The liquid volume of the solvent portion is measured.
20. The liquid is evaporated at 70°F and 105°C until particulate weight becomes constant.
21. The beaker with particulate is desiccated at 70°F for two hours.
22. The beaker plus particulate is weighed with an analytical balance.
23. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross organic solvent extractable particulate matter.
24. Weight of the organic solvent extractable matter in the equal amount of the field organic solvent is calculated for the blank correction.
25. The gross organic solvent extractable particulate matter minus the blank correction is reported as net organic solvent extractable matter.

II. FIELD PROCEDURE

1. Before a test begins, the first two impingers are each filled with 100 ml/150 ml of water.
2. At the end of the test, the liquid sample volume is measured by a measuring cylinder.
3. The liquid sample is poured into a suitable container (glass or plastic, nonreactive with the sample).

III. POSTFIELD PROCEDURE

A. Composite Particulate Matter

1. Liquid sample is evaporated in a tared beaker at 70°F and 105°C until particulate weight becomes constant.
2. The beaker plus particulate is desiccated at 70°F for two hours.
3. The beaker plus particulate is weighed with an analytical balance.
4. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross composite particulate matter.
5. Weight of the composite particulate matter in the equal amount of the field water and the field organic solvent is calculated for blank correction.
6. The gross composite particulate matter minus the corresponding blank correction is reported as net composite particulate matter.

B. Water Soluble and Water Insoluble Particulate Matter

Water Insolubles

1. The liquid sample is filtered with a tared lab filter which is also washed with water.
2. The lab filter is dried at 105°C until particulate weight becomes constant.
3. The lab filter is desiccated at 70°F for two hours.
4. The lab filter is weighed with an analytical balance.
5. The difference between the used weight and the tare weight of the lab filter is reported as water insoluble particulate matter.

Water Solubles

6. The lab filtered liquid is collected in a tared beaker.
7. The liquid volume is measured.
8. The pH of the liquid is measured.
9. The liquid is evaporated at 105°C until particulate weight becomes constant.
10. The beaker with particulate is desiccated at 70°F for two hours.
11. The beaker plus particulate is weighed with an analytical balance.
12. The difference between the beaker plus particulate weight and the tared beaker weight is reported as gross water soluble particulate matter.
13. Weight of the water soluble particulate matter in the equal amount of field water is calculated for blank correction.
14. The gross water soluble particulate matter minus the blank correction is reported as net water soluble particulate matter.

NOTE: (III) A. Water solubles, water insolubles, and organic solvent extractables are included but not identified. B. Organic solvent extractables are included but not identified. C. Water solubles analysis may be bypassed. If so, follow the procedure by replacing "water" with the organic solvent.

Moisture Content

The moisture content of the gas sampled was determined from the volume of gas sampled and the amount of water condensed and absorbed out of the gas. The condenser consisted of a stainless steel coil condenser tube, welded to a collection reservoir, with an exhaust tube or a series of glass impingers that bubbled the sample through a known volume of impinger liquid. Both types of condensers were immersed in an ice bath to maintain the temperature of exit gases between 40 and 60°F. Any remaining moisture was removed by passing the gas stream through a container of tared silica gel desiccant. The total liquid moisture volume was then calculated from the moisture (liquid volume) collected in the condenser or impingers and the weight increase in the desiccant.

The total gaseous moisture volume was computed from the liquid volume using the density of liquid water, its molecular weight, and the molar volume at standard conditions (68°F and 29.92 in. Hg). This volume was added to the standard volume of dry gas sampled, and the sum was divided back into the gaseous moisture volume. The result is the percent H₂O, by volume, in the actual gas stream.

Equipment Calibration

Sample Meter System. The sample meter system--consisting of the pump, vacuum gauge, valves, orifice meter, and dry gas meter--was initially calibrated by stringent laboratory methods before it was used in the field. After the initial acceptance, the calibration was rechecked after each field test series. The recheck provided a method that could be used more often and with less effort to ensure that the calibration has not changed. When the quick check indicated that the calibration factor had changed, the tester again used the complete calibration procedure to obtain a new calibration factor. After recalibration, the metered sample volume was multiplied by either the initial or the recalibrated calibration factor--that is, the one that yields the lower gas volume for each test run.

Before initial calibration of the metering system, a leak check was conducted. The meter system must be leak free. Both positive (pressure) and negative (vacuum) leak checks were performed.

Temperature Gauges. Impinger Thermometer. This thermometer, used to measure temperature of the gas leaving the impinger train, was initially compared with a mercury-in-glass thermometer that meets ASTM E-1 No. 63C or 63F specifications.

Dry Glass Thermometers. The thermometers used to measure the metered gas sample temperature were initially compared with a mercury-in-glass thermometer as above, using a similar procedure.

Stack Temperature Sensor. The stack temperature sensor was calibrated before field use. Each sensor was uniquely marked for identification. The calibration was performed over the range of temperatures anticipated during actual sampling. For temperatures up to 450°C (761°F), a reference mercury-in-glass thermometer was used.

Probe Nozzle. Probe nozzles were calibrated before initial use in the field. Using a micrometer, the i.d. of the nozzle was measured to the nearest 0.025 mm (0.001 in.). Three measurements were made using measured diameters each time to obtain the average. The difference between the high and low numbers did not exceed 0.1 mm (0.004 in.).

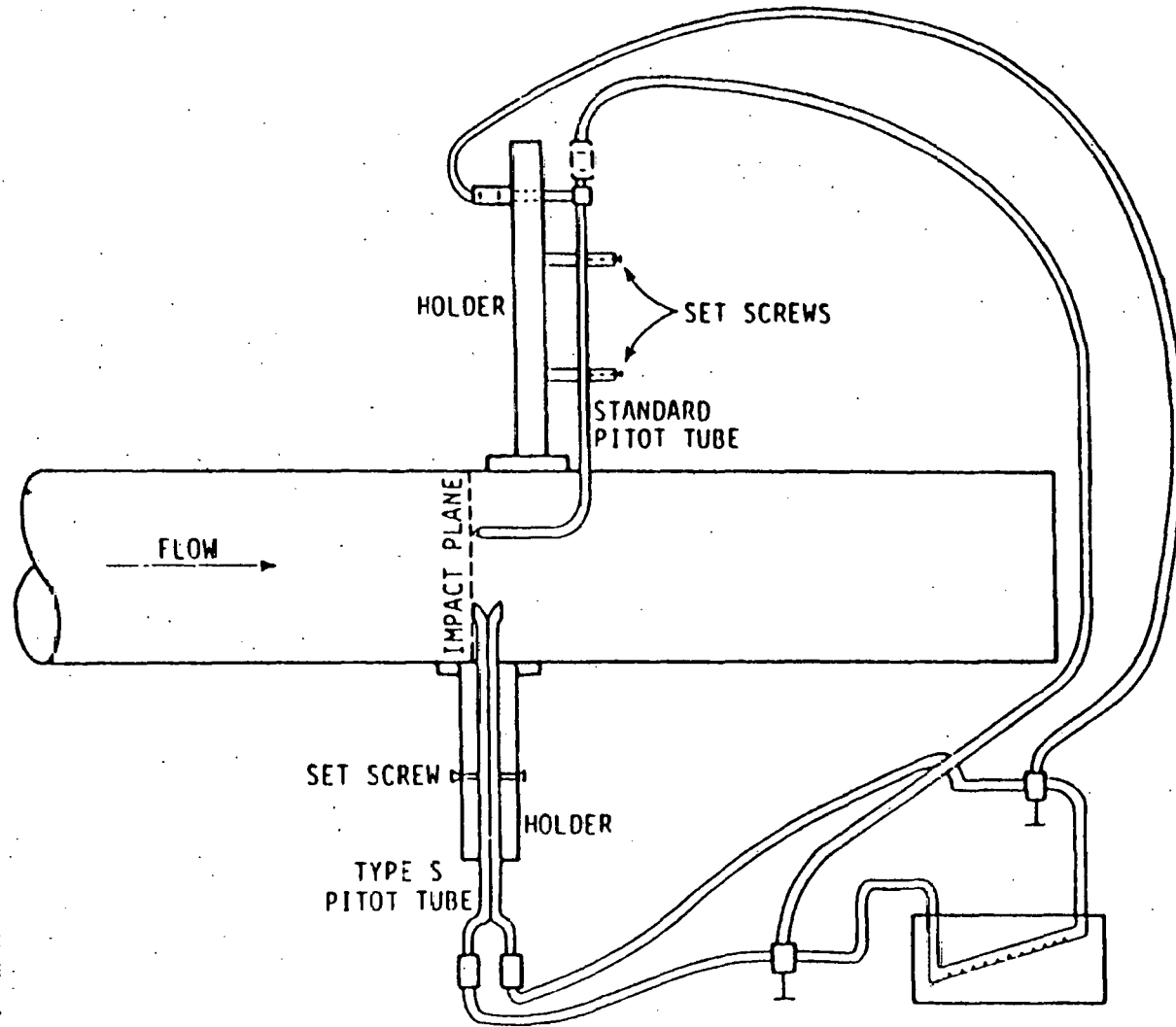
Type S Pitot Tube. The pitot tubes were calibrated using the calibration system setup recommended in EPA Method No. 2 (see Figure A-2). The calibration procedure was as follows: One leg of the Type S pitot tube was marked with an "A" and the other with a "B." To obtain calibration data for either the A or B sides, a manometer was filled with clean fluid of the proper density. All pitot lines and fittings were leak-checked, repaired, or replaced, if necessary.

The inclined manometer was leveled and zeroed. The calibration system I.D. fan was turned on to allow the flow to stabilize.

The standard type pitot tube was positioned near the center of the duct, and the entry port sealed with a rag or duct tape. The pitot tube was checked to make sure it was properly aligned and perpendicular to the duct.

The I.D. fan speed was adjusted to give the desired velocity head, as measured by the standard pitot tube, and the Δp_{std} was recorded on a data form. The Type S pitot tube was then connected to the manometer. The tube was inserted and located at the same point in the duct as that

Figure A-2
Pitot Tube Calibration Setup



measured by the standard tube, and was aligned with leg A facing directly upstream. The velocity head (Δp_s) was read and recorded on the data form, and the tube was removed from the duct, and disconnected from the manometer.

The procedure was repeated until three sets of velocity head measurements for each pitot tube were obtained. If necessary, the complete procedure was repeated with leg B of the Type S pitot tube facing upstream.

The Type S pitot tube coefficient, $C_{p(S)}$, was calculated for each set of measurements, using the following equation:

$$C_{p(S)} = C_{p(std)} (\Delta p_{std} / \Delta p_s)^{1/2}$$

where $C_{p(S)}$ = the Type S pitot tube coefficient; $C_{p(std)}$ = the standard pitot tube coefficient (use 0.99 if coefficient is unknown and tube is designed according to guidelines in Section 1.7 of the EPA method); Δp_{std} = the velocity head measured by the standard pitot tube, cm (in.) H_2O ; and Δp_s = the velocity head measured by the Type S pitot tube, cm (in.) H_2O .