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Gas Suspension Absorption (GSA)
Demonstration Plant
Air Toxics Characterization

Final Report

Prepared for

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March 15, 1995

NOTICE

This document is a draft. It has not been formally released by AirPol Inc. It should not, at this stage, be construed to represent actual results. It is being circulated for comments on its technical merit and policy implications.

ABSTRACT

This report summarizes results of a project to characterize air toxic emissions of selected hazardous air pollutants (HAPs) from the AirPol Gas Suspension Absorption SO₂ control technology. This project was sponsored by AirPol Inc., the Tennessee Valley Authority (TVA), and the U.S. Department of Energy (DOE). The GSA process utilizes a semi-dry lime scrubber for SO₂ and HCl removal. Most of the solids in the GSA reactor are removed from the flue gas and recycled into the reactor. The flue gas from the GSA reactor/cyclone is passed through a dust collector for final particulate control. AirPol demonstrated the process in a 10 MW pilot-scale plant utilizing a slipstream from a coal-fired utility boiler. The pilot plant consisted of the GSA reactor/cyclone, an ESP, and a small, 1 MW equivalent pulsed jet baghouse.

The 10 MW pilot-plant was tested in September and October, 1993 at the TVA National Center for Emissions Research located in West Paducah Kentucky. The test program included evaluation of two process configurations:

Series. The baghouse was operated in series with the ESP, i.e., the flue gas from the GSA reactor/cyclone passed first through the ESP and then the fabric filter;

Parallel. The baghouse was operated in parallel with the ESP, meaning that 15-16 percent of the flue gas leaving the GSA reactor/cyclone was introduced to the fabric filter; thus, both the ESP inlet stream and the fabric baghouse stream contained equivalent concentrations of all flue gas constituents;

Two test conditions were evaluated in each configuration: baseline, with no lime introduction to the system; and demonstration, with lime injection into the GSA.

Three test runs were performed under each condition. Samples for key gaseous, liquid and solid streams were collected and analyzed for each run. The HAPs measured included 13 trace metals, HCl, and HF. This report presents all field data and laboratory analysis results. Mass balances, removal efficiencies, and emission factors for HAPs also are presented.

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ABBREVIATIONS AND SYMBOLS

acf	actual cubic foot
acfm	actual cubic feet per minute
acm	actual cubic meter
APCD	air pollution control device
APCL	Applied Physics and Chemistry Laboratory
As	arsenic
ASTM	American Society for Testing and Materials
aq	aqueous
Ba	barium
Be	beryllium
BI	fabric filter inlet flue gas sampling location
BO	fabric filter outlet flue gas sampling location
BP	baseline parallel configuration
BS	baseline series configuration
Btu	British thermal unit
Ca	calcium
Ca(OH) ₂	calcium hydroxide (also lime or hydrated lime)
Ca/S	calcium to sulfur molar ratio
CaSO ₃	calcium sulfite
CaSO ₄	calcium sulfate
CaCl ₂	calcium chloride
Cd	cadmium
CAAA	Clean Air Act Amendments of 1990
CC	confidence coefficient
CEMS	continuous emissions monitoring system
CI	confidence interval
Cl	chloride
Co	cobalt
CO ₂	carbon dioxide
Cr	chromium
CTT	clean coal technology
CTE	Commercial Testing and Engineering Company
CV-AAS	cold vapor atomic absorption spectroscopy
DA-AAS	direct aspiration-atomic absorption spectroscopy
DOE	Department of Energy
DP	demonstration parallel configuration
DS	demonstration series configuration
dscf	dry standard cubic foot (20°C, 760 mm Hg)
dscm	dry standard cubic meter (20°C, 760 mm Hg)
EER	Energy and Environmental Research Corporation
EI	ESP inlet flue gas sampling location
EO	ESP outlet flue gas sampling location
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
F	fluoride
FB	field blank
F _d	dry F factor
FF	fabric filter (also baghouse)

ABBREVIATIONS AND SYMBOLS
(continued)

ft	foot
ft ²	square foot
g	gram
GCVw	gross calorific value (Btu/lb), wet basis
GF-AAS	graphite furnace atomic absorption spectroscopy
GI	GSA inlet flue gas sampling location
gr	grain
GS	Greenburg-Smith
GSA	gas suspension absorption
HAP	hazardous air pollutant
HCl	hydrogen chloride
HF	hydrogen fluoride
Hg	mercury
HPLC	high performance liquid chromatography
H ₂ O	water
H ₂ O ₂	hydrogen peroxide
HNO ₃	nitric acid
IC	ion chromatograph
ICAP	inductively coupled argon plasma
in	inch
kg	kilogram
lb	pound
m	meter
m ²	square meter
MBC	mass balance closure
MDL	method detection limit
mg	milligram
Mg	manganese
min	minute
MJ	megajoule
ml	milliliter
MMBtu	million British thermal units
Mn	manganese
Mod	modified stem
MS	matrix spike
MSD	matrix spike duplicate
MW	megawatt
MWe	megawatt (electric)
N/A	not applicable
NCER	National Center for Emission Research
ND	not detected
NDIR	non-dispersive infrared absorption spectroscopy

ABBREVIATIONS AND SYMBOLS
(continued)

NDM	maximum not detected
NDUV	non-dispersive ultraviolet absorption spectroscopy
Ncm	normal cubic meter (0°C, 760 mm Hg)
Ncfm	normal cubic foot per minute (0°C, 760 mm Hg)
Ni	nickel
Nm³	normal cubic meter (0°C, 760 mm Hg)
NO_x	oxides of nitrogen
NPL	National Priorities List
O₂	oxygen
Pb	lead
PEA	performance evaluation audit
PM	particulate matter
ppm	part per million by volume
PQL	practical quantitation limit
QA	quality assurance
QC	quality control
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RPD	relative percent difference
Sb	antimony
scfm	standard cubic foot per minute (20°C, 760 mm Hg)
Se	selenium
sec	second
SO₂	sulfur dioxide
SO₃	sulfur trioxide
SS4	coal process stream
SS5	GSA cyclone solids process stream
SS7	lime slurry process stream
SS9A	ESP field 1 solids process stream
SS9B	ESP fields 2-4 solids process stream
SS11	fabric filter solids process stream
SS13	re-injected fly-ash process stream
SS14	trim water process stream
TC	thermocouple
TSA	technical system audit
TVA	Tennessee Valley Authority
UARG	Utility Air Regulatory Group
V	vanadium
--	not determined
°C	degrees centigrade
°F	degrees Fahrenheit

SI CONVERSION FACTORS

	<u>English (US) units</u>	X	<u>Factor =</u>	<u>SI units</u>
Area:	1 ft ²	x	9.29 x 10 ⁻²	= m ²
	1 in ²	x	6.45	= cm ²
Flow Rate	1 gal/min	x	6.31 x 10 ⁻⁵	= m ³ /s
	1 gal/min	x	6.31 x 10 ⁻²	= L/s
Length:	1 ft	x	0.30	= m
	1 in	x	2.54	= cm
	1 yd	x	0.91	= m
Mass:	1 lb	x	4.54 x 10 ²	= g
	1 lb	x	0.454	= kg
	1 gr	x	0.065	= g
Volume:	1 ft ³	x	28.3	= L
	1 ft ³	x	0.0283	= m ³
	1 gal	x	3.78	= L
	1 gal	x	3.78 x 10 ⁻³	= m ³
Temperature	°F + 32	x	1.8	= °C
	°R	x	0.556	= K

ACKNOWLEDGMENTS

This sampling and analysis program was funded by AirPol Inc. with support from the U.S. Department of Energy. The principal authors of this report were Glenn England, William Oberg, and Greg Rooney. The authors wish to acknowledge the staff of AirPol and the Tennessee Valley Authority/National Center for Emission Research for their support and assistance during the field campaign, especially Frank Hsu and Bindu Baghat of AirPol, and Edward Puschaver and Tom Burnett of TVA.

1.0 EXECUTIVE SUMMARY

This report summarizes results of a project to characterize emissions of selected hazardous air pollutants (HAPs) from the Gas Suspension Absorption (GSA) process. This project was sponsored by the U.S. Department of Energy (DOE), AirPol Inc. (the technology developer), and the Tennessee Valley Authority (TVA), as part of a demonstration of the GSA process under DOE's Clean Coal Technology program. The site of the demonstration was the TVA National Center for Emissions Research located in West Paducah, Kentucky. The air toxics characterization field tests took place in September and October, 1993.

1.1 GSA Demonstration Process

The demonstration plant treated a flue gas slip stream from a coal-fired boiler (Shawnee Unit 9) equivalent to approximately 10 MWe electrical generation. The GSA demonstration plant (Figure 1-1) employs a semi-dry scrubber followed by an electrostatic precipitator (ESP) and a small fabric filter. The temperature of the flue gas leaving the GSA absorber is approximately 140°F, or approximately 20°F above the adiabatic saturation temperature. Fly ash, spent sorbent, and unreacted sorbent are mostly removed from the flue gas in a high-efficiency cyclone and recycled back to the absorber. Particulate matter which penetrates the cyclone is removed in an ESP and/or fabric filter. The gas flow through the fabric filter, capable of handling approximately 15 percent of the gas flow through the GSA absorber, could be arranged either in parallel with the ESP or in series downstream of the ESP.

Emissions were characterized under four test conditions:

- Baseline parallel (BP) - parallel fabric filter configuration without lime slurry injection; and
- Demonstration parallel (DP) - parallel fabric filter configuration with lime slurry injection.
- Baseline series (BS) - series fabric filter configuration without lime slurry injection;
- Demonstration series (DS) - series fabric filter configuration with lime slurry injection;

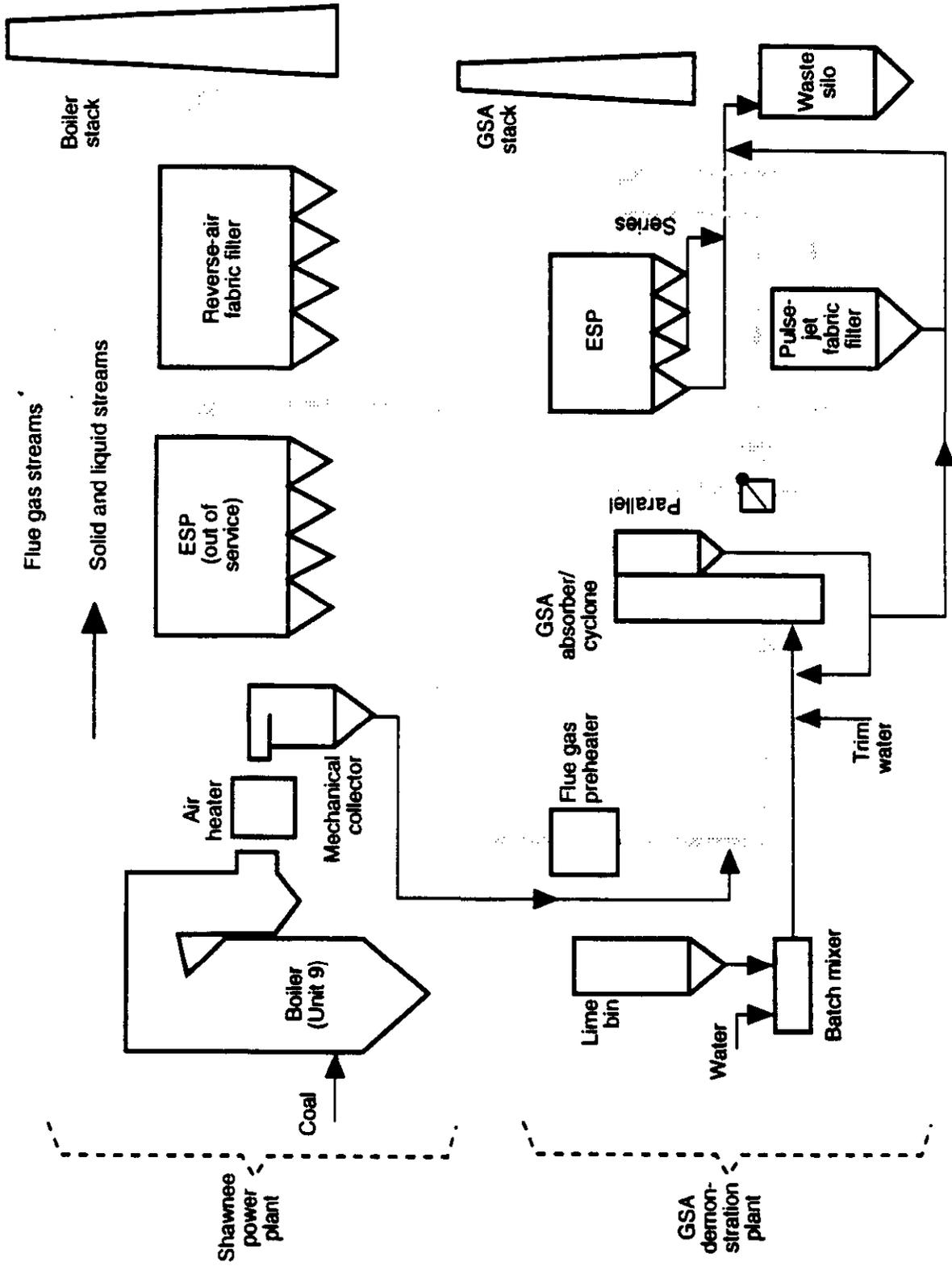


Figure 1-1. Overview of GSA demonstration plant.

1.2 Test Measurements

The HAPs considered in this project were:

- Hydrochloric acid (HCl) and hydrofluoric acid (HF);
- Trace metals (arsenic, antimony, barium, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and vanadium). Due to an analytical laboratory error, flue gas samples were not analyzed for beryllium and nickel.

Other measurements made during the tests by EER and by TVA characterized flue gas particulate, sulfur dioxide (SO₂), and visible emissions. Process operating parameters such as oxygen (O₂) concentration, temperature, pressures, flow rates, etc. were monitored by TVA. Emissions measurements were performed in triplicate under each test condition using EPA reference methods. To evaluate the fate of trace elements in the system, samples of liquid and solid streams entering and leaving the process were collected and analyzed in addition to flue gas samples.

1.3 Results

Table 1-1 summarizes average mass balance closure across the GSA pilot plant under each test condition. Mass balance closure across the whole system is within the project mass balance objectives (50 to 150 percent) for most tests and metals except for antimony. Antimony was present at levels below the detection limits of the test methods in most cases. The uncertainty for antimony removal efficiency was reasonable; therefore, the high mass balance closure is due to high detection limits (and high calculated antimony flow rate) attributed to the solids leaving the system. Chlorine mass balances for parallel configuration demonstration tests could not be calculated because insufficient data are available.

Tables 1-2 to 1-4 present average removal efficiencies and emission factors for three conceptual process configurations:

- GSA absorber/cyclone followed by an ESP (Arrangement I);
- GSA absorber/cyclone followed by a fabric filter (Arrangement II); and

TABLE 1-1. MASS BALANCE CLOSURE ACROSS GSA PILOT PLANT

	Series configuration				Parallel configuration			
	Baseline		Demonstration		Baseline		Demonstration	
	Mean	2.5% CC	Mean	2.5% CC	Mean	2.5% CC	Mean	2.5% CC
Total System								
Antimony	H 4540	6457	H 2581	1559	H 1998	2183	H 1750	733
Arsenic	L 42	29	75	88	137	228	H 183	78
Barium	70	101	114	115	74	37	H 197	126
Cadmium	L 37	42	105	52	64	67	H 203	20
Chromium	L 49	49	76	22	50	51	80	33
Cobalt	53	27	56	88	74	24	H 236	177
Lead	L 29	50	L 33	11	L 37	47	L 21	26
Manganese	84	14	131	57	83	24	100	46
Mercury	L 38	43	L 30	12	73	27	51	37
Selenium	60	29	L 17	54	107	72	L 4	1
Vanadium	L 42	40	56	74	50	35	83	175
Chlorine (as chloride)	122	91	L 46	17	88	8	-	-

L = low closure (less than 50 percent)

H = high closure (greater than 50 percent)

TABLE 1-2. REMOVAL EFFICIENCY AND EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT I (GSA + ESP)

Test configuration	Removal Efficiency			Emission factors		
	IA - Series		IB - Parallel	IA - Series		IB - Parallel
	Efficiency %	Uncertainty %		Emission factor lb/E12 Btu	Uncertainty %	
Baseline						
Trace Metals						
Antimony	89.71	18	96.61	13	0.04	15
Arsenic	98.74	8	98.43	8	5.28	132
Barium	98.37	8	99.52	8	19.60	21
Beryllium (5)	98.76	--	98.40	--	0.97	--
Cadmium	97.42	11	85.01	11	0.18	102
Chromium	99.09	9	98.09	9	6.12	182
Cobalt	98.38	10	98.13	10	1.16	21
Lead	98.79	9	97.33	9	2.45	148
Manganese	99.20	9	98.53	9	8.42	28
Mercury	79.15	38	62.45	12	0.33	59
Nickel (5)	98.76	--	98.40	--	7.61	--
Selenium	73.05	28	79.73	35	34.69	88
Vanadium	98.73	14	98.76	13	7.57	166
Particulate (2)	99.58	10	99.54	4	0.034	17
HCl	-4.96	811	-0.05	15932	(3)	48
HF	-18.38	547	-0.05	15932	(3)	139
					NDM	6.12
						0.03
					(3)	17239
					(3)	491
Demonstration						
Trace Metals						
Antimony	84.72	38	98.77	14	0.18	334
Arsenic	99.96	8	96.36	48	0.16	57
Barium	99.63	9	92.71	90	3.42	17
Beryllium (5)	99.43	--	94.63	--	0.45	--
Cadmium	98.68	11	93.27	65	0.09	229
Chromium	99.48	10	95.11	59	1.98	17
Cobalt	98.66	9	94.27	64	0.88	17
Lead	99.88	9	92.08	107	0.20	382
Manganese	99.20	9	98.53	9	69.36	402
Mercury	88.27	25	-38.89	1919	0.13	121
Nickel (5)	99.43	--	94.63	--	3.51	--
Selenium	76.87	89	99.81	10	20.21	293
Vanadium	99.18	14	93.37	76	6.61	21
Particulate (2)	99.85	4	96.70	43	0.012	79
HCl	99.95	12	98.12	13	ND(4)	18
HF	98.89	13	99.40	32	ND(4)	62
					ND(4)	25.90
					ND	0.05
					ND	42.05
					(4)	141.55
					ND(4)	414
					21(1)	49
					1083(1)	
					1230(1)	
					23(1)	
					1242(1)	
					1120(1)	
					--	
					838(1)	
					1149(1)	
					1038(1)	
					1236(1)	
					1152(1)	
					20(1)	
					--	
					32.85	
					ND	

Notes:

- (1) Uncertainty based on two runs.
- (2) Emission factor in lb/E6 Btu.
- (3) No measurements at ESP outlet made; estimated based on fabric filter inlet results.
- (4) Single run at ESP outlet; estimated including fabric filter inlet results.
- (5) Estimated based on uncontrolled emission factors calculated from coal analysis and average removal efficiency of all trace metals except mercury, selenium, cadmium, and antimony.

TABLE 1-3. REMOVAL EFFICIENCY AND EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT II (GSA + FF)

		Removal Efficiency		Emission factors	
Test configuration		Parallel			
Value		Efficiency	Uncertainty	Emission factor	Uncertainty
		%	%	lb/E12 Btu	%
Baseline	Trace Metals				
	Antimony	96.68	14	ND	0.07 17
	Arsenic	99.83	8		0.71 53
	Barium	99.54	8	ND	4.09 14
	Beryllium (2)	99.38	--		0.48 --
	Cadmium	71.40	13		2.21 33
	Chromium	99.46	9	ND	2.37 15
	Cobalt	98.69	10	ND	1.05 14
	Lead	99.51	9		0.94 53
	Manganese	99.57	9		3.22 61
	Mercury	31.97	527		1.12 254
	Nickel (2)	99.38	--		3.79 --
	Selenium	99.93	9	ND	0.06 14
	Vanadium	99.07	13	ND	7.91 18
Particulate (1)	99.89	4		0.008 21	
HCl	-10.99	479		18142 18	
HF	7.12	488		1534 185	
Demonstration	Trace Metals				
	Antimony	98.65	14	ND	0.06 15
	Arsenic	99.98	8		0.08 238
	Barium	92.71	90	ND	3.39 13
	Beryllium (2)	98.47	--		1.19 --
	Cadmium	78.73	20		1.35 52
	Chromium	99.50	9	ND	1.97 13
	Cobalt	98.91	9	ND	0.88 13
	Lead	99.61	10		0.59 111
	Manganese	99.57	9		5.08 122
	Mercury	49.23	136		0.74 146
	Nickel (2)	98.47	--		9.37 --
	Selenium	99.80	10	ND	0.05 13
	Vanadium	99.00	13	ND	6.56 17
Particulate (1)	99.94	4		0.005 79	
HCl	99.96	12	ND	7.32 16	
HF	96.85	15	ND	22.48 17	

Notes:

(1) Emission factor in lb/E6 Btu.

(2) Estimated based on uncontrolled emission factors calculated from coal analysis and average removal efficiency of all trace metals except mercury, selenium, cadmium, and antimony.

TABLE 1-4. REMOVAL EFFICIENCY AND EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT III (GSA + ESP + FF)

		Removal Efficiency		Emission factors	
Test configuration		Series			
Value		Efficiency %	Uncertainty %	Emission factor lb/E12 Btu	Uncertainty %
Baseline	Trace Metals				
	Antimony	89.67	17	ND	30
	Arsenic	99.98	8	0.07	186
	Barium	99.69	8	ND	28
	Beryllium (2)	99.52	--	0.38	--
	Cadmium	94.03	11	0.47	85
	Chromium	99.65	8	ND	29
	Cobalt	98.66	10	ND	28
	Lead	99.69	9	0.61	25
	Manganese	99.77	9	2.21	112
	Mercury	99.86	14	0.11	236
	Nickel (2)	99.52	--	2.96	--
	Selenium	99.11	10	1.17	120
	Vanadium	99.17	14	ND	31
Particulate (1)	99.89	10	0.009	88	
HCl	-18.88	371	18435	16	
HF	-91.24	249	4208	55	
Demonstration	Trace Metals				
	Antimony	95.00	19	ND	18
	Arsenic	99.99	8	ND	16
	Barium	99.49	9	ND	16
	Beryllium (2)	99.63	--	0.29	--
	Cadmium	97.37	12	0.22	80
	Chromium	99.66	10	ND	16
	Cobalt	99.13	10	ND	16
	Lead	99.88	9	0.27	60
	Manganese	99.77	9	1.36	283
	Mercury	90.16	27	0.12	196
	Nickel (2)	99.63	--	2.29	--
	Selenium	99.96	10	ND	16
	Vanadium	99.46	14	ND	20
Particulate (1)	99.94	4	0.005	40	
HCl	99.95	13	210	413	
HF	98.99	13	ND	13	

Notes:

(1) Emission factor in lb/E6 Btu.

(2) Estimated based on uncontrolled emission factors calculated from coal analysis and average removal efficiency of all trace metals except mercury, selenium, cadmium, and antimony.

- GSA absorber/cyclone followed by an ESP and fabric filter in series (Arrangement III).

The statistical uncertainty of the results also is shown. Removal efficiencies and emission factors for beryllium and nickel are estimated based on coal analysis and removal efficiency of other metals since direct flue gas measurements were not made. Arrangement I was evaluated for both series and parallel test configurations (IA and IB, respectively), which enables the effect of slightly increased ESP specific collection area (for Arrangement IB) to be examined. Emissions results downstream of the GSA are generally below detection limits for many substances, which provides evidence of good removal efficiency for these substances. Removal efficiency of particulate matter and trace metals, except for volatile metals (mercury, selenium), is generally greater than 98 to 99 percent for all configurations. Mercury removal efficiency ranges from 62 to greater than 99 percent except in cases where measurement uncertainty is large. Mercury removal is slightly greater under demonstration conditions for conceptual arrangement I (GSA + ESP) and slightly lower under demonstration conditions for conceptual arrangement III (GSA + ESP + FF). These differences are only marginally significant considering the measurement uncertainty. Selenium removal is less than 90 percent in most cases for Arrangement I, but was greater than 99 percent when the fabric filter was employed (Arrangements II and III). Selenium was not detected at the conceptual arrangement outlet and mass balances are low for most demonstration test conditions. This suggests reported selenium capture efficiencies may be biased high. Cadmium exhibits slightly lower removal efficiency than most other metals, especially for conceptual arrangement II (GSA + FF). Cadmium removal efficiency is consistently lower for parallel configuration tests compared to series configuration tests. QA/QC results for cadmium suggest measurement artifacts may account for some or all of this variability. Removal efficiencies for antimony ranged from 85 to 98.8 percent; however, these results should be used with caution because of the poor mass balances for this element.

2.0 INTRODUCTION, PROJECT OBJECTIVES, AND TEST PROGRAM

Hazardous air pollutants (HAPs) are substances released to the atmosphere which are known or suspected of being toxic to human health or potential human carcinogens. Emissions of these substances, in sufficient amounts, may represent a potential health hazard in exposed populations. Trace elements associated with the mineral matter in coal and the various substances formed during coal combustion have the potential to produce emissions of air toxics from coal-fired electric utilities. Technologies designed to control emission of acid rain precursors from utility boilers offer the potential to simultaneously reduce (or increase) emissions of HAPs.

The following sub-section briefly summarizes the background surrounding this project. The project objectives, an overview of the test program, and project organization are presented in the subsequent sub-sections. A guide to this report is provided at the end of this section.

2.1 Background

The emission of HAPs and acid rain precursors has received considerable emphasis in recent regulations. Title III of the 1990 federal Clean Air Act Amendments (CAAA) requires the U.S. Environmental Protection Agency (EPA) to evaluate the need for regulating 189 individual or classes of HAPs in three reports to Congress. The first of these reports will deal specifically with the electric utility industry. The existing database on HAPs emissions from utility boilers is only partially complete with respect to the range and types of systems which have been characterized. Many previous test results are incomplete or suspect due to inconsistent or invalidated test methodologies, or due to incomplete or non-existent documentation of data quality. Therefore, industry and government have undertaken to develop new data to fill the data gaps. For example, the U.S. Department of Energy (DOE), in collaboration with the Electric Power Research Institute (EPRI), EPA, and the Utility Air Regulatory Group (UARG), is conducting comprehensive tests of conventional electric utility plants and as well as advanced control technologies for acid rain precursors oxides of nitrogen (NO_x) and sulfur dioxide (SO_2). Other state and local regulations are already in place or under development that would restrict emissions of the 189 HAPs listed in Title III of the CAAA plus many additional substances, broadly referred to as "air toxics". It has been suggested by some that the cost of controlling air toxics emissions from electric utility boilers may be many times that for acid rain precursors. Thus, the successful commercialization of an advanced control technology for acid rain precursor emissions may be strongly influenced by its effect on air toxics emissions.

AirPol Inc. has developed an advanced SO₂ control technology called Gas Suspension Absorption (GSA). AirPol, TVA, and DOE are co-funding a demonstration of this technology under the DOE's Clean Coal Technology (CCT) Program (Round 3). GSA is being demonstrated on a 10 MWe equivalent pilot-scale plant at TVA's National Center for Emission Research (NCER) in West Paducah, Kentucky. The CAAA requires EPA to evaluate the potential impact of acid rain precursor control technologies on HAP emissions. Because HAP and other air toxic emissions are likely to be an important factor in commercializing new technologies for acid rain precursor control, DOE is establishing a database of HAP emissions from selected technologies being developed under the CCT program. Therefore, the GSA project was selected for limited air toxic tests under the environmental monitoring provisions of the CCT program.

2.2 Project Objectives

The overall goals of the AirPol GSA demonstration project were to:

- Achieve high SO₂ removal with high lime utilization;
- Achieve acceptable ESP performance;
- Demonstrate the effectiveness of the GSA process for air toxics removal; and
- Determine fabric filter performance both downstream of the ESP and immediately after the GSA absorber/cyclone.

The specific objectives of the overall GSA demonstration are provided elsewhere. The specific objectives of the GSA air toxics characterization tests were to:

- Determine emissions of hydrogen chloride (HCl), hydrogen fluoride (HF), and trace metals (As, Ba, Cd, Cr, Co, Hg, Mn, Pb, Sb, Se, V), and total particulate matter;
- Evaluate the impact of particulate control device configuration (ESP alone, fabric filter alone, or ESP plus fabric filter in series) on final emissions of HAPs;

- Establish the net removal efficiency of trace metals, HCl, HF, and total particulate matter for the GSA reactor/cyclone with three particulate control device configurations (ESP alone, fabric filter alone, or ESP plus fabric filter in series);
- Establish the partitioning of trace metals introduced with the coal between flue gas emissions and other effluent streams;
- Compare emissions of HCl, HF, and trace metals with lime slurry injection (demonstration tests) to those without (baseline tests);
- Develop a mass balance analysis for total mass, trace metals, and chlorine around the entire process and across each major component of the system;
- Document process operating conditions during field sampling; and
- Document data quality and ensure that it is suitable both for developing commercialization strategies and for use by EPA in preparing Reports to Congress under the CAAA.

2.3 Summary of Test Program

A detailed site-specific sampling and analysis plan was prepared prior to the tests. The test plan included:

- Specification of target operating conditions for the boiler, GSA, ESP, and fabric filter that were representative of normal performance;
- Definition of a sampling and measurement matrix which provided for characterization of target HAP emissions and mass balances for selected elements;
- Specification of sampling and analytical procedures suitable for characterization of emissions in gaseous, solid and liquid streams; and
- Definition of quality assurance/quality control (QA/QC) activities which would provide test results consistent with the requirements of an EPA Category II Quality Assurance Project Plan.

Table 2-1 summarizes the field test activities. Emissions were characterized under two process configurations. The gas flow through the fabric filter, capable of handling approximately 15 percent of the gas flow through the GSA absorber, could be arranged either in parallel with the ESP, with a slipstream of the GSA outlet gas directed to the baghouse inlet, or in series, with a slipstream of the ESP outlet gas introduced to the baghouse inlet. These two fabric filter configurations are referred to as "parallel" and "series" test conditions, respectively. For each configuration, measurements were conducted with and without lime slurry injection in the GSA absorber. These are referred to as "demonstration tests" and "baseline tests," respectively. The demonstration plant and operating conditions during the test are described further in Section 3.

The air toxics that were addressed are:

- HAPs listed in CAAA Title III: hydrochloric acid (HCl), hydrofluoric acid (HF), and trace metals (arsenic, antimony, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium).
- Other trace metals considered as air toxics in other federal, state, or local regulations: barium and vanadium.

These are the HAPs of greatest interest. Since most of the trace metals in the flue gas are associated with solid-phase particulate, total particulate emissions were also measured. Since other studies have shown that organic HAPs are of less concern and the GSA was not expected to significantly affect these emissions, they were not measured in this project. Other measurements made during the tests characterized flue gas SO₂ and visible emissions. Standard EPA (or other) test methods were applied where such methods existed. Process operating parameters such as oxygen (O₂) concentration, temperatures, pressures, flow rates, etc. were monitored also. To evaluate the fate of trace elements in the system, samples of liquid and solid streams entering and leaving the process were collected and analyzed in addition to flue gas samples. These streams included process inputs (coal, lime slurry, trim water, and re-injected fly ash) and outputs (GSA cyclone solids, ESP ash, and fabric filter ash). The streams were analyzed for trace metals, chlorine, and other parameters necessary to achieve the project objectives. Section 4 describes the sampling and analytical procedures in more detail.

TABLE 2-1. SUMMARY OF FIELD TESTS

	9/21/93	9/22/93	9/23/93	9/27/93	9/28/93	9/29/93
Series Demonstration						
Series Baseline						
Trace metals/particulate						
GSA Inlet (SS 1)	Run 1	Run 2	Run 3	Run 1 (4)	Run 2	Run 3,4 (5)
ESP Inlet (SS 2)	Run 1 (2)	Run 2	Run 3,4	Run 1 (4)	Run 2	Run 3,4
ESP Outlet (SS 3)	Run 1	Run 2	Run 3	Run 1 (4)	Run 2	Run 3,4
FF Outlet (SS 10)	Run 1	Run 2	Run 3	Run 1 (4)	Run 2	Run 3,4
FF Inlet (SS 12)	Run 1	Run 2	Run 3	Run 1 (4)	Run 2	Run 3,4
HCl and HF						
GSA Inlet (SS 1)	Run 1 (1)	Run 2	Run 3,4	Run 1 (3)	Run 2,3	Run 4
ESP Inlet (SS 2)	Run 1	Run 2	Run 3	Run 1 (3,6)	Run 2,3 (6)	Run 4 (6)
ESP Outlet (SS 3)	Run 1 (6)					
FF Outlet (SS 10)	Run 1	Run 2	Run 3	Run 1 (3)	Run 2,3	Run 4
FF Inlet (SS 12)	Run 1 (1)	Run 2	Run 3,4	Run 1 (3)	Run 2,3	Run 4
Process Sampling						
Coal (SS 4)	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Lime Slurry (SS 7)	Run 1	Run 2	Run 3			
Trim Water (SS 14)	Run 1 (6)	Run 2 (6)	Run 3 (6)			
Re-injected ash (SS 13)	Run 1 (6)	Run 2 (6)	Run 3 (6)	Run 1 (6)	Run 3 (6)	Run 4 (6)
GSA solids (SS 5)	Run 1	Run 2	Run 3	Run 1 (3)	Run 2	Run 4
ESP Ash - Field 1 (SS 9A)	Run 1	Run 2	Run 3	Run 1 (3)	Run 2	Run 3, 4
ESP Ash - Fields 2-4 (SS 9B)	Run 1	Run 2	Run 3	Run 1 (3)	Run 2	Run 3, 4
FF Ash (SS 11)	Run 1	Run 2	Run 3	Run 1 (3)	Run 2	Run 3, 4

	10/13/93	10/14/93	10/15/93	10/19/93	10/20/93	10/21/93	10/22/93
Parallel Demonstration							
Parallel Baseline							
Trace metals/particulate							
GSA Inlet (SS 1)	(7)	Run 1	Run 2,3				
ESP Inlet (SS 2)	(7)	Run 1 (12)	Run 2,3	Run 1 (6,8)	(9)	Run 2 (6)	Run 3,4 (6)
ESP Outlet (SS 3)			Run 2,3 (6)	Run 1 (6,8)	(9)	Run 2 (6)	Run 3,4 (6)
FF Outlet (SS 10)	(7)	Run 1	Run 2,3	Run 1 (8)	(9)	Run 2	Run 3,4
FF Inlet (SS 12)	(7)	Run 1	Run 2,3	Run 1 (8)	(9)	Run 2	Run 3,4
HCl and HF							
GSA Inlet (SS 1)	Run 1 (6)	Run 2 (6)	Run 3 (6)	Run 1 (6,8)	(9)	Run 2,3 (6)	Run 4 (6)
ESP Inlet (SS 2)		Run 2 (6)	Run 3 (6)				
ESP Outlet (SS 3)			Run 3 (6)				
FF Outlet (SS 10)	Run 1	Run 2	Run 3	Run 1 (8)	(9)	Run 2,3	Run 4
FF Inlet (SS 12)	Run 1	Run 2	Run 3 (10)	Run 1 (8)	(9)	Run 2,3	Run 4
Process Sampling							
Coal (SS 4)	Run 1	Run 2	Run 3	Run 1	(9)	Run 2	Run 3
Lime Slurry (SS 7)	Run 1	Run 2	Run 3				
Trim Water (SS 14)	Run 1 (6)	Run 2 (6)	Run 3 (6)				
Re-injected ash (SS 13)	Run 1 (6)	Run 2 (6)	Run 3 (6)	Run 1 (6)	(9)	Run 2 (6)	Run 4 (6)
GSA solids (SS 5)	Run 1	Run 2	Run 3	Run 1 (6,8)	(9)	Run 2 (6)	Run 4 (6)
ESP Ash - Field 1 (SS 9A)	Run 1 (6)	Run 2 (6)	Run 3 (6)	Run 1 (6,8)	(9)	Run 2 (6)	Run 3, 4 (6)
ESP Ash - Fields 2-4 (SS 9B)	Run 1 (6)	Run 2 (6)	Run 3 (6)	Run 1 (6,8)	(9)	Run 2 (6)	Run 3, 4 (6)
FF Ash (SS 11)	Run 1 (11)	Run 2	Run 3 (10)	Run 1 (8)	(9)	Run 2	Run 3, 4

- (1) Invalid run - train backflushed due to high vacuum in duct.
- (2) Invalid run - meterbox calibration.
- (3) Invalid run - High lime in process samples indicates process line-out not complete; runs considered not representative of normal baseline operation.
- (4) Metals runs aborted due to baghouse failure.
- (5) Low isokinetics due to blocked pitot; flag data, correct results, and accept run.
- (6) Samples were not part of planned test matrix.
- (7) Metals runs cancelled due to boiler mill outage.
- (8) Data suspect due to process conditions.
- (9) Tests cancelled due to unplanned baghouse maintenance.
- (10) Sample destroyed in shipment.
- (11) Chloride data not available.
- (12) Acetone rinse destroyed in shipment; particulate and metals data invalid.

Emissions measurements were performed in triplicate for each test. Series configuration tests began on September 21, 1993 and ended on September 29, 1993. Parallel configuration tests were conducted from October 14 to October 22, 1993. Solid and liquid samples were collected concurrently with gas-phase sampling to the extent possible. All particulate/trace metals samples and most HCl/HF samples were obtained simultaneously at each flue gas sampling location. Generally, HCl and HF sampling was conducted immediately following metals sampling. In some cases, test runs were invalidated in the field. Whenever possible, these runs were subsequently repeated to provide three valid samples for each test. After the field campaign began, it was decided to collect a significant number of samples in addition to those planned. The footnotes in Table 2-1 describe factors affecting the test results; these factors are discussed further in Section 5.

2.4 Project Organization

The principal organizations involved in the air toxics tests were:

- AirPol Inc.;
- Tennessee Valley Authority;
- U.S. Department of Energy; and
- Energy and Environmental Research Corporation and its subcontractors.

The project management structure is illustrated in Figure 2-1. The project was co-funded by DOE, AirPol, and TVA. AirPol was responsible for technical direction and overall coordination of planning, reporting, and site preparation for the air toxics tests. TVA was responsible for operating the GSA system, collecting process data, and coal sampling. EER was responsible for developing the sampling and analysis plan, sample collection, sample analysis, data reduction, reporting, and quality assurance. Samples (except coal) were analyzed for trace metals by Applied P and Ch Laboratories, Inc. (APCL), and for HCl, HF, and chlorine by Pyramid Laboratories (Pyramid). Coals were analyzed for ultimate analysis and heating value by TVA, and for trace metals, chlorine, and other parameters by Commercial Testing and Engineering Inc. (CTE).

2.5 Key Contacts

The following persons may be reached for additional information regarding this test project:

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 (615) 751-3938

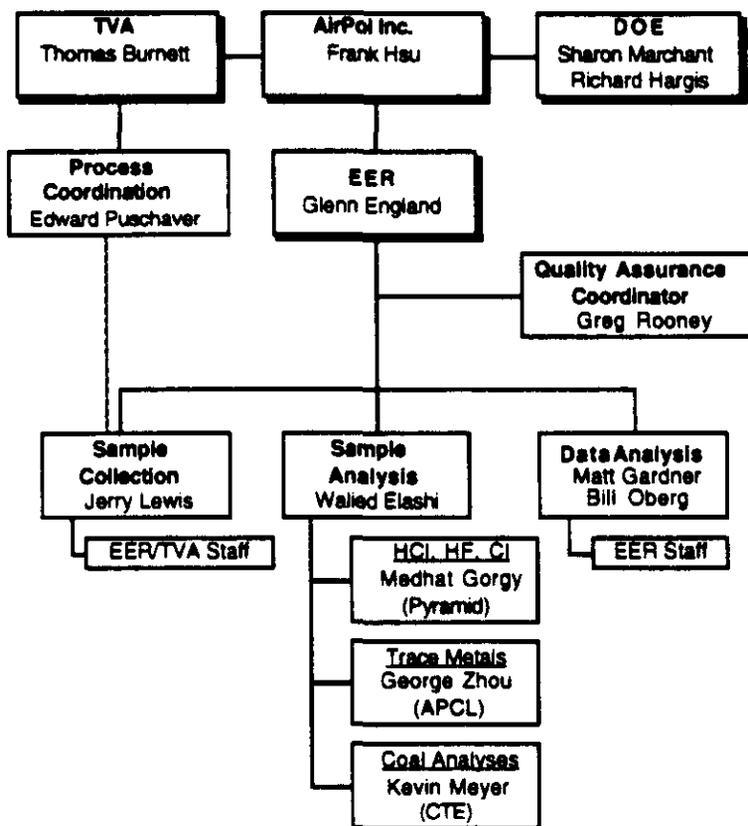


Figure 2-1. Project management structure for air toxics measurement project.

2.6 Report Organization

The results of this project are presented in this report as follows:

Section 1—Executive Summary. Provides a concise summary of the project, key results, and conclusions;

Section 2—Introduction. Provides background, project objectives, and summarizes the test program;

Section 3—Process Description. Provides a description of the demonstration plant and operating conditions during the tests;

Section 4—Sampling and Analytical Procedures. Summarizes the sampling and analytical procedures;

Section 5—Results. Presents the test measurement results;

Section 6—Mass Balances, Removal Efficiencies, and Emission Factors. Presents emissions factors, removal efficiencies, trace element partitioning, and mass balance results derived from the test measurement results; and

Section 7—Quality Assurance. Presents the key QA/QC data and discusses impacts on the test results.

Section 8—Uncertainty Analysis. Discusses statistical uncertainty associated with the measurements and dependent test results.

The appendices, bound separately, include a compilation of detailed test data for reference purposes.

3.0 PROCESS DESCRIPTION

3.1 AirPol GSA Overview

The AirPol Gas Suspension Absorption process is a low-cost retrofit technology employing a semi-dry scrubber to achieve more than 90 percent SO₂ removal in coal-fired boiler applications. It has been used successfully in commercial waste-to-energy plants in Denmark to scrub HCl from flue gases. Combustion gases pass through a vertical reactor, where a suspension of lime (Ca(OH)₂), reaction products, and fly ash in water is injected through a single spray nozzle. The lime reacts with SO₂ and HCl in the flue gas to form primarily calcium sulfite (CaSO₃·⁻), calcium sulfate (CaSO₄), and calcium chloride (CaCl₂), which are solids. Most of the solids are separated from the gases in a cyclone and recirculated back into the system to increase the lime utilization. The treated flue gases are sent through a dust collector before being released into the atmosphere. The process has the potential to achieve a high lime utilization rate with high sulfur coals and concurrent removal of HAPs from the flue gas. The relative simplicity of the system and potential for high lime utilization make the economics favorable compared to conventional wet or dry scrubbers.

3.2 Process Description

A flexible pilot plant was constructed at the NCER to demonstrate the process. Flue gas for the pilot plant is drawn from a pulverized coal-fired boiler at the TVA's Shawnee Power Plant. A 9.43 Nm³/sec (21,463 scfm) slipstream of flue gas from the boiler (approximately 10 MWe equivalent) is taken downstream of a mechanical particulate collector. The slipstream passes through a cross-flow preheater to allow control over the flue gas temperature at the demonstration plant inlet. Fly ash removed in the mechanical collector is reinjected into the demonstration plant to simulate various inlet particulate loadings.

The arrangement of the GSA demonstration plant is shown in Figure 3-1. The main components of the GSA pilot plant are:

- Slurry preparation system;
- Reactor;

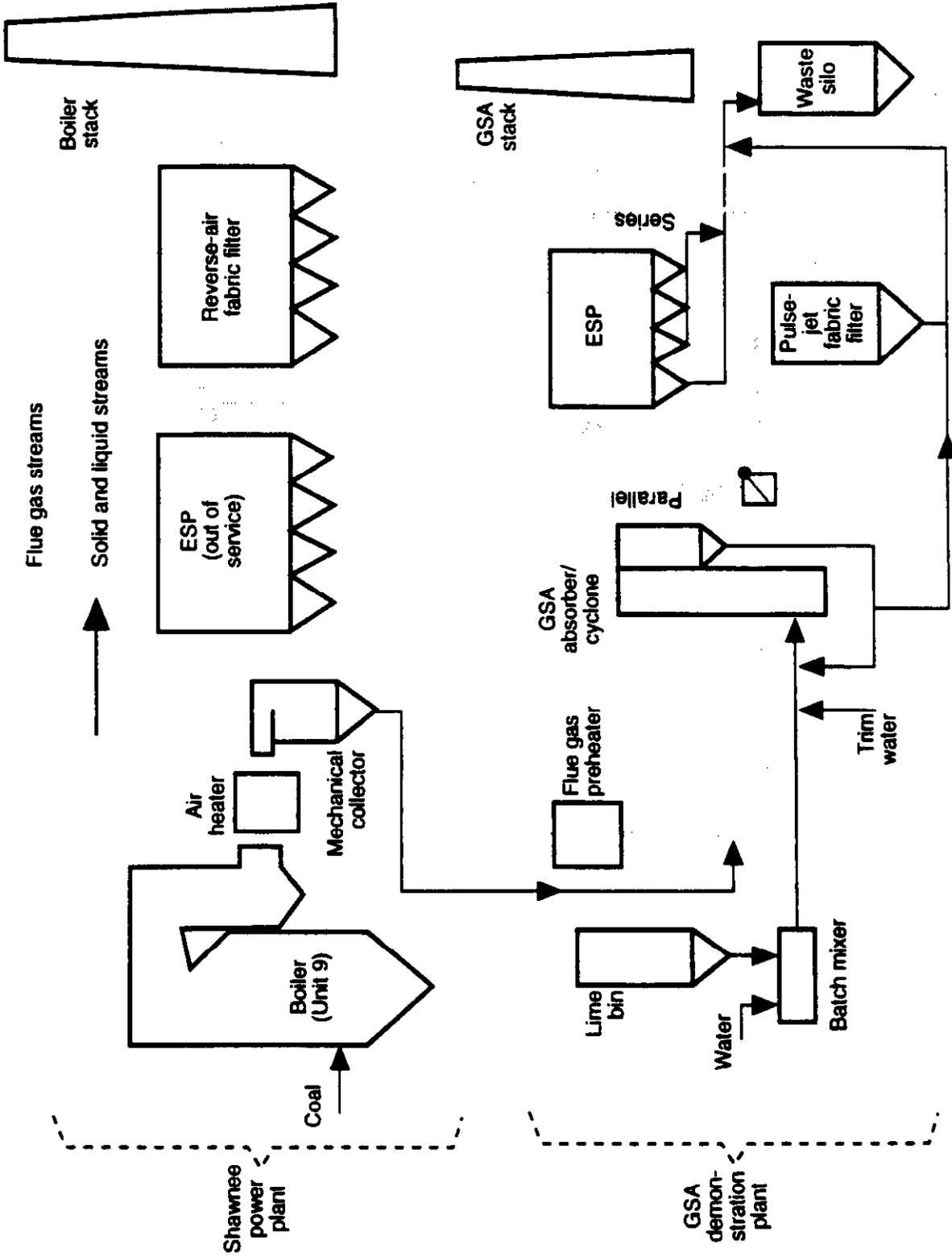
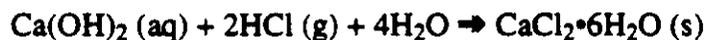
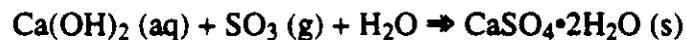


Figure 3-1. AirPot GSA pilot plant process arrangement.

- Cyclone separator
- Electrostatic precipitator;
- Pulsed-jet baghouse.

The lime slurry is prepared from hydrated lime in a batch mixer and pumped to a storage tank. The slurry is pumped from the storage tank to the GSA reactor, where it is injected upward through a two-fluid atomizer near the bottom of the reactor. The quantity of lime used is based on the SO₂ content of the flue gas and the amount of SO₂ removal required. Trim water is added to the slurry to cool the gas to the design temperature of approximately 62 to 68°C (145-155°F).

The SO₂-laden flue gas from the preheater enters the GSA reactor at the bottom of the reactor and flows upward. Most of the water in lime slurry droplets, heated by the flue gas, evaporates in the reactor, decreasing the gas temperature and leaving semi-dry solids. At gas temperatures close to the adiabatic saturation temperature, the primary reactions in the GSA system are:



The design gas temperature is approximately 10-16°C (18-28°F) above the adiabatic saturation temperature. The resulting solids and unreacted lime are entrained in the flue gas along with the fly ash from the boiler. The flue gas passes up through the reactor and exits at the top into a cyclone-type mechanical collector. The cyclone removes most of the particles from the flue gas (90+ percent) and nearly all of these solids are recycled to the reactor via a screw conveyor, increasing lime utilization. The remaining solids are discharged in the form of a dry, by-product material. These reactions are thought to take place primarily in the thin layer of fresh lime slurry coating the dry recycle solids; thus the surface area added by the recycled fly ash enhances both the SO₂ removal and the drying process in the reactor. The system is relatively forgiving to atomizer problems (e.g., pluggage, erosion) since SO₂ removal continues to occur via the recycled solids

for short periods of time even when the atomizer is removed for maintenance, and the high concentration of solids (approximately 200-800 grains/scf) is thought to simultaneously clean the inner surface of the reactor.

The flue gas from the cyclone flows to an electrostatic precipitator for final particulate removal. The ESP has four separately energized fields in series with a 10-in. plate spacing. The plates are 23 ft. high and form 8 parallel gas passages. The specific collection area is approximately 19.7 m²/dscm/sec (360 ft²/1000 acfm) under baseline conditions (i.e., without lime slurry or trim water injection) and approximately 24.1 m²/dscm/sec (440 ft²/1000 acfm) with the GSA in operation. The solids collected in the ESP are conveyed mechanically to a waste silo. In addition, a slipstream (approximately 1 MWe equivalent) of the flue gas from the main GSA/ESP plant may be removed from the ESP inlet or outlet, passed through a pulsed-jet baghouse, and returned to the main plant ductwork downstream of the ESP. The baghouse has a nominal air-to-cloth ratio of 1.21 dscm/min/m² (4.0 acfm/ft²) and the bags are cleaned by a low-pressure, high-volume, ambient air stream delivered by a rotating manifold. The solids collected in the baghouse are conveyed pneumatically to the waste silo. The treated flue gas is passed to an induced draft fan, reheated, and discharged to the atmosphere through a stack.

3.3 Process Control

The primary control points in the GSA system are: (1) the SO₂ concentration in the flue gas, (2) the flue gas wet-bulb temperature at the reactor inlet, (3) the flue gas temperature at the reactor/cyclone outlet, and (4) the pressure drop in the reactor. The SO₂ concentration in the stack can be used to determine whether the lime slurry flow rate is increased, held constant, or decreased. If the SO₂ concentration in the outlet flue gas is too high, the lime slurry flow rate can be increased until the SO₂ concentration drops to the desired range. The wet-bulb temperature is measured at the reactor inlet. The flue gas temperature at the reactor/cyclone outlet, in combination with the wet-bulb temperature measured at the reactor inlet, determines the approach-to-saturation temperature in the reactor/cyclone. The approach-to-saturation temperature in the reactor/cyclone is controlled by the amount of trim water added to the lime slurry. The pressure drop across the reactor/cyclone is an indirect indication of the bed density, i.e., the higher the pressure drop, the denser the bed of solids. The solids recycle rate is controlled by a separate control loop. Thus, the operation and control of the GSA system requires the measurement of only temperatures, pressures, and the SO₂ concentration in the flue gas in the stack.

Process Operating Conditions During Test Program

The key target operating conditions during the demonstration were:

Gas flow rate at inlet venturi:	566 Ncm/min (20,000 Ncfm)
Gas temperature at GSA reactor inlet:	
Demonstration tests	160°C (320°F)
Baseline tests	132°C (270°F)
Added inlet particulate loading ¹ :	3400 mg/acm (1.5 gr/acf)
Approach to saturation (demonstration only):	6.7°C (12°F)
Solid recirculation rate (demonstration only):	18.9 kg/s (2500 lb/min)
Ca/S molar input ratio (demonstration only):	1.4 to 1.6
SO ₂ removal (demonstration only):	90 percent

Two slightly different modes of operation were employed during demonstration tests. During the series configuration demonstration tests, the input calcium-to-sulfur ratio (Ca/S) was held constant at 1.4 and the SO₂ removal was allowed to vary. During the parallel configuration demonstration tests, Ca/S was varied to maintain overall SO₂ removal constant at approximately 90 percent. The target approach to saturation temperature was 6.7°C(12°F) for both demonstration test configurations.

Process operating data, was acquired by NCER staff during testing to document the operating conditions and to verify steady-state operation of the facility, ensuring the comparability of emissions data taken on different operating days. Tables 3-1 and 3-2 summarize the average process operating parameters during valid flue gas sampling periods on each test day for series and parallel configuration tests, respectively. Target operating conditions were achieved for each series of tests. The confidence intervals are very small relative to the mean value for all operating parameters throughout each condition, indicating consistent process operation from day-to day during each series of runs. Therefore, the emissions results can be compared without concern over differences in process operating conditions.

¹Equivalent concentration of reinjected fly ash in inlet flue gas.

TABLE 3-1. PROCESS OPERATING DATA FOR SERIES CONFIGURATION TESTS

Parameter	Units	Parameter	Demonstration tests						Baseline tests							
			9/21/93		9/22/93		9/23/93		9/28/93		9/29/93		Avg			
			Target	9/21/93	9/22/93	20000	20006	19993	87.1	87.9	3.0	CI	Target	9/28/93	9/29/93	Avg
SO2 removal efficiency	%	SO2_RET	90	87.4	89.3	20000	20006	19993	87.1	87.9	3.0 <td>NA</td> <td>NA</td> <td>NA</td> <td>NA</td> <td>NA</td>	NA	NA	NA	NA	NA
Flue gas flow rate (venturi inlet)	Ncfm	SFG_IVEN	20000	20000	20006	20000	20006	19993	20000	20000	17	20000	20000	20000	20001	13
Flue gas temperature (GSA reactor inlet)	deg F		320	295	297	297	292	292	295	295	7	270	288	288	290	23
Flue gas temperature (venturi inlet)	deg F	TD_IVEN	-	290	291	286	286	286	289	289	7	-	281	281	285	40
Flue gas temperature (ESP outlet)	deg F	TD_EPO	-	147	146	145	145	145	146	146	2	-	256	223	239	212
Trim water flow rate	GPM	GPM_TRW	-	5.87	5.49	5.27	5.27	5.27	5.54	5.54	0.76	-	0	0	0	0
Lime slurry flow rate	GPM	GPM_LS	-	4.08	4.61	4.52	4.52	4.52	4.40	4.40	0.70	-	0	0	0	0
Flyash reinjection rate	lb/min	LBM_FA	6.8*	7.29	7.355	7.33	7.33	7.33	7.32	7.32	0.08	6.4*	6.78	6.69	6.73	0.59
Approach to saturation	deg F	ASAT_DO	12	13.2	12.0	12.0	12.0	12.0	12.4	12.4	1.7	NA	131.5	131.6	132	0
GSA pressure drop	in H2O	DP_RVES	-	0.18	0.18	0.16	0.16	0.16	0.17	0.17	0.04	-	-0.02	-0.02	-0.02	0.02
ESP pressure drop	in H2O	DP_ESP	-	1.74	1.65	1.85	1.85	1.85	1.75	1.75	0.25	-	1.56	1.54	1.55	0.13
Opacity (ESP outlet)	%	OPACITY	-	2.18	1.76	1.85	1.85	1.85	1.93	1.93	0.54	-	0.94	0.66	0.80	1.76
Recycle flow rate	lb/min	LBM_REC	2500	2771	2553	2644	2644	2644	2656	2656	272	NA	0	0	N/A	0
Recycle ratio	lb/lb Ca	REC_RAT	-	295	227	241	241	241	254	254	89	-	0	0	N/A	0
Boiler load	MW	BOIL_LD	-	146	147	147	147	147	147	147	1	-	148	148	148	1
GSA inlet SO2 (venturi)	ppm	SO2_IVEN	-	1745	1798	1715	1715	1715	1753	1753	104	-	1818	1832	1825	89
GSA inlet SO2 (preheater)	ppm	SO2_PHX	-	1631	1699	1626	1626	1626	1652	1652	101	-	1728	1740	1734	79
GSA inlet O2 (venturi)	%	O2_IVEN	-	6.62	6.26	6.61	6.61	6.61	6.50	6.50	0.52	-	6.51	6.60	6.56	0.59
ESP inlet SO2	ppm	SO2_EPI	-	207	206	214	214	214	209	209	12	-	1545	1552	1549	44
ESP inlet O2	%	O2_EPI	-	6.94	6.90	6.65	6.65	6.65	6.83	6.83	0.39	-	7.16	7.12	7.14	0.23
ESP outlet SO2	ppm	SO2_EPO	-	173	156	180	180	180	170	170	30	-	1574	1581	1577	42
ESP outlet O2	%	O2_EPO	-	7.46	7.42	7.49	7.49	7.49	7.46	7.46	0.08	-	8.04	8.09	8.07	0.32
Baghouse inlet SO2	ppm	SO2_PJI	-	173	156	180	180	180	170	170	30	-	1574	1581	1577	42
Baghouse inlet O2	%	O2_PJI	-	7.46	7.20	7.49	7.49	7.49	7.38	7.38	0.39	-	8.04	8.09	8.07	0.32
Baghouse outlet SO2	ppm	SO2_PJO	-	153	147	171	171	171	157	157	30	-	1442	1461	1451	126
Baghouse outlet O2	%	O2_PJO	-	7.84	7.88	7.93	7.93	7.93	7.88	7.88	0.11	-	8.21	8.35	8.28	0.89

*Corresponds to target inlet particulate loading of 1.5 gr/acf at target flow rate and inlet temperature.

TABLE 3-2. PROCESS OPERATING DATA FOR PARALLEL CONFIGURATION TESTS

Parameter	Units	Parameter	Demonstration tests					Baseline tests					
			Target	10/13/93	10/14/93	10/15/93	Mean	CI	Target	10/21/93	10/22/93	Avg	CI
SO2 removal efficiency	%	SO2_RET	90	91.1	91.5	91.5	91.3	0.5	NA	NA	NA	19998	NA
Flue gas flow rate (venturi inlet)	Nc/m	SFG_IVEN	20000	20010	19997	20001	20003	17	20000	19996	19998	21	NA
Flue gas temperature (GSA reactor inlet)	deg F		320	291	293	297	293	7	270	288	291	32	288
Flue gas temperature (venturi inlet)	deg F	TD_IVEN	-	284	292	296	291	15	-	287	284	40	284
Flue gas temperature (ESP outlet)	deg F	TD_EPO	-	146	147	148	147	2	-	242	247	70	247
Trim water flow rate	GPM	GPM_TRW	-	3.84	4.41	4.43	4.23	0.83	-	0	0	0	0
Lime slurry flow rate	GPM	GPM_LS	-	4.65	5.60	5.69	5.31	1.43	-	0	0	0	0
Flyash reinjection rate	lb/min	LBM_FA	6.8*	7.14	7.25	7.34	7.24	0.25	6.4*	6.99	6.74	1.57	6.87
Approach to saturation	deg F	ASAT_DO	12	12.0	12.9	12.1	12.4	1.2	NA	132.7	130.7	13	132
GSA pressure drop	in H2O	DP_RVES	-	0.17	0.19	0.19	0.18	0.03	-	-0.05	-0.04	0.02	-0.05
ESP pressure drop	in H2O	DP_ESP	-	1.62	1.52	1.60	1.58	0.13	-	1.48	1.51	0.15	1.50
Opacity (ESP outlet)	%	OPACITY	-	0.71	1.45	1.68	1.28	1.26	-	2.75	3.02	1.67	2.89
Recycle flow rate	lb/min	LBM_REC	2500	2544	2417	2406	2456	191	NA	0	0	0	N/A
Recycle ratio	lb/lb Ca	REC_RAT	-	241	203	201	215	56	-	0	0	0	N/A
Boiler load	MW	BOIL_LD	-	124	148	149	140	35	-	149	146	21	147
GSA inlet SO2 (venturi)	ppm	SO2_IVEN	-	1721	1844	1827	1797	166	-	1798	1804	40	1801
GSA inlet SO2 (preheater)	ppm	SO2_PHX	-	1662	1778	1773	1738	163	-	1746	1716	190	1731
GSA inlet O2 (venturi)	%	O2_IVEN	-	6.94	6.25	5.94	6.38	1.27	-	6.58	6.24	2.16	6.41
ESP inlet SO2	ppm	SO2_EPI	-	134	162	159	152	37	-	1564	1627	403	1596
ESP inlet O2	%	O2_EPI	-	7.45	6.77	6.45	6.89	1.27	-	7.19	6.75	2.79	6.97
ESP outlet SO2	ppm	SO2_EPO	-	124	129	128	127	6	-	1571	1544	170	1557
ESP outlet O2	%	O2_EPO	-	7.91	7.28	7.03	7.40	1.13	-	7.88	7.56	2.03	7.72
Baghouse inlet SO2	ppm	SO2_PJI	-	134	162	159	152	37	-	1564	1627	403	1596
Baghouse inlet O2	%	O2_PJI	-	7.91	7.28	7.28	6.63	4.22	-	7.88	7.54	2.14	7.71
Baghouse outlet SO2	ppm	SO2_PJO	-	52	53	50	52	3	-	1528	1563	222	1546
Baghouse outlet O2	%	O2_PJO	-	7.74	7.05	6.81	7.20	1.20	-	8.34	7.87	3.01	8.10

*Corresponds to target inlet particulate loading of 1.5 gr/acf at target flow rate and inlet temperature.

The major characteristics of the coal fired during the test program are shown in Table 3-3. The coal was Andalex medium sulfur coal. The sulfur content ranged from 2.3 to 2.8 percent, corresponding to an equivalent SO₂ emission rate of 856 to 1130 mg/MJ (1.99 to 2.45 lb/MMBtu). Moisture content during the parallel configuration tests was slightly lower compared to series configuration tests; the difference is not significant (within 10 percent). Ash content also was fairly constant, after accounting for variations in moisture content. The volume of dry flue gas generated per million Btu at 100 percent theoretical air (0 percent excess O₂), otherwise known as the dry "F factor" F_d, is also shown for reference. F_d was used later for calculating emission factors discussed in Section 6.

Testing of each process configuration began with demonstration tests, then the lime slurry was turned off and baseline tests were performed. A period of three days was planned to allow conditioning of the ESP and to purge the lime from the system. During series configuration tests, demonstration tests were completed on a Friday. Maintenance on the process was required on the following day, so process operation under baseline conditions did not begin until late on Saturday. After testing was completed on the following Tuesday as planned, it was discovered that GSA and ESP solids showed evidence of high lime content (very light color) which was later confirmed by analysis. Therefore, these tests had to be repeated the following day. During parallel configuration tests, the changeover allowed nearly three full days of operation under baseline operation and this appeared to be sufficient to purge all of the lime from the system. A two-week period was inserted between the series and parallel configuration tests to allow time for the equipment change-over and tuning of the process prior to toxics testing.

The process monitors were calibrated daily prior to the start of testing. Once testing started, the process was closely monitored to ensure the process was operating at target conditions. At the first sign of process upsets, NCER staff notified EER so that sampling could be interrupted until the process problem was rectified. Testing would then continue after the problem was resolved. As indicated by the process data shown in Tables 3-1 and 3-2, operation of the process was generally smooth. There were two significant operating problems which occurred during the test program. During parallel configuration tests on October 13, a boiler mill outage occurred. This outage was unrelated to the operation of the GSA pilot plant but affected the inlet flue gas conditions. Therefore, tests were aborted on this day. The second problem occurred during tests on October 19-20, 1993. A large rag which was being used to seal the sampling port opening during sampling at the baghouse inlet was sucked into the flue gas stream due to the very low static pressure and became entangled in the baghouse hopper discharge screw. This prevented the

hopper from emptying, which was noticed early on October 20. Therefore, the process was shut down to remove the rag and inspect the bags for possible damage. No significant damage to the bags was found and testing resumed on October 21.

TABLE 3-3. COAL ULTIMATE ANALYSIS AND HEATING VALUE

Parameter	Series configuration						Parallel configuration							
	Demonstration			Baseline			Demonstration			Baseline				
	Run 1 21-Sep	Run 2 22-Sep	Run 3 23-Sep	Average	Run 2&3 28-Sep	Run 4 29-Sep	Average	Run 1 13-Oct	Run 2 14-Oct	Run 3 15-Oct	Average	Run 2&3 21-Oct	Run 4 22-Oct	Average
Ultimate Analysis (as received)														
C %wt	65.3	65.3	63.8	64.8	64.0	63.7	63.9	64.0	64.6	65.8	64.8	65.5	66.6	65.8
H %wt	4.8	4.8	4.6	4.7	4.6	4.7	4.7	4.2	4.2	4.7	4.4	4.8	4.8	4.8
S %wt	2.8	2.7	2.4	2.6	2.6	2.7	2.6	2.3	2.7	2.8	2.6	2.4	2.6	2.5
N %wt	1.3	1.3	1.2	1.3	1.2	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
O %wt	5.1	5.8	5.0	5.3	4.8	5.3	4.9	6.1	5.7	6.0	6.0	6.4	5.3	6.1
Ash %wt	10.9	11.0	11.8	11.2	11.6	11.2	11.4	12.3	11.8	12.0	12.0	8.9	10.8	9.5
Total Moisture %wt	9.9	9.1	11.1	10.0	11.2	11.1	11.2	9.9	9.7	7.4	9.0	10.7	8.7	10.0
Total %wt	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Gross Calorific Value														
As received Btu/lb	11,408	11,571	11,568	11,516	11,237	11,257	11,244	11,316	11,487	11,751	11,518	11,760	11,816	11,779
Dry Btu/lb	12,661	12,729	13,012	12,801	12,654	12,663	12,657	12,559	12,721	12,690	12,657	13,169	12,942	13,093
DAF Btu/lb	14,404	14,482	14,569	14,485	14,537	14,488	14,521	14,526	14,633	14,579	14,580	14,627	14,678	14,644
Sulfur (as SO2) lb/MMBtu	2.45	2.33	2.07	2.29	2.31	2.40	2.34	1.99	2.35	2.34	2.23	2.04	2.17	2.08
Dry F Factor (Fd) dsc/MMBtu	10241	10063	9830	10044.5	10165.42	10122	10150.9	9885.3	9864.1	9938.7	9896.04	9889.379	10041	9939.78

Note: The dry F-Factor was calculated according to EPA Method 19 Code of Federal Regulations 40 CFR 60, equation 19-13: $Fd = K | Khd \%H + Kc \%C + Ks \%S + Kn \%N - Ko \%O | / GCVw$

where:

- K = 1,000,000 Btu/MMBtu
- Khd = 3.64 scf/lb/%
- Kc = 1.53 scf/lb/%
- Ks = 0.57 scf/lb/%
- Kn = 0.14 scf/lb/%
- Ko = 0.46 scf/lb/%
- GCVw = Gross Calorific Value (Btu/lb) on as received basis
- %H, %C, %S, %N, %O are weight percent from ultimate analysis (as received basis)

4.0 SAMPLING AND ANALYTICAL PROCEDURES

In this section, sampling and analytical procedures used during this project will be discussed. Detailed information on the specific sampling locations and procedures were provided in the Sampling and Analysis Plan. These are summarized in this section.

4.1 Sampling Locations

Samples were collected from each of the locations listed in Table 4-1. These are also shown relative to the process arrangement in Figure 4-1. Integrated coal samples were collected by the Shawnee plant staff from the automatic plant coal sampler feeding the coal bunkers (location 4). The flue gas slipstream from the Shawnee plant was sampled from the 1.02 m (40 in.) diameter round duct upstream of the flow venturi (GSA inlet - location 1). This location is also upstream of the flue gas heater which raises the flue gas temperature entering the GSA absorber. The flue gas leaving the GSA cyclone was sampled in the 1.02 m (40 in.) diameter downward-inclined round duct between the cyclone outlet and the ESP inlet (location 2). An "egg-crate" flow straightener was located in this duct upstream of the sampling location to remove swirling flow imparted by the GSA cyclone. Location 2 is upstream of the the fabric filter slipstream take-off used for parallel configuration tests. The flue gas leaving the ESP was sampled in the vertical 0.91 m (36 in.) square duct downstream of the fabric filter slipstream take-off used for series configuration tests but upstream of the point where the fabric filter slipstream rejoins the ESP outlet stream. The flue gas entering the fabric filter was sampled in the horizontal 0.81 m (32 in.) square duct just near the fabric filter. The flue gas leaving the fabric filter was also sampled in a horizontal square duct of similar dimensions.

4.2 Sampling and Analytical Methods - Flue Gas

Five process gas stream locations were sampled: the GSA inlet, ESP inlet, ESP outlet, baghouse inlet, and baghouse outlet. Measurements at each location were made using the methods shown in Table 4-2. With these measurements, flue gas temperature, moisture content, and velocity also were determined at each location.

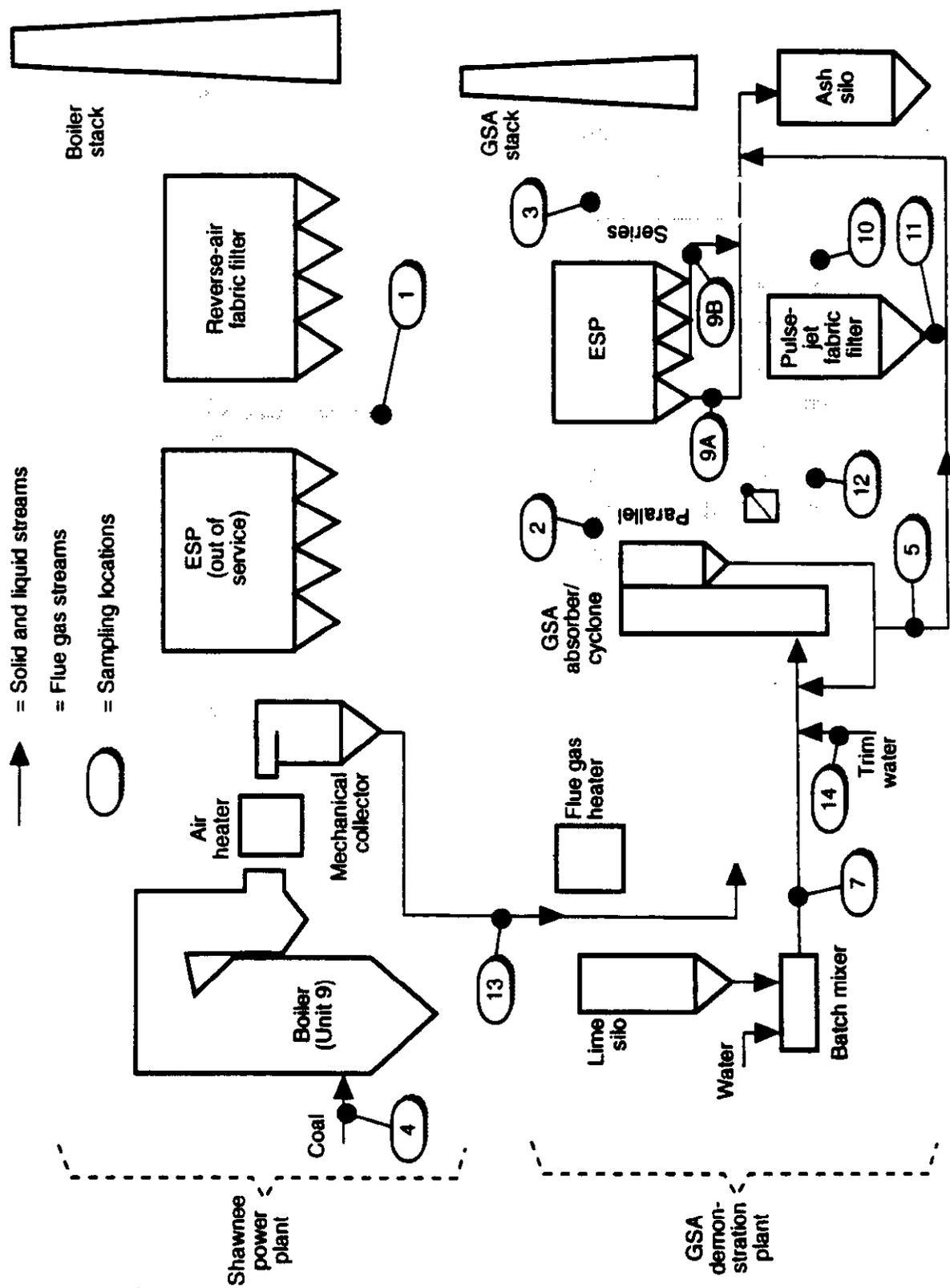


Figure 4-1. Sampling locations.

TABLE 4-1. SAMPLING LOCATIONS

Location Number	Description	Location
1	GSA inlet flue gas	Round horizontal duct
2	ESP inlet flue gas	Round inclined duct
3	ESP outlet flue gas	Square vertical duct
4	Crushed coal (solid)	Integrated coal sampler
5	GSA cyclone solids	Valve on bottom of cyclone
6	(deleted)	
7	Lime slurry (liquid)	Valve off feed line
8	(deleted)	
9A	ESP solids - field 1	Valve off auger
9B	ESP solids - fields 2, 3, 4	Grab sample from ash stream
10	Fabric filter outlet flue gas	Square horizontal duct
11	Fabric filter solids	Catch pot below fabric filter hopper
12	Fabric filter inlet flue gas	Square horizontal duct
13	Re-injected fly ash (solid)	Feed hopper
14*	Trim water feed (liquid)	Valve upstream of pump

TABLE 4-2. FLUE GAS SAMPLING AND ANALYTICAL METHODS

Analyte	Sampling		Analytical	
	Principle	Reference	Principle	Reference
Metals	Integrated sample	EPA Method 29 (draft)	DA-AAS, GF-AAS, CV-AAS	EPA Method 29
Particulate			Gravimetric	EPA Method 5
HCl, HF	Integrated sample	EPA Method 26A	IC	EPA Method 26A
O ₂	CEMS*	EPA Method 3A	Paramagnetic	EPA Method 3A
CO ₂		EPA Method 3A	NDIR	EPA Method 3A
SO ₂		EPA Method 6C	NDUV	EPA Method 6C

*Using existing plant CEM system.

4.2.1 Trace Metals and Particulate Emissions

Trace metals and particulate matter were determined according to EPA Method 29 (EMTIC CTM-012, June 30, 1992), modified for the determination of particulate as allowed in the method. The sample was obtained isokinetically from all flue gas sampling locations, filtered at 121°C (250°F), and the target analytes were absorbed in a series of impingers containing nitric acid/hydrogen peroxide followed by acidified potassium permanganate. The optional empty knockout impinger in the first position, allowed in the method, was used due to the high moisture content and large sample volumes. Sampling periods ranged from 72 minutes to 300 minutes depending on the sampling location. Particulate matter collected on the filter and inside the probe liner was determined gravimetrically according to EPA Method 5. The filters and impinger filtrate were then digested in acid and analyzed for; barium, chromium, manganese and vanadium by

direct aspiration atomic absorption spectroscopy (DA-AAS); cadmium, lead, selenium and antimony by graphite furnace atomic absorption spectroscopy (GF-AAS) and mercury by cold vapor atomic absorption spectroscopy (CV-AAS).

There were four modifications made to EPA Method 29. Sampling modifications included the use of HPLC-grade reagents for field sample train preparation to lower background interferences. Because of the large gas sample volumes and high SO₂ content of the flue gas, the volume of nitric acid/hydrogen peroxide solution was modified as shown in Table 4-3 to prevent the hydrogen peroxide from being consumed by the SO₂. The strength of the solutions was not modified. This necessitated the use of two-liter (jumbo) impingers at some locations. The analysis procedure was also modified. The final digest volumes of the nitric acid and potassium permanganate solutions were reduced from 300 ml and 150 ml, respectively, to 100 ml to obtain lower overall method detection limits. Also, the acidified potassium permanganate was filtered prior to analysis for mercury; the filtered solids were analyzed separately and added to the total., as described in proposed revisions to EPA Method 101A (EMTIC CTM-013, June 30, 1992).

TABLE 4-3. MODIFICATIONS TO MULTIPLE METALS TRAIN IMPINGER SET-UP

Impinger	Reagent Quantity					
	No.	Type	Contents	Baseline	Demonstration	
				All Locations	Loc 1	Loc. 2,3,10,12
1	1/2 stem	Empty	--	--	--	
2	GS Jumbo	5% HNO ₃ /10% H ₂ O ₂	500 ml	500 ml	200 ml*	
3	Mod Jumbo	5% HNO ₃ /10% H ₂ O ₂	500 ml	500 ml	200 ml*	
4	Mod	Empty	--	--	--	
5	GS	4% KMnO ₄ /10% H ₂ SO ₄	100 ml	100 ml	100 ml	
6	Mod	4% KMnO ₄ /10% H ₂ SO ₄	100 ml	100 ml	100 ml	
7	Mod	Silica gel	200-300 g	200-300 g	200-300 g	

GS = Greenburg-Smith

Mod = modified stem

*Note normal size (500 ml) impingers may be used.

4.2.2 HCl and HF Emissions

Emissions of HCl and HF were determined using EPA Method 26A at all flue gas sampling locations. This method employs isokinetic sampling and full-size impingers. Sampling was performed at a single point in the ducts. The sampling periods were generally 60 minutes long. In this method the sample is filtered at 121°C (250°F) to remove particulate including halide salts, and

passed through a series of impingers placed in an ice bath. The impingers contained first dilute sulfuric acid followed by sodium hydroxide. The sulfuric acid collected the gaseous hydrogen halides, as the hydrogen halides become solubilized by the acidic solution. This solution is then analyzed for fluoride and chloride by ion chromatography (IC). The sodium hydroxide solution serves as an SO₂ scrubber and was not analyzed.

Modifications to the published method were limited to sampling. Due the high moisture content of the flue gas, the optional knockout impinger allowed in the method was included, but was placed after the two sulfuric acid impingers in the third position. Because of the high SO₂ content of the flue gases and long sampling periods desired, the strength of the sodium hydroxide solution was increased to a normality of 0.1 to 0.5 and the volume was increased from 100 ml to 200 ml. This modification was made at the GSA inlet during all tests and at the remaining locations only during baseline tests. In addition, all of the sodium hydroxide solution was placed in the fourth impinger instead of divided between the fourth and fifth, and 100 ml of 10 percent hydrogen peroxide solution was added to the fifth impinger instead to prevent degradation of the sampling train pumps and control consoles due to acid corrosion.

4.2.3 O₂ and SO₂ Concentration

Measurements of major gas species O₂ and SO₂ concentrations were made concurrently with the toxics measurements using the existing plant continuous emissions monitoring system (CEMS). The sampling and instrumentation generally followed the EPA reference methods, utilizing heated sample lines and moisture removal (down to the ambient temperature dew point) prior to introduction to the analyzers; thus, all measurements were made on a dry basis. A paramagnetic analyzer was used to determine O₂ concentration, and SO₂ concentration was analyzed using a non-dispersive ultraviolet (NDUV) analyzer. The CEMS was calibrated daily prior to each test run.

4.3 Sampling and Analytical Methods-Solid and Liquid Streams

Grab samples of crushed coal, reinjected fly ash, GSA solids, ESP solids, fabric filter solids, trim water samples, and lime slurry samples were collected concurrently with flue gas sampling. Grab sampling was performed following general guidance given in "Methods of Evaluating Solid Waste," EPA SW-846. Table 4-4 outlines the collection methods used at each

location. Crushed coal samples were collected from the integrated coal sampler by TVA personnel and delivered daily to EER personnel. The sample consisted of a single 24-hour integrated sample. The ESP solids, the fabric filter solids and the reinjected fly ash samples were all collected as a hot dry ash. The ESP solids and reinjected fly ash were sampled hourly and composited at the end of each test, whereas the filter solids were only sampled once at the end of each test. The individual grab samples, gathered hourly in small containers, were combined at the end of each test and divided into a single composite sample of appropriate size by the "cone and quarter" technique. The lime slurry and trim water were collected as non-solids, that is the lime slurry was in paste form and the trim water was a liquid. The samples were collected hourly in a small containers and at the end of each test were combined in a plastic pail lined with Tedlar bags and decanted into a single composite sample. These samples were placed in tightly sealed containers with zero headspace to prevent leakage during shipment and storage and reduce any loss of volatile compounds.

TABLE 4-4. SOLID AND LIQUID SAMPLE COLLECTION PROCEDURES

Stream (location #)	Sample Frequency	Compositing frequency
Crushed coal (4)	Single 24-hr integrated sample	Each day
GSA solids (5)	Once per hour	Each test run
Lime slurry (7)	Once per hour	Each test run
ESP solids-field 1 (9A)	Once per hour	Each test run
ESP solids-field 2,3,4 (9B)	Once per hour	Each test run
Fabric filter solids (11)	Once at end of test	not required
Reinjected fly ash (13)	Once per hour	Each test run
Trim water (14)	Once per hour	Each test run

The laboratory analysis methods for solids samples, except coal, are shown in Tables 4-5 and 4-6. Trim water samples were analyzed for chlorine by directly injecting into the ion chromatograph (IC). The lime slurry (location 7), GSA solids (location 5), ESP solids (locations 9A and 9B), and baghouse solids (location 11) samples were prepared for chlorine analysis by extraction in water, followed by injection of the filtrate into the IC. To verify that the extraction procedure removed all the chlorine from the samples, a selected number of samples were also analyzed by a modification of ASTM Method D4208, which is generally applicable to coal. In the ASTM method, the sample is ashed completely in an oxygen bomb with a dilute base, which adsorbs the chlorine vapors. The bomb is rinsed with water and the chloride is determined by ion selective electrode. Table 4-7 compares results obtained with the two methods for all the output solids sampling locations and the coal. A set of samples was analyzed for baseline and

demonstration conditions to verify that high calcium concentrations (due to lime slurry injection during demonstration tests) would not interfere with the method. Results from the two different method generally compare well for all samples except coal. Further, the water extraction method yielded significantly lower detection limits. Thus, coal chlorine results are reported based on ASTM Method D4208 results. The chloride results for other samples are based on the extraction method.

TABLE 4-5. ANALYTICAL METHODS FOR LIME SLURRY, TRIM WATER, REINJECTED FLY ASH, AND GSA SOLIDS

Analyte	Analytical Principle	Reference
Total Chloride	IC	EPA Method 6010*
Arsenic, antimony, cadmium, lead, selenium	GF-AAS	EPA 7000 series*
Barium, chromium, cobalt, manganese, vanadium	ICAP	EPA Method 6010
Mercury	EPA Method 7471	CV-AAS
Moisture	Gravimetric	ASTM D3173

**Test Methods for Evaluation of Solid Wastes*, EPA SW-846, 3rd Edition (November 1986, reissued July 1992 and November 1992)

Arsenic, antimony, cadmium, lead, selenium, and mercury were determined in solids samples using atomic absorption spectroscopy (AAS) techniques. For ESP solids and fabric filter solids, barium, chromium, cobalt, manganese, and vanadium were determined analyzed using AAS techniques; in the other samples, inductively-coupled argon plasma emission spectroscopy (ICAP) was used. Lower detection limits for these metals were achieved with ICAP.

Table 4-8 presents the methods used for analysis of coal samples. Coal samples for mercury analysis were prepared using two different methods and analyzed using CV-AAS. In ASTM method D3684, the sample is combusted in an oxygen bomb and the vapors are adsorbed in nitric acid and potassium permanganate. In the double-gold amalgamation method, the sample is heated and mercury vapors are absorbed on a gold foil. The gold foil is then heated to desorb the mercury into the analyzer. Table 4-9 shows that both methods yielded similar results, increasing the confidence in the coal mercury results.

TABLE 4-6. ANALYTICAL METHODS FOR ESP ASH AND FABRIC FILTER ASH

Analyte	Analytical Method	Reference
Total Chloride	IC	EPA 6010*
Arsenic, antimony, cadmium, lead, selenium	GF-AAS	EPA 7000 series*
Barium, chromium, cobalt, manganese, vanadium	DA-AAS	EPA 7000 series*
Mercury	CV-AAS	EPA Method 7471*

**Test Methods for Evaluation of Solid Wastes*, EPA SW-846, 3rd Edition (November 1986, reissued July 1992 and November 1992)

TABLE 4-7. COMPARISON OF METHODS FOR CHLORINE DETERMINATION IN SOLID SAMPLES

Sample location/type	Parallel configuration Demonstration test Run 2		Parallel configuration Baseline test Run 2	
	Water extraction	ASTM D4208	Water extraction	ASTM D4208
4/Coal	0.0001	0.02	0.00069	ND 0.01
5/GSA solids	0.01	0.02	0.00041	ND 0.01
9A/ESP solids 1	0.078	0.05	0.0014	ND 0.01
9B/ESP solids 2-4	0.073	0.08	0.0005	ND 0.01
11/Fabric filter solids	0.072	0.07	0.01	0.02
13/Reinjected fly ash	0.0003	ND 0.01	0.0003	ND 0.01

ND = not detected; detection limit reported.

TABLE 4-8. ANALYTICAL METHODS FOR COAL

Analysis	Parameter	Method Reference	Principle and Modifications
	Total moisture	ASTM D3173 "Moisture in the Analysis Sample of Coal and Coke"	Dry at 104 to 110°C in oven; gravimetric analysis.
	Ash	ASTM D3174 "Ash in the Analysis Sample of Coal and Coke"	Combust sample, gravimetric analysis; report results both as concentration in coal ash and as concentration in coal on dry coal and as-received coal basis.
Trace metals content of coal ash	Ba, Be, Cd, Cr, Co, Mn, Ni, Pb, Sb, V	ASTM D3683 "Trace Elements in Coal or Coke Ash by Atomic Absorption" (modified) ³	Air-dry coal; combust coal to ash at 500°C; acid digestion in nitric, hydrochloric, hydrofluoric, and boric acids; analysis of Ba, Be, Cd, Cr, Co, Mn, Ni, Pb, and V by inductively coupled plasma emission spectroscopy (ICP) instead of atomic absorption spectrophotometry (AAS); analysis of Sb by graphite furnace AAS; if Ba, Be, Cd, Cr, Co, Mn, Ni, Pb, or V are not detected using ICP, analyze using GF-AAS or most sensitive technique; report results both as concentration in coal ash and as concentration in coal on dry coal and as-received coal basis.
Mercury in coal	Hg	ASTM D3684 "Total Mercury in Coal by the Oxygen Bomb Combustion/Atomic Absorption Method"	Combust coal in oxygen bomb with nitric acid; add KMnO ₄ ; analysis by cold-vapor atomic absorption spectrophotometry; report results both as concentration in coal ash and as concentration in coal on dry coal and as-received coal basis.
Mercury in coal	Hg	Bituminous Coal Research Report #2 "Analytical Methods for Determining Mercury in Coal and Coal Mine Water" (1975)	Combust coal in quartz tube with oxygen over heated silver wire; collect Hg vapors on gold amalgamators, then reheat to release Hg vapors to analyzer; analysis by cold-vapor atomic absorption spectrophotometry; report results both as concentration in coal ash and as concentration in coal on dry coal and as-received coal basis.
Arsenic and selenium in coal	As, Se	ASTM D3684 "Total Mercury in Coal by the Oxygen Bomb Combustion/Atomic Absorption Method" (modified)	Combust coal in oxygen bomb with nitric acid; analysis by graphite furnace atomic absorption spectrophotometry; report results both as concentration in coal ash and as concentration in coal on dry coal and as-received coal basis.
Calculate results on as-received and dry bases	All results	ASTM D3180 "Practice for Calculating Coal and Coke Analyses from As-Determined to Different Bases"	
Sample preparation	All samples	ASTM D2013 "Method of Preparing Coal Samples for Analysis"	

²Add method ASTM D3302 for determination of free moisture prior to determination of total moisture; sum results of both analyses for total coal moisture as-received.

³ Modifications include substitution of analysis by ICP for Ba, Be, Cd, Cr, Co, Mn, Ni, Pb, and V, and GF-AAS for Sb.

TABLE 4-9. COMPARISON OF MERCURY IN COAL RESULTS WITH TWO DIFFERENT METHODS

Configuration	Test Condition	Mercury ($\mu\text{g/g}$)		RPD (%)
		DGA	ASTM 3684	
Series	Baseline	0.08	0.09	89
Series	Demonstration	0.07	0.08	88
Parallel	Baseline	0.08	0.09	89
Parallel	Demonstration	0.08	0.07	114
Average		0.078	0.083	94
Standard Deviation		0.005	0.010	13

DGA = double gold amalgamation/CV-AAS

RPD = relative percent difference, relative to ASTM method.

This section of the report presents the primary results of the air toxics tests. Over 400 samples were collected in the field and reduced to approximately 170 samples that were analyzed. Over 2,000 analytical determinations were performed. The measured concentration of each target HAP in each of the sample streams is presented for each run, along with the mean and the 2.5% confidence coefficient (95% confidence interval) as an indicator of result precision. As described earlier, it was planned to obtain one set of runs for selected samples on each test date, for a total of three samples of each selected stream; however, if a run was invalidated in the field for any reason, it was repeated at the earliest opportunity when possible and this resulted in some test runs which were not concurrent with the balance of the data for that run. Since the process operation was generally very repeatable from day to day (see Section 3.4), this is not expected to affect the test results.

Due to the small population of samples (generally between 1 and 3) available for any particular measurement, it is not considered statistically valid to discard any of the data points using traditional outlier analysis. Therefore, all run data were included in the average results unless a specific QA/QC problem occurred to invalidate the run result. This leads to relatively large confidence intervals for most of the trace metals measurements relative to the absolute concentration. Since the data may reflect real variations in the process rather than measurement uncertainty alone, the reader should use caution in applying traditional statistical data analysis techniques to screen the data. The reader is referred to Section 7 for a discussion of QA/QC issues and other deviations from the Sampling and Analysis Plan. More detailed test results are presented in Appendix B.

5.1 Test Chronology and Factors Affecting Test Results

The field portion of the test program was conducted between September 21, 1993 and October 22, 1993, following mobilization and set-up at the NCER. Series configuration tests were conducted first. The tests were interrupted for two weeks after completion of series configuration tests for changeover of the fabric filter to the parallel configuration and process testing. Table 5-1 summarizes the chronology of testing for air toxics. The table shows the test date and time of day for each of the flue gas sampling runs. Process samples (solids and liquids) were collected concurrently on each day of testing.

TABLE 5-1. TEST CHRONOLOGY

CONFIGURATION	TEST CONDITION	DATE	TIME	SAMPLE	RUN NO.
SERIES	DEMONSTRATION	21 SEP 93	09:00-11:15	M26A HCl	1
			13:00-18:15	M29 Metals	1
		22 SEP 93	08:30-10:00	M26A HCl	2
			12:30-17:30	M29 Metals	2
		23 SEP 93	09:45-11:15	M26A HCl	3
			12:45-18:15	M29 Metals	3
			18:45-20:00	M26A HCl	4
SERIES	BASELINE	28 SEP 93	08:45-10:30	M26A HCl	2
			11:00-16:30	M29 Metals	2
			16:30-18:00	M26A HCl	3
		29 SEP 93	09:00-14:00	M29 Metals	3
			14:30-15:45	M26A HCl	4
			16:45-21:00	M29 Metals	4
PARALLEL	DEMONSTRATION	13 OCT 93	08:45-10:15	M26A HCl	1
			14 OCT 93	08:45-17:15	M29 Metals
		15 OCT 93	17:45-18:45	M26A HCl	2
			08:30-15:15	M29 Metals	2
			16:00-17:15	M26A HCl	3
			19:00-23:30	M29 Metals	3
PARALLEL	BASELINE	21 OCT 93	08:15-12:45	M29 Metals	2
			13:15-14:30	M26A HCl	2
			15:45-17:00	M26 HCl	3
		22 OCT 93	08:30-12:45	M29 Metals	3
			13:15-14:30	M26A HCl	4
			15:30-19:45	M29 Metals	4

A significant number of additional samples were collected in addition to those planned. During on-site set-up prior to testing, two significant process streams were identified that were not known at the time the Sampling and Analysis Plan was prepared: reinjected fly ash and trim water. It was decided to add these streams to the sampling matrix. Several key assumptions were made in designing the original sampling matrix:

- During baseline tests, HCl removal across the GSA and ESP would be negligible; therefore, HCl at the ESP inlet and outlet locations could be estimated based on measurements at the GSA inlet and fabric filter inlet. Hence, HCl measurements at the ESP inlet and outlet locations during baseline tests were not planned.

- In the series configuration, HCl concentration at the ESP outlet and fabric filter inlet would be similar; therefore, HCl at the ESP outlet could be estimated based on fabric filter inlet measurements. Hence, HCl measurements at the ESP outlet during demonstration tests were not planned.
- Since inlet flue gas flow and conditions would be constant for all test conditions, HCl, particulate, and trace metals removal across the GSA absorber/cyclone would be similar for both parallel and series configurations. Hence, Method 29 and Method M26A measurements at the GSA inlet and ESP inlet during parallel configuration baseline tests were not planned, and HCl measurements at the GSA inlet and ESP inlet were not planned for parallel configuration demonstration tests.
- Since SCA only increases by about 15 percent in the parallel configuration, HCl, particulate, and trace metals removal efficiency across the ESP would be similar for series and parallel configurations. Further, series configuration tests would provide the worst-case conditions for ESP performance (lowest SCA). Hence, measurements at the ESP outlet were not planned during parallel configuration tests.

Just prior to starting the test program, it was decided to add Method 26A and Method 29 samples at several additional locations to validate these assumptions and provide a more complete data set. A brief discussion of the significant factors which occurred during the testing is provided below.

5.1.1 Series Configuration

Demonstration Tests

Series configuration testing commenced on 9/21/93 under demonstration test conditions. Flue gas sampling for particulate and trace metals was performed at all five sampling locations. HCl sampling was performed at all locations except the ESP outlet. During Method 26A sampling on 9/21/93 (Run 1), both the GSA Inlet (location 1) and fabric filter outlet (location 10) trains were invalidated because the impinger solutions back-washed when the sample flow was inadvertently shut off at the end of the run before removing the probe from the duct. This was caused by the very low static pressure (-18 to -30 in. WC gage) in the duct. The Method 29 run on 9/21/93 at the

ESP inlet (location 2) also was considered invalid because the dry gas meter failed the field calibration audit. Sampling continued without event on 9/22-23/93. Make-up runs also were performed for the invalidated samples on 9/23/94. In addition to the planned samples, a single Method 26A sample also was collected at the ESP outlet on 9/21/93 to validate the assumption that HCl concentration is similar to that at the fabric filter inlet, and samples of trim water (location 14) and reinjected fly ash (location 13) were collected for each test day.

Baseline Tests

Baseline series testing commenced on September 27, 1993, after allowing three days for system conditioning without lime slurry and trim water injection. Flue gas particulate and metals sampling was performed at all five locations, and HCl sampling was performed at all locations except the ESP outlet. All samples collected on 9/27/93 (Run 1) were later considered invalid because process samples indicated the presence of lime in significant amounts. This suggested that the system had not reached true baseline conditions. The following day, inspection of process samples indicated normal baseline conditions had been reached. Sampling continued as planned on 9/28-29/93. Process solid and liquid samples were collected on each test day. Make-up sampling was performed for HCl on 9/28/93 (Runs 2 and 3) and for particulate and metals on 9/29/93 (Runs 3 and 4). Additional process output samples also were collected on 9/29/93 except for GSA solids.

5.1.2 Parallel Configuration

Demonstration Tests

Demonstration parallel testing commenced on 10/13/93. Flue gas HCl samples were collected at the GSA inlet, fabric filter inlet, and fabric filter outlet on 10/13/93; however, flue gas particulate and trace metals tests were aborted because of an unplanned boiler mill outage on Unit 9. Testing resumed on 10/14/93, with particulate, trace metals, and HCl sampling at all locations except the ESP outlet. On 10/15/93, flue gas samples were collected at all five locations for all target substances. Make-up runs for the aborted particulate and metals runs also were performed on 10/15/93. All other process solid and liquid samples were collected on each test day.

Baseline Tests

Baseline tests in the parallel configuration commenced on 10/19/93, after allowing three days for system conditioning without lime slurry and trim water injection. This time, process samples were judged sufficiently free of lime. During tests on 10/19/93, a foreign object became entangled in the screws of the fabric filter which resulted in the suspension of testing until the screws could be cleared. Testing resumed on 10/21/93. Flue gas particulate and trace metals samples were collected at all locations except the GSA inlet and HCl samples were collected at the GSA inlet, fabric filter inlet, and fabric filter outlet. Make-up runs for HCl samples also were performed on 10/21/93 and for particulate and trace metals on 10/22/93. Make up process output samples except for GSA solids also were collected on 10/22/93.

5.2 Handling of Detection Limits and Quality Control Data

The guidelines for handling non-detected data and field quality control sample results for this program are consistent with guidelines adopted for other recent U.S. DOE projects¹. The guidelines relevant to this project are summarized below.

5.2.1 Treatment of Results Below Detection Limits

The following procedures apply to calculation of mean results for replicate measurements and to summation of sample fractions (e.g., in summing the front half and back half of the multiple metals train for flue gas sampling):

- All values detected. The arithmetic mean or sum is taken, as appropriate. No special techniques are required and the data are not flagged.
- All values below the detection limit. The data are flagged as "ND" (not detected) and the full detection limits are used in all calculations. For example, in cases where all three runs are below the detection limit, the mean is flagged as "ND" and the mean of the detection limits for the three runs is reported. For the multiple metals trains where results are ND in

¹England, G. C. et. al., "Assessment of Toxic Emissions From a Coal Fired Power Plant Utilizing an ESP," Draft Final Report, Revision 1, U.S. Department of Energy Contract DE-AC22-93PC93252 (December 23, 1993).

all fractions of the train, the sum of the detection limits for each fraction is reported and the sum is flagged as "ND".

- Some values are detected and some are non-detected. As an approximation of the true value, half of the detection limits for non-detected values and the actual values for detected values are used to calculate reported values. For example, the mean for three test runs with results of 10, 8, and ND 6 would be:

$$(10 + 8 + 6/2)/3 = 7$$

As an example of summing individual sample fractions to calculate the total sample result, summing the different mercury fractions in the multiple metals sampling train where the values in the KMnO_4 , front half, and back half fractions were 50 μg , ND 1 μg , and ND 2 μg , respectively, would yield:

$$(50 + 1/2 + 2/2) = 51.5 \mu\text{g}$$

In reporting the sums or averages of mixed (detected and non-detected) data, the results are not flagged. The only exception to this rule occurs when the mean is less than the highest detection limit of the ND values. In this case, the mean is reported as "NDM" and the maximum detection limit is provided. For example, the mean of three results that were 5, ND 4, and ND 3 would be:

$$(5 + 4/2 + 3/2)/3 = 2.8$$

The mean is less than the highest ND result, and therefore would be reported instead as NDM 4.

5.2.2 Treatment of Method 29 (Multiple Metals Train) Field Blanks

Field *reagent* blank samples and field *train* blank samples were collected to evaluate contamination potential. Field reagent blanks are samples of the individual reagents and filters that were used in the field to charge and recover the trains. They provide an indication of contamination introduced in the reagents themselves or laboratory procedures. Field train blanks are samples from complete trains that are charged, leak-checked at the sampling location,

recovered, and analyzed in the same manner as the test samples. They provide an indication of cumulative contamination introduced at all steps of the test procedure. Method 29 (multiple metals train) discusses and allows correction of test sample results for field reagent blank results. The field reagent blank results for this project were below detection limits (not detected or ND) for all metals and for particulate. The method does not provide specific guidance for treatment of undetected values in blanks. DOE guidance for this project specified that any blank correction should not produce results below either the detection limits or zero. Therefore, the field reagent blank values were treated as zeros (i.e., no correction was made). The method is silent on the subject of field train blanks. Since the method specifically discusses handling of field *reagent* blank results but does not discuss field *train* blank results, test results were not corrected for field train blanks. However, field train blank results were significant and are discussed in Section 7.

EPA Method 5 allows particulate sample results to be corrected for acetone field reagent blank concentration. This was allowed in the method because of the poor quality of acetone that is sometimes used for routine compliance testing. Because EER utilized HPLC-grade acetone during these tests, no acetone blank correction was made.

5.2.3 Treatment of Method 26A (HCl/HF Train) Field Blanks

Field train and field reagent blanks also were collected for the Method 26A samples used to determine HCl and HF emissions. Although the methods allow correction of analytical results for laboratory blanks, they are silent on the subject of field blanks. Therefore, corrections for field train blanks were considered if measured levels were found. In this program, field train blanks and field reagent blanks did not contain detectible levels of chloride or fluoride. The method is silent on the treatment of non-detected blank results. Therefore, the non-detected blank results were treated as zeros; i.e., no correction was made to any field samples.

5.3 Series Configuration Test Results

This section presents results of series configuration tests, in which a slipstream of flue gas from the ESP outlet was introduced to the fabric filter inlet.

5.3.1 Flue Gas Sampling Conditions - Series Configuration

Tables 5-2 and 5-3 summarize average conditions at each of the flue gas sampling locations during series configuration tests. GSA inlet conditions are very consistent for all series configuration tests, with no significant differences in flow rate, oxygen, or moisture content. Conditions at the other flue gas sampling locations are also very consistent from run to run. It should be noted that the GSA inlet sampling location was upstream of the flue gas heater; therefore, these temperatures are slightly lower than at the actual entrance to the GSA reactor. Isokinetic sampling rate is slightly low for two baseline GSA inlet runs. The values are within the range allowing for correction of the particulate data², therefore the results of these runs were accepted and corrected. The correction was extended to the trace metals data also, since most of the target metals are expected to be in the solid phase (except mercury and selenium). Gas flow rate at the fabric filter inlet is slightly lower than at the outlet. The difference is believed to be due to a combination of measurement uncertainty and air infiltration in the fabric filter.

Table 5-4 summarizes the duration of flue gas sampling for the Method 26A and Method 29 sample trains, and the actual sample gas volumes obtained. For a given analytical detection limit in the laboratory, increasing the sample volume decreases the overall method detection limit. The planned minimum sample volumes were 3.40 dscm (120 dscf) for Method 29 samples and 1.70 dscm (60 dscf) for Method 26A samples. Actual sample volumes for Method 26A samples are approximately two-thirds of the planned volume. This was done in order to accommodate last-minute changes in the sampling matrix using the same size sampling team by reducing the time required to collect the samples by approximately one-half and sampling at a higher rate. The increase in HCl detection limits due to decreased sample volume was offset by a decrease in the laboratory analytical chloride detection limits by about a factor of two. Thus, this change did not adversely impact the actual HCl detection limits relative to the target.

Method 29 sample gas volumes are within -20 percent to +70 percent of the planned volume except at the ESP inlet. Due to frequent filter plugging at the ESP inlet location during demonstration tests caused by the extremely high particulate loading, it was decided to reduce the sample volume at this location. Sample volumes at the ESP inlet are approximately one-third of the planned value under demonstration conditions and one-half the planned volume under baseline

²Shigehara, R. T., "A Guideline for Evaluating Compliance Test Results (Isokinetic Sampling Rate Criterion)," in Stack Sampling Technical Information. A Collection of Monographs and Papers, EPA-450/2-78-042a (October, 1978).

TABLE 5-2. FLUE GAS PARAMETERS - SERIES CONFIGURATION, BASELINE TESTS

	Run	Units	Value*				
			GSA inlet	ESP inlet	ESP outlet	Baghouse inlet	Baghouse outlet
Velocity	A	m/sec	19.6	21.7	21.2	14.0	10.9
	B		19.1	21.5	20.9	13.2	10.8
	C		19.1	20.5	20.9	13.6	10.8
	Mean		19.2	21.2	21.0	14.0	10.8
	2.5% CC		0.7	1.6	0.4	1.0	0.1
Flow rate	A	dscm/min	588	633	456	83.8	93.7
	B		581	634	453	79.6	94.5
	C		576	602	454	81.9	94.7
	Mean		582	623	454	81.8	94.3
	2.5% CC		15	45	3	5.2	1.3
Temperature	A	°C	150	139	131	123	121
	B		146	139	131	123	118
	C		148	140	132	124	119
	Mean		148	140	131	123	119
	2.5% CC		5	1	1	1	3
Moisture	A	% Vol.	7.8	7.6	7.2	7.0	6.7
	B		7.9	7.3	6.9	6.9	6.5
	C		7.6	7.6	7.0	6.9	6.6
	Mean		7.8	7.5	7.0	7.0	6.6
	2.5% CC		0.4	0.4	0.3	0.2	0.3
O2 (dry)	A	% Vol.	6.41	7.22	8.12	8.12	8.34
	B		6.56	7.08	8.05	8.05	8.35
	C		6.71	7.23	8.21	8.21	8.36
	Mean		6.56	7.18	8.13	8.13	8.35
	2.5% CC		0.37	0.21	0.20	0.20	0.02
Isokinetic ratio	A	%	99.4	99.2	96.6	94.9	99.3
	B		84.7	99.2	99.1	99.5	99.2
	C		85.9	100.0	98.7	99.4	99.2
	Mean		90.0	99.5	98.1	97.9	99.2
	2.5% CC		20.3	1.1	3.3	6.5	0.1

*All results taken from multiple metals trains data.

**TABLE 5-3. FLUE GAS PARAMETERS - SERIES CONFIGURATION,
DEMONSTRATION TESTS**

	Run	Units	Value*				
			GSA inlet	ESP inlet	ESP outlet	Baghouse inlet	Baghouse outlet
Velocity	A	m/sec	19.9	17.4	18.6	14.3	11.0
	B		20.1	16.2	18.8	13.9	11.1
	C		19.6	19.2	18.8	13.7	11.0
	Mean		19.8	17.6	18.7	14.0	11.0
	2.5% CC		0.7	3.7	0.4	0.7	0.1
Flow rate	A	dscrm/min	591	575	444	93.6	102
	B		595	526	453	90.3	103
	C		576	621	446	89.2	101
	Mean		587	574	448	91.0	102
	2.5% CC		25	118	12	5.8	2
Temperature	A	°C	152	67.8	68.9	66.7	70.0
	B		154	67.8	68.9	68.3	70.0
	C		151	68.3	68.3	66.1	68.9
	Mean		152	68.0	68.7	67.0	69.6
	2.5% CC		5	0.8	0.8	2.9	1.6
Moisture	A	% Vol.	8.2	13.6	13.1	13.2	12.2
	B		8.3	14.8	12.5	13.5	12.8
	C		9.3	15.1	13.8	14.0	13.3
	Mean		8.6	14.5	13.1	13.6	12.8
	2.5% CC		1.6	1.9	1.6	0.9	1.4
O2 (dry)	A	% Vol.	6.62	6.94	7.46	7.46	7.84
	B		6.21	6.55	7.14	7.14	7.55
	C		6.29	6.81	7.31	7.31	7.91
	Mean		6.37	6.77	7.30	7.30	7.77
	2.5% CC		0.54	0.49	0.40	0.40	0.47
Isokinetic ratio	A	%	95.8	103.0	97.5	98.3	96.1
	B		99.8	99.2	98.9	102.9	99.4
	C		100.4	99.6	100.3	101.5	100.5
	Mean		98.7	100.6	98.9	100.9	98.7
	2.5% CC		6.2	5.2	3.5	5.9	5.7

*All results taken from multiple metals trains data.

TABLE 5-4. SUMMARY OF FLUE GAS SAMPLING DURATION AND VOLUMES - SERIES CONFIGURATION

Test Condition	Sample Date	Sample Train	GSA Inlet		Baghouse Inlet		Baghouse Outlet		ESP Inlet		ESP Outlet	
			Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)
Baseline	9/28/93	HCl	60	43.5	60	40.9	60	40.5	60	39.2	--	--
		Metals	160	114.8	192	100.8	300	185.9	120	65.7	240	183.5
		HCl	60	41.2	60	39.8	60	39.6	60	37.8	--	--
	9/29/93	Metals	160	94.1	192	97.5	300	186.0	120	65.5	240	186.0
		HCl	60	34.8	60	34.0	60	40.2	60	41.9	--	--
		Metals	160	96.4	192	101.2	300	155.2	120	62.7	240	185.3
Demonstration	9/21/93	HCl	--	--	--	--	60	37.9	60	41.5	60	44.7
		Metals	160	113.8	168	104.4	300	196.5	60	42.0	60	180.5
		HCl	60	42.7	60	35.9	60	42.6	60	38.4	--	--
	9/22/93	Metals	160	119.4	168	104.2	300	203.6	60	36.7	60	186.6
		HCl	60	42.5	60	38.5	60	42.7	60	42.3	--	--
		Metals	160	114.8	180	107.7	300	203.7	60	32.4	60	186.9
		HCl	60	42.1	60	37.5	--	--	--	--	--	

conditions. This results in an increase in detection limits for most metals by a factor of three and two, respectively, at the ESP inlet; in most cases this did not significantly affect the test results because of the very high loading. Sample volumes were increased by 50 to 70 percent at the fabric filter outlet and ESP outlet because of the very light particulate loading observed at these locations. This resulted in a decrease in overall method detection limits by a factor of 1.5 to 1.7.

5.3.2 Flue Gas Particulate Results - Series Configuration

Table 5-5 presents the results of particulate measurements in the flue gas obtained from the Method 29 sample train for both baseline and demonstration conditions. Due to air in-leakage into the system, dilution at each sampling location is slightly different. To facilitate comparisons of measurements made at different locations, all concentrations are corrected to 3 percent oxygen according to the following formula:

$$C_{3\%O_2} = C_{as\ measured} \times (20.9-3.0)/(20.9-O_{2,\ as\ measured})$$

where: $C_{3\%O_2}$ = pollutant concentration corrected to 3% O₂
 $C_{as\ measured}$ = pollutant concentration at measured O₂ concentration
 $O_{2,\ measured}$ = O₂ concentration measured at sampling location.

Based on the results of sample train blanks, particulate measurements are free from significant contamination. Mean particulate loading at the inlet to the GSA is slightly higher during baseline tests than demonstration tests, although the confidence interval for the baseline data is fairly large (± 57 percent) compared to the demonstration data (± 19 percent) so this difference probably is not significant. Note that the two highest particulate loadings at the GSA inlet are measured for the two runs that had low isokinetic sampling rates. This could imply that most of the particulate matter at this location is greater than about 5 μm , which represent those particles most likely to bias the results.

The mean particulate loading at the ESP inlet (i.e., GSA outlet) is approximately equal to that at the GSA inlet under baseline conditions; this reflects the fact that the reinjected fly ash stream accounts for a significant fraction of the total fly ash input to the GSA reactor. Thus, the mechanical cyclone collector would appear to be removing an amount approximately equal to the reinjected fly ash input. However, this conclusion should be tempered considering the large

TABLE 5-5. PARTICULATE RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	mg/dscm	2,863	(4) 4,669	(4) 4,852	4,128	2,731
	2 ESP inlet	mg/dscm	4,717	2,202	4,481	3,800	3,451
	3 ESP outlet	mg/dscm	46.66	47.07	43.32	45.68	5.10
	12 Fabric filter inlet	mg/dscm	59.45	31.32	60.45	50.41	41.08
	10 Fabric filter outlet	mg/dscm	7.167	14.88	14.11	12.05	10.55
Demonstration	Flue gas (note 1): Run No. (note 3)	—	1	2	3		
	1 GSA inlet	mg/dscm	2,941	3,112	3,419	3,157	602
	2 ESP inlet	mg/dscm	10,001	11,995	12,876	11,624	3,659
	3 ESP outlet	mg/dscm	19.89	18.17	10.74	16.27	12.08
	12 Fabric filter inlet	mg/dscm	28.45	17.18	11.69	19.11	21.23
	10 Fabric filter outlet	mg/dscm	7.937	6.354	6.333	6.875	2.286
	7 Lime slurry (note 2)	wt. %	30.1	28.1	28.8	29.0	2.5

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Percent solids, reported as 100-(% moisture)
- (3) For ESP inlet, runs 2,3,4 used.
- (4) Results corrected for low isokinetic ratio.

confidence interval for the ESP inlet (± 91 percent) and GSA inlet results. Mean concentration of particulate at the GSA inlet is slightly lower for demonstration tests compared to baseline, but the difference is within confidence interval of the measurements. Under demonstration conditions, the particulate loading at the ESP inlet is nearly four times that at the GSA inlet. This reflects the additional solids introduced with the lime slurry and solids production due to reaction of lime and SO_2 in addition to the reinjected fly ash.

Particulate loading at the ESP outlet and fabric filter inlet is very similar, as expected since the fabric filter slipstream is taken from the ESP outlet in this configuration. Particulate loading at the ESP outlet is approximately two orders of magnitude lower than at the ESP inlet for baseline conditions, indicating reasonably good ESP removal efficiency (see Section 6 for additional discussion of removal efficiencies), and even lower for demonstration test conditions. Particulate loadings at the fabric filter outlet are the lowest. Despite the much higher particulate loading at the ESP inlet under demonstration conditions compared to baseline, the ESP outlet concentrations are lower. This indicates that ESP removal efficiency was significantly enhanced during demonstration tests. Concentrations of total particulate at the outlet of both the ESP and the fabric filter are well below the federal New Source Performance Standard (NSPS) of approximately 164 mg/dscm (0.072 gr/dscf) for utility boilers built after August 1971 for both baseline and demonstration conditions. Particulate concentration at the ESP outlet for baseline tests is slightly below the NSPS of 49 mg/dscm (0.021 gr/dscf) for utility boilers built after September 1978, and is considerably below this level during demonstration tests.

Finally, Table 5-5 also shows the solids concentration in the lime slurry, for reference purposes. Solids concentration in the lime slurry averages 29 percent.

5.3.3 Trace Metals Results - Series Configuration

Trace metals results are presented in a series of tables, one for each metal. For example, in Table 5-6, antimony concentration in each of the sample streams is shown for each run during baseline and demonstration tests. The mean and 2.5 percent confidence coefficient also are shown to provide an indication of average emissions and data variability, respectively. The 2.5 percent confidence coefficient, based on the single-tailed normal probability function, is calculated as follows:

TABLE 5-6. ANTIMONY RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	ND 0.131	ND(4) 0.147	(4) 1.485	0.541	1.931
	2 ESP inlet	µg/dscm	1.964	4.310	2.270	2.848	3.168
	3 ESP outlet	µg/dscm	ND 0.091	ND 0.089	ND 0.090	ND 0.090	0.002
	12 Fabric filter inlet	µg/dscm	ND 0.173	ND 0.173	ND 0.170	ND 0.172	0.004
	10 Fabric filter outlet	µg/dscm	ND 0.090	ND 0.089	ND 0.107	ND 0.095	0.025
	4 Coal	mg/kg	ND 0.5			ND 0.5	NA
	13 Reinject fly ash	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
	5 Cyclone solids	mg/kg	ND 0.08	—	ND 0.08	ND 0.08	0.00
	9a ESP ash field 1	mg/kg	ND 10	ND 10	ND 10	ND 10	0
	9b ESP ash field 2-4	mg/kg	ND 10	ND 10	ND 10	ND 10	0
11 Fabric filter ash	mg/kg	ND 10	—	ND 10	ND 10	0	
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	1.774	1.157	ND 0.132	0.999	2.061
	2 ESP inlet	µg/dscm	2.167	ND 0.410	ND 0.473	0.870	2.476
	3 ESP outlet	µg/dscm	0.644	ND 0.083	ND 0.084	0.243	0.804
	12 Fabric filter inlet	µg/dscm	ND 0.162	ND 0.157	ND 0.152	ND 0.157	0.012
	10 Fabric filter outlet	µg/dscm	ND 0.082	ND 0.077	ND 0.079	ND 0.079	0.006
	4 Coal	mg/kg	ND 0.5			ND 0.5	NA
	13 Reinject fly ash	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
	7 Lime slurry (note 3)	mg/kg	ND 0.08	—	—	ND 0.08	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.002	ND 0.002	NA
	5 Cyclone solids	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
9a ESP ash field 1	mg/kg	ND 10	ND 10	ND 10	ND 10	0	
9b ESP ash field 2-4	mg/kg	ND 10	ND 10	ND 10	ND 10	0	
11 Fabric filter ash	mg/kg	ND 10	ND 10	ND 10	ND 10	0	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

$$CC_{2.5} = t \times \sigma/n^{0.5}$$

where: $CC_{2.5}$ = 2.5 percent confidence coefficient

t = Student "t" factor

σ = standard deviation

n = number of measurements

The Student "t" factor is a statistical parameter which increases as the number of measurements decreases. The 95 percent confidence interval is equal to \pm the 2.5 percent confidence coefficient. Three complete sets of data were generally obtained except for coal, lime slurry, and trim water. A single composite (of three runs) coal sample for each condition was analyzed. Lime slurry and trim water samples for each test run were initially analyzed using less sensitive analytical techniques. Nearly all trace metals results were below the detection limits. Therefore, a single archive sample of lime slurry and trim water was analyzed using more sensitive analytical techniques. Since all of the lime slurry used during the test program came from the same batch and since all the trim water came from the same supply throughout the test, these archive sample results are believed to be representative of the entire test program; hence, they are reported in the tables. In many cases, the 2.5 percent confidence coefficient is equal to or greater than the mean result. This is typical of results based on 3 or fewer individual samples and should not necessarily be the only criteria used to judge the reliability of test results.

It should be noted that most trace metals results are corrected for bias caused by slightly low isokinetic sampling rate³ at the GSA inlet for two test runs during series configuration baseline tests. The correction factor is applied to all trace metals except mercury and selenium. This is because the major fractions of the latter two metals are expected to be in the vapor phase and hence would not be biased significantly by anisokinetic sampling. The procedure for correcting the results is discussed in Section 7.

Quality control samples analyzed for metals included reagent blanks and field sample train blanks. All trace metals were below detection limits in the reagent blanks, hence no blank corrections to the data were made. Field sample train blanks were collected and analyzed for all five sample locations. Several of these results indicated the possibility of sample contamination.

³This was caused by repeated pitot tube pluggage due to the high particulate loading.

Accuracy and precision of laboratory analytical results was generally good for trace metals. Refer to Section 7 for discussion of these QA/QC results.

Specific results for each metal are discussed in the following paragraphs.

Antimony

Antimony results are dominated by undetected results. Detection limits for antimony were the highest of all the target trace metals and results for the same stream were typically very variable from run to run. Antimony concentration is below detection limits in the coal. In the other streams, antimony is above detection limits in only 4 of 31 samples for baseline conditions, and in 4 of 33 samples during demonstration conditions. Antimony was detected only in some of the flue gas samples, mostly in the GSA inlet and ESP inlet streams. The confidence interval of detected results is approximately 1.5 to 3 times the mean detected value. Given the small number of samples with detected results and the low precision of the detected levels, the antimony results should be used with caution.

Arsenic

Table 5-7 shows arsenic results for series configuration tests. Detection limits for arsenic were among the lowest of all the target metals; consequently, it was detected in most streams. During baseline tests, arsenic was detected in 29 of 31 samples and in 26 of 33 samples during demonstration tests. The precision of the flue gas results at the GSA inlet and ESP inlet is relatively good. Arsenic concentration at the GSA inlet is similar for baseline and demonstration test conditions. Arsenic is below the detection limits in the flue gas at the fabric filter outlet in all but one sample, while measurable concentrations were found at the ESP outlet. Arsenic concentrations at the ESP outlet are considerably lower for demonstration tests compared to baseline, although the difference is within the fairly large confidence interval of the baseline measurements. Arsenic is below detection limits in all but one of the sample train blanks, indicating no significant contamination issues; however, accuracy of low concentration measurements in the flue gas may be less than high concentration samples since low level audit sample results did not fall within normal limits. See Section 7 for additional discussion of QA/QC results. Confidence interval for the solid and liquid samples is more significant, typically greater than ± 50 percent of the mean value. Precision of the results in the solid samples is mixed. Significant concentrations of arsenic were found in the reinjected fly ash, at more than twice the

TABLE 5-7. ARSENIC RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	169.2	(4) 211.8	(4) 218.1	199.7	66.03
	2 ESP inlet	µg/dscm	317.3	254.4	278.2	283.3	78.98
	3 ESP outlet	µg/dscm	11.36	5.899	4.135	7.131	9.355
	12 Fabric filter inlet	µg/dscm	4.298	2.822	3.527	3.549	1.834
	10 Fabric filter outlet	µg/dscm	ND 0.063	ND 0.063	0.208	0.090	0.208
	4 Coal	mg/kg	4			4	NA
	13 Reinject fly ash	mg/kg	78	31.4	35.3	48.2	64.2
	5 Cyclone solids	mg/kg	16.5	—	16.2	16.4	1.9
	9a ESP ash field 1	mg/kg	27	16	25	22.7	14.6
	9b ESP ash field 2-4	mg/kg	9	14	21	14.7	15.0
11 Fabric filter ash	mg/kg	34	—	8	21.0	165.2	
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	177.0	177.2	220.5	191.6	62.2
	2 ESP inlet	µg/dscm	93.3	131.4	215.5	146.8	155.3
	3 ESP outlet	µg/dscm	0.249	0.162	0.238	0.216	0.118
	12 Fabric filter inlet	µg/dscm	0.267	ND 0.111	ND 0.108	0.126	0.226
	10 Fabric filter outlet	µg/dscm	ND 0.058	ND 0.054	ND 0.056	ND 0.056	0.005
	4 Coal	mg/kg	4			4	NA
	13 Reinject fly ash	mg/kg	51.8	112	25.2	63.0	110.5
	7 Lime slurry (note 3)	mg/kg	0.96	—	—	0.96	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.001	ND 0.001	NA
	5 Cyclone solids	mg/kg	22.3	14.9	19.3	18.8	9.2
9a ESP ash field 1	mg/kg	17	14	15	15.3	3.8	
9b ESP ash field 2-4	mg/kg	12	5	16	11.0	13.8	
11 Fabric filter ash	mg/kg	15	54	24	31.0	50.7	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

concentration found in the ESP and fabric filter solids samples. Arsenic was detected at levels near the detection limit in the lime slurry.

Barium

Table 5-8 presents barium concentrations in all streams. Barium was detected in 28 of 31 samples during baseline testing, but in only 23 of 33 samples during demonstration testing. Barium was below detection limits in all the sample train blanks, indicating the samples were free from significant contamination. The precision in streams where barium was detected is generally low (large confidence interval). In particular, barium concentration at the GSA inlet appears to be much higher for baseline tests compared to demonstration; however, the baseline confidence interval is ± 157 percent of the mean and the demonstration confidence interval is ± 176 percent of the mean. Barium concentration in the coal also is 5 times higher for demonstration conditions compared to baseline (the opposite of what one would expect based on the flue gas results). The high barium concentration reported for the series demonstration coal sample appears to be an outlier when compared to the other three results obtained during the tests. Although there was no deviation from sampling or analytical procedures that could be identified and no unusual problems in analyzing these samples was reported by the laboratory, the apparent inconsistency in the results gives some concern for the reliability of the GSA inlet and coal results for the series demonstration tests.

Comparing the ESP inlet and outlet results, there was significant barium removal across the ESP. While the ESP inlet results are similar, barium concentrations at the ESP outlet and fabric filter inlet, which show good precision, are significantly lower for demonstration conditions compared to baseline. Baseline results indicate significant barium removal across the fabric filter; however, results at both the fabric filter inlet and outlet are below detection limits during demonstration tests, preventing any significant conclusion regarding removal efficiency. Barium concentration at the fabric filter outlet is below detection limits for both baseline and demonstration conditions. Barium was detected in the reinjected fly ash at concentrations well above the output solids, and was detected in the lime slurry at low levels.

Beryllium

Table 5-9 presents results of beryllium measurements made during series tests. Due to an analytical laboratory error, beryllium results for all flue gas samples and several solids samples

TABLE 5-8. BARIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	229.8	(4) 881.8	(4) 1134	748.6	1159
	2 ESP inlet	µg/dscm	1724	1216	1166	1368	767
	3 ESP outlet	µg/dscm	25.38	28.67	25.42	26.49	4.69
	12 Fabric filter inlet	µg/dscm	44.03	34.85	38.30	39.06	11.52
	10 Fabric filter outlet	µg/dscm	ND 4.919	ND 4.889	ND 5.859	ND 5.222	1.370
	4 Coal	mg/kg	115			115	NA
	13 Reinjectd fly ash	mg/kg	183.2	82.4	96.8	120.8	135.4
	5 Cyclone solids	mg/kg	86.4	—	79	82.7	47.0
	9a ESP ash field 1	mg/kg	105	71	56	77	62
	9b ESP ash field 2-4	mg/kg	50	84	96	77	59
	11 Fabric filter ash	mg/kg	67	—	32	50	222
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	114.3	96.6	324.4	178.4	314.8
	2 ESP inlet	µg/dscm	1250	1838	1228	1439	860
	3 ESP outlet	µg/dscm	ND 4.823	ND 4.555	ND 4.613	ND 4.664	0.350
	12 Fabric filter inlet	µg/dscm	ND 8.880	ND 8.590	ND 8.333	ND 8.601	0.680
	10 Fabric filter outlet	µg/dscm	ND 4.474	ND 4.221	ND 4.347	ND 4.347	0.314
	4 Coal	mg/kg	612			612	NA
	13 Reinjectd fly ash	mg/kg	118.3	175.9	138.7	144.3	72.6
	7 Lime slurry (note 3)	mg/kg	1.43	—	—	1.43	NA
	14 Trim water (note 3)	mg/kg	—	—	0.039	0.039	NA
	5 Cyclone solids	mg/kg	75.3	57	59.3	63.9	24.8
	9a ESP ash field 1	mg/kg	53	63	ND 3.1	39	80
9b ESP ash field 2-4	mg/kg	69	39	39	49	43	
11 Fabric filter ash	mg/kg	36	63	37	45	38	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

TABLE 5-9. BERYLLIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	0.6			0.6	NA
	13 Reinjecting fly ash	mg/kg	2.27	1.27	1.37	1.6	1.4
	5 Cyclone solids	mg/kg	0.68	-	0.71	0.7	0.2
	9a ESP ash field 1	mg/kg	-	-	-	-	-
	9b ESP ash field 2-4	mg/kg	-	-	-	-	-
	11 Fabric filter ash	mg/kg	-	-	-	-	-
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	1.1			1.1	NA
	13 Reinjecting fly ash	mg/kg	1.52	1.92	1.73	1.7	0.5
	7 Lime slurry (note 2)	mg/kg	ND 0.015	-	-	ND 0.015	NA
	14 Trim water (note 2)	mg/kg	-	-	ND 0.0003	ND 0.0003	NA
	5 Cyclone solids	mg/kg	0.48	0.37	0.42	0.4	0.1
	9a ESP ash field 1	mg/kg	-	-	-	-	-
9b ESP ash field 2-4	mg/kg	-	-	-	-	-	
11 Fabric filter ash	mg/kg	-	-	-	-	-	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.

were not obtained. Results were obtained for coal, re-injected fly ash, cyclone solids, lime slurry, and trim water samples. Beryllium is present at low levels in the coal, cyclone solids, and reinjected fly ash. Beryllium was not detected in the lime slurry or trim water samples.

Cadmium

Cadmium results are shown in Table 5-10. Cadmium also was measured to very low detection limits. Hence, cadmium was detected in 27 of 31 samples during baseline tests and in 27 of 33 samples during demonstration tests. Significant concentrations of cadmium were detected in 3 of 5 flue gas sample train blanks, indicating the possibility of contamination either in the field or in the laboratory (see Section 7 for additional discussion of QA/QC results). Precision of the results at the GSA inlet and ESP inlet is good, but is not as good at locations after the ESP where the absolute concentrations are much lower. The low precision at these locations may be due to both proximity to the detection limits and background contamination. Precision of cadmium concentrations in the solids samples also is low.

Cadmium concentration in the GSA inlet flue gas is similar for baseline and demonstration conditions. Cadmium concentrations at the ESP outlet are lower for demonstration conditions compared to baseline, but the difference is within the confidence intervals of the measurements. Cadmium was detected at trace levels in the lime slurry but was below detection limits in the trim water. Elevated cadmium concentrations were found in the fabric filter ash for both baseline and demonstration test conditions. This suggests cadmium may be strongly concentrated in the finest particles, although the degree of concentration suggested by the results is unlikely.

Chromium

Results of chromium measurements during series configuration tests are presented in Table 5-11. Chromium was detected in 28 of 31 baseline samples and in 23 of 33 demonstration samples. Chromium was not detected in any of the field train blank samples, indicating the samples were free from significant contamination. However, the low level flue gas audit sample result is outside of normal acceptance limits, indicating the accuracy of chromium measurements at the ESP outlet and fabric filter outlet may be below program objectives. See Section 7 for additional discussion of QA/QC results. The precision of the chromium measurements in the flue gas streams is fair to good at most locations. Mean concentration of chromium at the GSA inlet is slightly lower for demonstration tests compared to baseline, but the difference is within confidence

TABLE 5-10. CADMIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	5.903	(4) 7.937	(4) 8.338	7.393	3.243
	2 ESP inlet	µg/dscm	9.378	8.292	9.054	8.908	1.385
	3 ESP outlet	µg/dscm	0.323	0.289	0.134	0.249	0.250
	12 Fabric filter inlet	µg/dscm	0.459	0.306	0.451	0.405	0.214
	10 Fabric filter outlet	µg/dscm	0.398	0.684	0.820	0.634	0.535
	4 Coal	mg/kg	0.04			0.04	NA
	13 Reinject fly ash	mg/kg	0.296	0.327	0.292	0.305	0.05
	5 Cyclone solids	mg/kg	ND 0.004	—	ND 0.004	ND 0.004	0.00
	9a ESP ash field 1	mg/kg	0.9	0.6	0.8	0.77	0.38
	9b ESP ash field 2-4	mg/kg	ND 0.3	1.5	0.6	0.75	1.55
11 Fabric filter ash	mg/kg	16	—	17	16.5	6.4	
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	6.837	6.374	8.703	7.305	3.063
	2 ESP inlet	µg/dscm	6.332	11.573	8.343	8.749	6.569
	3 ESP outlet	µg/dscm	0.234	ND 0.003	0.150	0.129	0.290
	12 Fabric filter inlet	µg/dscm	0.240	0.233	0.405	0.293	0.242
	10 Fabric filter outlet	µg/dscm	0.434	ND 0.228	0.351	0.300	0.257
	4 Coal	mg/kg	0.10			0.10	NA
	13 Reinject fly ash	mg/kg	0.28	0.367	0.239	0.295	0.162
	7 Lime slurry (note 3)	mg/kg	0.011	—	—	0.011	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.0007	ND 0.0007	NA
	5 Cyclone solids	mg/kg	0.33	ND 0.004	ND 0.004	0.111	0.468
9a ESP ash field 1	mg/kg	0.6	1	0.9	0.83	0.52	
9b ESP ash field 2-4	mg/kg	ND 0.3	0.7	0.5	0.45	0.50	
11 Fabric filter ash	mg/kg	26.8	25	17.6	23.1	12.1	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

TABLE 5-11. CHROMIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	302.4	(4) 458.3	(4) 624.2	461.6	399.8
	2 ESP inlet	µg/dscm	702.8	587.9	684.1	658.3	153.2
	3 ESP outlet	µg/dscm	9.304	1.778	13.74	8.274	15.02
	12 Fabric filter inlet	µg/dscm	17.63	16.09	21.33	18.35	6.69
	10 Fabric filter outlet	µg/dscm	ND 2.86	ND 2.84	ND 3.40	ND 3.03	0.80
	4 Coal	mg/kg	14			14	NA
	13 Reinjected fly ash	mg/kg	97	33.3	25.7	52.0	97.3
	5 Cyclone solids	mg/kg	27.6	—	26.8	27.2	5.1
	9a ESP ash field 1	mg/kg	51	34	36	40.3	23.1
	9b ESP ash field 2-4	mg/kg	13	25	44	27.3	38.8
	11 Fabric filter ash	mg/kg	26	—	28	27.0	12.7
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	360.7	329.8	378.5	356.4	61.2
	2 ESP inlet	µg/dscm	455.0	663.9	582.2	567.0	261.6
	3 ESP outlet	µg/dscm	ND 2.800	ND 2.645	ND 2.679	ND 2.708	0.202
	12 Fabric filter inlet	µg/dscm	ND 5.156	ND 4.988	ND 4.838	ND 4.994	0.395
	10 Fabric filter outlet	µg/dscm	ND 2.598	ND 2.451	ND 2.524	ND 2.524	0.183
	4 Coal	mg/kg	17			17	NA
	13 Reinjected fly ash	mg/kg	15.7	20	17.5	17.7	5.4
	7 Lime slurry (note 3)	mg/kg	4.51	—	—	4.51	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.009	ND 0.009	NA
	5 Cyclone solids	mg/kg	15.4	15.9	14.8	15.4	1.4
	9a ESP ash field 1	mg/kg	19	26	33	26.0	17.4
9b ESP ash field 2-4	mg/kg	13	12	31	18.7	26.6	
11 Fabric filter ash	mg/kg	49	34	30	37.7	24.9	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

interval of the measurements. Chromium was below detection limits at the ESP outlet and fabric filter inlet under demonstration conditions, compared to significantly higher levels measured there under baseline operation. Chromium concentrations at the fabric filter outlet are below detection limits for all test runs. Precision of results in the process solids is more varied. Except for a single high measurement, concentrations in the reinjected fly ash are similar to concentrations in the ESP solids and baseline fabric filter ash. Concentration in the demonstration fabric filter solids is generally higher than in the other streams, which could be an indication of contamination from construction materials. Chromium was measured in the lime slurry at relatively lower concentrations.

Cobalt

Table 5-12 presents cobalt concentrations measured during series configuration tests. Cobalt was detected in 28 of 31 baseline samples, but in only 18 of 33 demonstration samples. Cobalt was below detection limits in all of the field train blanks, indicating the samples were free from significant contamination. Precision of cobalt measurements in the flue gas streams is fair to good except for measurements close to the detection limits. Mean concentration of cobalt at the GSA inlet is slightly lower for demonstration tests compared to baseline, but the difference is within confidence interval of the measurements. The cobalt concentrations are significantly lower at the ESP outlet compared to the inlet, indicating good removal efficiency in the ESP. Cobalt concentration at the ESP outlet is slightly lower for demonstration tests compared to baseline, but the difference is not significant since the measured values were close to the detection limits. Cobalt was below detection limits at the ESP outlet, fabric filter inlet, and fabric filter outlet for demonstration tests. Precision of measurements in the solids streams is low for output solids but good for the coal and reinjected fly ash. Concentrations of cobalt in the reinjected fly ash and the output solids streams is similar for baseline tests. Cobalt was not detected in the lime slurry and hence lower concentrations in the output solids during demonstration conditions are probably due to dilution by spent and un-reacted sorbent.

Lead

The results of lead concentration measurements for series configuration tests are presented in Table 5-13. Lead was detected in all of the baseline test samples and in 28 of 33 demonstration test samples. Lead also was detected in 2 of 5 field sample train blanks, at levels that were significant relative to the fabric filter inlet measurements. Thus, measurement results for this

TABLE 5-12. COBALT RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	41.36	(4) 62.62	(4) 77.31	60.43	44.90
	2 ESP inlet	µg/dscm	119.3	120.7	118.6	119.5	2.6
	3 ESP outlet	µg/dscm	1.582	1.673	1.462	1.572	0.263
	12 Fabric filter inlet	µg/dscm	3.302	4.619	3.098	3.673	2.051
	10 Fabric filter outlet	µg/dscm	ND 1.270	ND 1.262	ND 1.512	ND 1.348	0.353
	4 Coal	mg/kg	4			4	NA
	13 Reinject fly ash	mg/kg	5.21	4.81	4.96	4.99	0.50
	5 Cyclone solids	mg/kg	4.37	—	4.29	4.33	0.51
	9a ESP ash field 1	mg/kg	6	4	4	4.67	2.87
	9b ESP ash field 2-4	mg/kg	2	4	4	3.33	2.87
	11 Fabric filter ash	mg/kg	5	—	4	4.50	6.35
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	49.83	42.44	57.32	49.87	18.48
	2 ESP inlet	µg/dscm	64.63	99.10	94.83	86.19	46.67
	3 ESP outlet	µg/dscm	ND 1.245	ND 1.175	ND 1.191	ND 1.204	0.091
	12 Fabric filter inlet	µg/dscm	ND 2.292	ND 2.217	ND 2.150	ND 2.220	0.176
	10 Fabric filter outlet	µg/dscm	ND 1.154	ND 1.089	ND 1.122	ND 1.122	0.081
	4 Coal	mg/kg	4			4	NA
	13 Reinject fly ash	mg/kg	4.22	4.94	4.85	4.67	0.97
	7 Lime slurry (note 3)	mg/kg	ND 0.35	—	—	ND 0.35	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.007	ND 0.01	NA
	5 Cyclone solids	mg/kg	1.96	1.8	3.43	2.40	2.23
	9a ESP ash field 1	mg/kg	ND 0.65	ND 0.65	4	1.55	4.81
9b ESP ash field 2-4	mg/kg	ND 0.65	ND 0.65	3	1.22	3.37	
11 Fabric filter ash	mg/kg	5	4	5	4.67	1.43	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

TABLE 5-13. LEAD RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	72.04	(4) 150.5	(4) 188.5	137.01	147.5455505
	2 ESP inlet	µg/dscm	265.5	211.1	226.0	234.2	69.8
	3 ESP outlet	µg/dscm	2.104	2.249	5.581	3.311	4.887
	12 Fabric filter inlet	µg/dscm	3.276	2.562	3.920	3.253	1.688
	10 Fabric filter outlet	µg/dscm	0.820	0.894	0.756	0.823	0.171
	4 Coal	mg/kg	4			4	NA
	13 Reinject fly ash	mg/kg	30.6	9.3	11.1	17.00	29.35
	5 Cyclone solids	mg/kg	1.81	—	1.96	1.89	0.95
	9a ESP ash field 1	mg/kg	13	8	11	10.67	6.25
	9b ESP ash field 2-4	mg/kg	7	10	12	9.67	6.25
	11 Fabric filter ash	mg/kg	16	—	13	14.50	19.06
	Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3	
1 GSA inlet		µg/dscm	91.21	76.04	132.9	100.1	73.2
2 ESP inlet		µg/dscm	159.4	190.5	168.2	172.7	39.8
3 ESP outlet		µg/dscm	0.764	ND 0.046	ND 0.047	0.270	1.029
12 Fabric filter inlet		µg/dscm	1.814	2.171	1.792	1.926	0.529
10 Fabric filter outlet		µg/dscm	0.372	0.283	0.467	0.374	0.229
4 Coal		mg/kg	5			5	NA
13 Reinject fly ash		mg/kg	18.1	26.9	12.5	19.17	18.03
7 Lime slurry (note 3)		mg/kg	ND 0.035	—	—	ND 0.035	NA
14 Trim water (note 3)		mg/kg	—	—	ND 0.001	ND 0.001	NA
5 Cyclone solids		mg/kg	1.84	0.56	0.41	0.94	1.95
9a ESP ash field 1		mg/kg	4	8	6	6.00	4.97
9b ESP ash field 2-4		mg/kg	8	ND 2.3	5	4.72	7.08
11 Fabric filter ash	mg/kg	14	17	13	14.67	5.17	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

location may be clouded by potential sample contamination (see Section 7). Precision of the flue gas measurements is fair. Mean concentration of lead at the GSA inlet is slightly lower for demonstration tests compared to baseline, but the difference is within confidence interval of the measurements. Concentrations at the ESP outlet are significantly lower than at the inlet indicating good removal in the ESP. ESP outlet and fabric filter inlet concentrations compare well for baseline tests, but appear somewhat higher at the fabric filter inlet for demonstration tests due to two ESP outlet samples that are below the detection limit. The differences are barely outside the confidence intervals of the respective measurements. Precision of the solids measurements is fair to low. Lead concentration is surprisingly low in the baseline GSA ash, suggesting all of the lead may be associated with fine particles not well controlled by the mechanical collector. Lead also is moderately enriched in the fabric filter ash samples compared to the other output solids, but this is probably not statistically significant. Lead was detected in the coal but not in the lime slurry.

Manganese

Manganese test results for the series configuration are presented in Table 5-14. Manganese was detected in all of the baseline test samples and in all but one of the demonstration test samples. Manganese was detected in 1 of 5 sample train blanks; however, the level was insignificant except for fabric filter outlet measurements. Precision of the flue gas measurements is only fair. Concentrations at the GSA inlet are lower for demonstration tests compared to baseline, but the difference is within the confidence interval of the measurements. Significantly lower concentrations were measured at the ESP outlet compared to the ESP inlet indicating good removal of manganese in the ESP. ESP outlet concentrations are similar for baseline and demonstration tests, except for a single high result during demonstration tests. Precision of the process solid results also is fair to low even though levels were well above the detection limits. Manganese was not detected in the trim water and was detected at a relatively low level in the lime slurry. The variability of the results, particularly for demonstration tests, suggests they should be used cautiously.

Mercury

Table 5-15 shows series configuration mercury results. Mercury was detected in about half of the baseline samples (16 of 31) and demonstration samples (18 of 33), indicating only trace levels of mercury in the system. Nearly all of the detected results occurred in the flue gas streams at generally low levels. Mercury was not detected in any of the sample train blanks, indicating the

TABLE 5-14. MANGANESE RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	486.0	(4) 910.2	(4) 848.2	748.1	569.2
	2 ESP inlet	µg/dscm	915.9	712.8	874.9	834.6	266.8
	3 ESP outlet	µg/dscm	10.11	11.61	12.41	11.38	2.903
	12 Fabric filter inlet	µg/dscm	18.29	11.88	15.94	15.37	8.060
	10 Fabric filter outlet	µg/dscm	4.496	1.945	2.520	2.987	3.324
	4 Coal	mg/kg	17			17	NA
	13 Reinject fly ash	mg/kg	67.9	122	112	100.6	71.51
	5 Cyclone solids	mg/kg	145.4	—	137.4	141.4	50.82
	9a ESP ash field 1	mg/kg	85	32	35	50.67	73.96
	9b ESP ash field 2-4	mg/kg	25	53	58	45.33	44.19
	11 Fabric filter ash	mg/kg	104	—	68	86.00	228.67
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	358.0	331.1	500.9	396.6	226.7
	2 ESP inlet	µg/dscm	603.8	957.2	1025	861.9	561.7
	3 ESP outlet	µg/dscm	8.297	3.795	277.9	96.66	390.0
	12 Fabric filter inlet	µg/dscm	1.957	3.694	1.792	2.481	2.618
	10 Fabric filter outlet	µg/dscm	1.780	1.679	2.103	1.854	0.550
	4 Coal	mg/kg	32			32	NA
	13 Reinject fly ash	mg/kg	57	76.7	116.1	83.27	74.76
	7 Lime slurry (note 3)	mg/kg	4.67	—	—	4.670	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.001	ND 0.001	NA
	5 Cyclone solids	mg/kg	62.8	90.5	83.4	78.90	35.74
	9a ESP ash field 1	mg/kg	29	24	24	25.67	7.17
9b ESP ash field 2-4	mg/kg	18	16	26	20.00	13.15	
11 Fabric filter ash	mg/kg	97	93	136	108.7	59.02	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

TABLE 5-15. MERCURY RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results						Mean	2.5% CC
			A		B		C			
Baseline	Flue gas (note 1): Run No.	—	2		3		4			
	1 GSA inlet	µg/dscm	1.080		2.886		2.088		2.018	2.248
	2 ESP inlet	µg/dscm	2.693		1.756		1.648		2.032	1.428
	3 ESP outlet	µg/dscm	0.488		0.324		0.510		0.441	0.252
	12 Fabric filter inlet	µg/dscm	ND 0.061		0.223		ND 0.060		0.095	0.233
	10 Fabric filter outlet	µg/dscm	0.063		0.321		0.076		0.153	0.361
	4 Coal	mg/kg	0.075						0.075	NA
	13 Reinject fly ash	mg/kg	ND 0.1		ND 0.1		ND 0.1		ND 0.10	0.00
	5 Cyclone solids	mg/kg	ND 0.1		—		ND 0.1		ND 0.10	0.00
	9a ESP ash field 1	mg/kg	ND 0.03		ND 0.03		ND 0.03		ND 0.03	0.00
	9b ESP ash field 2-4	mg/kg	0.32		ND 0.03		ND 0.03		0.12	0.42
11 Fabric filter ash	mg/kg	1.2		—		ND 0.03		0.61	7.43	
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1		2		3			
	1 GSA inlet	µg/dscm	0.526		1.170		2.166		1.287	2.053
	2 ESP inlet	µg/dscm	0.371		2.194		1.724		1.430	2.351
	3 ESP outlet	µg/dscm	0.192		0.083		0.258		0.178	0.220
	12 Fabric filter inlet	µg/dscm	0.210		0.342		0.197		0.250	0.199
	10 Fabric filter outlet	µg/dscm	0.178		ND 0.027		0.290		0.161	0.328
	4 Coal	mg/kg	0.065						0.065	NA
	13 Reinject fly ash	mg/kg	ND 0.1		ND 0.1		ND 0.1		ND 0.10	0.00
	7 Lime slurry (note 3)	mg/kg	ND 0.1		—		—		ND 0.1	NA
	14 Trim water (note 3)	mg/kg	—		—		ND 0.0002		ND 0.0002	NA
	5 Cyclone solids	mg/kg	ND 0.1		ND 0.1		ND 0.1		ND 0.10	0.00
9a ESP ash field 1	mg/kg	ND 0.03		ND 0.03		ND 0.03		ND 0.03	0.00	
9b ESP ash field 2-4	mg/kg	ND 0.03		ND 0.03		ND 0.03		ND 0.03	0.00	
11 Fabric filter ash	mg/kg	1		0.6		1.4		1.00	0.99	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.

samples were free from any significant contamination. Precision of the flue gas measurements is fair for most baseline samples and low for most demonstration samples. Mean concentration of mercury at the GSA inlet is slightly lower for demonstration tests compared to baseline, but the difference is within confidence interval of the measurements. Mercury concentration in process solid samples is below detection limits for nearly all samples. Levels slightly above the detection limits were detected in the fabric filter ash samples. The low precision of the mercury results can generally be attributed to measured levels that are close to the method detection limits.

Nickel

Results of nickel measurements during series configuration tests are shown in Table 5-16. due to an analytical laboratory error, nickel results are not available for any of the flue gas samples and several of the solid samples. Nickel concentration in the reinjected fly ash is similar for baseline and demonstration tests. Nickel was present in the lime slurry at very low levels and was not detected in the trim water; consequently, concentration in the GSA solids is much lower during demonstration tests compared to baseline. The precision of the results that are available is good. Nickel was not measured in the sample train blanks; however, all other quality control results for nickel are within acceptance limits.

Selenium

Selenium results for series configuration tests (Table 5-17) show detectible concentrations in 28 of 31 baseline test samples but in only 17 of 33 demonstration test samples. Selenium was not detected in any of the sample train blanks, indicating no significant background levels in the samples. Precision of most results is fair to low. GSA inlet results are well above detection limits and are similar within confidence limits for both baseline and demonstration tests. Selenium concentration at the GSA inlet is slightly lower during demonstration tests compared to baseline, but within the confidence interval of the measurements. Selenium is significantly lower at the ESP outlet compared to the ESP inlet, indicating some removal in the ESP took place. Mean ESP outlet concentrations are slightly lower for demonstration tests compared to baseline tests, but the difference is within the confidence interval of the measurements. Interestingly, selenium at the fabric filter outlet is considerably lower (non-detected) for demonstration tests compared to baseline tests (detected in all runs), but this observation is also subject to the statistical uncertainty. Selenium was detected in the coal and lime slurry at levels comparable to the reinjected fly ash and

TABLE 5-16. NICKEL RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	9			9	NA
	13 Reinjectd fly ash	mg/kg	12.7	-	13.9	13.30	7.62
	5 Cyclone solids	mg/kg	12.4	-	11.7	12.05	4.45
	9a ESP ash field 1	mg/kg	-	-	-	-	-
	9b ESP ash field 2-4	mg/kg	-	-	-	-	-
11 Fabric filter ash	mg/kg	-	-	-	-	-	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	7			7	NA
	13 Reinjectd fly ash	mg/kg	15.1	18.1	14.3	15.83	4.98
	7 Lime slurry (note 2)	mg/kg	0.75	-	-	0.75	NA
	14 Trim water (note 2)	mg/kg	-	-	ND 0.001	ND 0.001	NA
	5 Cyclone solids	mg/kg	7.53	4.89	5.54	5.99	3.42
9a ESP ash field 1	mg/kg	-	-	-	-	-	
9b ESP ash field 2-4	mg/kg	-	-	-	-	-	
11 Fabric filter ash	mg/kg	-	-	-	-	-	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.

TABLE 5-17. SELENIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results				Mean	2.5% CC
			A	B	C			
Baseline	Flue gas (note 1): Run No.	—	2	3	4			
	1 GSA inlet	µg/dscm	124	165	134	141	53.1	
	2 ESP inlet	µg/dscm	106	99	105	103	9.43	
	3 ESP outlet	µg/dscm	27.90	58.57	54.22	46.90	41.22	
	12 Fabric filter inlet	µg/dscm	10.77	9.34	12.59	10.90	4.05	
	10 Fabric filter outlet	µg/dscm	0.714	2.129	1.922	1.588	1.899	
	4 Coal	mg/kg	1			1	NA	
	13 Reinjectd fly ash	mg/kg	3.47	3.65	3.2	3.44	0.56	
	5 Cyclone solids	mg/kg	6.5	—	8.6	7.55	13.34	
	9a ESP ash field 1	mg/kg	5	ND 0.11	4	3.02	6.42	
	9b ESP ash field 2-4	mg/kg	ND 0.11	ND 0.11	5	1.70	7.01	
11 Fabric filter ash	mg/kg	8	—	4	6.00	25.41		
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3			
	1 GSA inlet	µg/dscm	80.90	77.26	109.9	89.34	44.39	
	2 ESP inlet	µg/dscm	216.2	194.1	146.0	185.4	89.15	
	3 ESP outlet	µg/dscm	0.302	18.86	64.98	28.05	82.74	
	12 Fabric filter inlet	µg/dscm	ND 0.124	0.446	ND 0.116	0.189	0.468	
	10 Fabric filter outlet	µg/dscm	ND 0.063	ND 0.059	ND 0.061	ND 0.061	0.005	
	4 Coal	mg/kg	3			3	NA	
	13 Reinjectd fly ash	mg/kg	1.7	3.26	2.04	2.33	2.04	
	7 Lime slurry (note 3)	mg/kg	1.45	—	—	1.45	NA	
	14 Trim water (note 3)	mg/kg	—	—	ND 0.001	ND 0.00	NA	
	5 Cyclone solids	mg/kg	ND 0.1	ND 0.1	ND 0.1	ND 0.10	0.00	
9a ESP ash field 1	mg/kg	ND 0.11	ND 0.11	3	1.04	4.15		
9b ESP ash field 2-4	mg/kg	ND 0.11	ND 0.11	ND 0.11	ND 0.11	0.00		
11 Fabric filter ash	mg/kg	ND 0.11	ND 0.11	ND 0.11	ND 0.11	0.00		

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.

output solids. It should be noted that detection limits for ESP solids and fabric filter solids are higher than for other solid samples because different analytical techniques were used.

Vanadium

Table 5-18 presents vanadium results for series configuration tests. Vanadium was detected in 20 of 31 baseline test samples and in 18 of 33 demonstration test samples. Vanadium was not detected in any of the sample train blanks, indicating no significant contamination. Precision of the flue gas results is fair for detected values at the GSA inlet and ESP inlet. All other flue gas results are near or below the detection limits. Vanadium concentration at the GSA inlet is slightly lower during demonstration tests compared to baseline, but within the confidence interval of the measurements. Measurements across the ESP indicated significant vanadium removal. Vanadium was detected in the reinjected fly ash and in the lime slurry. Concentrations in some of the ESP and fabric filter ash are near or below the detection limit, contributing to the low precision of these results.

5.3.4 HCl and HF Results - Series Configuration

Table 5-19 presents HCl and chloride results for series configuration tests. Chloride was detected in all but one baseline test sample and in 23 of 35 demonstration samples. Inlet HCl concentrations are very similar for baseline and demonstration tests with good precision. HCl was measured in all flue gas streams except at the ESP outlet, since HCl concentrations at the fabric filter inlet were expected to be similar and little or no HCl removal across the GSA reactor/cyclone was expected to occur during baseline tests. Comparison of baseline HCl concentration at the GSA inlet to that at the fabric filter inlet confirms this expectation. Concentrations at the ESP inlet, fabric filter inlet, and fabric filter outlet indicate no significant removal of HCl across the GSA, ESP, or fabric filter during baseline tests. However, all results downstream of the GSA are below detection limits during demonstration tests, showing good HCl removal efficiency for these conditions. The precision of solids measurements generally is fair. As expected, concentration of chlorides in the solid output samples is considerably elevated in demonstration test samples compared to baseline, reflecting capture of HCl in the flue gas.

HF results for series configuration tests are presented in Table 5-20. Fluoride was measured in the flue gas samples only. HF was above detection limits in all of the baseline test samples but was detected only at the GSA inlet in demonstration test samples. Baseline

TABLE 5-18. VANADIUM RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	613	(4) 966	(4) 1140	906	667
	2 ESP inlet	µg/dscm	1247	940	993	1060	408
	3 ESP outlet	µg/dscm	21.18	ND 9.41	ND 9.57	10.22	16.77
	12 Fabric filter inlet	µg/dscm	ND 18.29	ND 18.27	ND 17.99	ND 18.18	0.43
	10 Fabric filter outlet	µg/dscm	ND 9.521	ND 9.462	ND 11.341	ND 10.108	2.654
	4 Coal	mg/kg	26			26	NA
	13 Reinjectd fly ash	mg/kg	30	44.4	36.3	36.90	17.93
	5 Cyclone solids	mg/kg	36.6	—	38.5	37.55	12.07
	9a ESP ash field 1	mg/kg	85	ND 1.7	52	45.95	104.21
	9b ESP ash field 2-4	mg/kg	ND 1.7	ND 1.7	62	21.23	86.49
11 Fabric filter ash	mg/kg	135	—	57	96.00	495.46	
Demonstration	Flue gas (note 1): Run No. (note 2)	—	1	2	3		
	1 GSA inlet	µg/dscm	821.1	742.0	900.8	821.3	197.3
	2 ESP inlet	µg/dscm	697.7	954.8	775.9	809.4	327.5
	3 ESP outlet	µg/dscm	ND 9.334	ND 8.815	ND 8.929	ND 9.026	0.678
	12 Fabric filter inlet	µg/dscm	ND 17.19	ND 16.63	ND 16.13	ND 16.65	1.32
	10 Fabric filter outlet	µg/dscm	ND 8.659	ND 8.170	ND 8.413	ND 8.414	0.607
	4 Coal	mg/kg	29			29	NA
	13 Reinjectd fly ash	mg/kg	21.3	30.4	29.6	27.10	12.52
	7 Lime slurry (note 3)	mg/kg	2.25	—	—	2.25	NA
	14 Trim water (note 3)	mg/kg	—	—	ND 0.005	ND 0.01	NA
	5 Cyclone solids	mg/kg	18.4	19.6	20.7	19.57	2.86
9a ESP ash field 1	mg/kg	ND 1.7	57	55	37.62	77.92	
9b ESP ash field 2-4	mg/kg	ND 1.7	ND 1.7	ND 1.7	ND 1.70	0.00	
11 Fabric filter ash	mg/kg	ND 1.7	59	71	43.62	92.01	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) For ESP inlet, runs 2, 3 and 4 used.
- (3) Results of original sample analysis below detection limits. Analysis of single archive sample using more sensitive test method shown.
- (4) Results corrected for low isokinetic ratio.

TABLE 5-19. HCl AND CHLORIDE RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC		
			A	B	C				
Baseline	Flue gas (1): Run No.	—	2	3	4				
	1 GSA inlet	mg/dscm	17.83	20.77	22.13	20.24	5.46		
	2 ESP inlet	mg/dscm	21.93	21.05	24.58	22.52	4.56		
	3 ESP outlet	mg/dscm	—	—	—	—	—		
	12 Fabric filter inlet	mg/dscm	18.55	26.49	20.80	21.95	10.17		
	10 Fabric filter outlet	mg/dscm	24.22	24.27	26.26	24.92	2.89		
	4 Coal	wt %	0.02			0.02	NA		
	13 Reinject fly ash	mg/kg	ND	0.02	4.4	4.3	2.90	6.21	
	5 Cyclone solids	mg/kg	4.3	—	4.7	4.50	2.54		
	9a ESP ash field 1	mg/kg	8.1	81	220	103.0	267.5		
	9b ESP ash field 2-4	mg/kg	40	10	7.1	19.0	45.3		
	11 Fabric filter ash	mg/kg	200	—	83	141.5	743.2		
	Demonstration	Flue gas (1): Run No.	—	1	2	3			
1 GSA inlet (2)		mg/dscm	26.1	22.6	22.9	23.87	4.82		
2 ESP inlet		mg/dscm	ND 0.0117	ND 0.0117	ND 0.0112	ND 0.0115	0.0007		
3 ESP outlet		mg/dscm	ND 0.0113	—	—	ND 0.0113	NA		
12 Fabric filter inlet (2)		mg/dscm	ND 0.0118	ND 0.0132	ND 0.0133	ND 0.0128	0.0021		
10 Fabric filter outlet		mg/dscm	ND 0.0116	ND 0.0118	ND 0.0122	0.006	0.001		
4 Coal		wt %	0.02			0.02	NA		
13 Reinject fly ash		mg/kg	ND	0.02	ND	0.02	4	1.34	5.71
7 Lime slurry		mg/L	26	26	26	26.0	0.0		
14 Trim water		mg/L	81	63	67	70.3	23.5		
5 Cyclone solids		mg/kg	91	98	120	103.0	37.6		
9a ESP ash field 1		mg/kg	820	1100	1100	1007	402		
9b ESP ash field 2-4		mg/kg	780	780	890	816.7	157.8		
11 Fabric filter ash	mg/kg	430	520	130	360.0	507.3			

Notes:

- (1) Reported as HCl, dry, corrected to 3% O₂.
- (2) Runs 2, 3 and 4 used.

TABLE 5-20. HF RESULTS - SERIES CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (1): Run No.	—	2	3	4		
	1 GSA inlet	mg/dscm	2.041	3.918	3.865	3.275	2.655
	2 ESP inlet	mg/dscm	2.869	3.804	6.064	4.246	4.081
	3 ESP outlet	mg/dscm					
	12 Fabric filter inlet	mg/dscm	2.659	6.329	2.587	3.858	5.316
	10 Fabric filter outlet	mg/dscm	5.704	4.448	6.915	5.689	3.065
Demonstration	Flue gas (1): Run No.	—	1	2	3		
	1 GSA inlet (2)	mg/dscm	2.89	2.97	2.69	2.85	0.36
	2 ESP inlet	mg/dscm	ND 0.0298	ND 0.0298	ND 0.0298	ND 0.0298	0
	3 ESP outlet	mg/dscm	ND 0.0289			ND 0.0289	NA
	12 Fabric filter inlet (2)	mg/dscm	ND 0.0302	ND 0.0374	ND 0.034	ND 0.0339	0.009
	10 Fabric filter outlet	mg/dscm	ND 0.0296	ND 0.0301	ND 0.0313	ND 0.0303	0.002

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Runs 2, 3, and 4 used.

concentrations were similar at all locations within the confidence interval of the measurements, suggesting little or no HF removal. During demonstration tests, HF was not detected in any of the flue gas streams downstream of the GSA reactor at detection limits two orders of magnitude lower than the GSA inlet level. This indicated most of the HF was removed in the GSA reactor.

Chloride and fluoride were not detected in any of the quality control blanks, indicating samples were free from any significant contamination. Accuracy and precision of laboratory results was very good, and both high level and low level audit sample results were acceptable.

5.4 Parallel Configuration Test Results

This section presents results of parallel configuration tests in which a slipstream of flue gas from the GSA reactor/cyclone outlet was introduced to the filter inlet.

5.4.1 Flue Gas Sampling Conditions - Parallel Configuration

Tables 5-21 and 5-22 summarize the average conditions at each of the flue gas sampling locations during parallel configuration tests. As with series configuration tests, the flow rate, temperature, moisture, and O₂ content of the flue gas at each location was very consistent from run to run. GSA inlet conditions compare well for baseline and demonstration tests. O₂ content increased and temperature and moisture content decreased from the inlet to the outlet of the system, indicating slight air in-leakage on the same order of magnitude as during series testing. Isokinetic sampling rate was within the 90-110 percent acceptance limits for all runs.

The duration of flue gas sampling and the actual sample volumes obtained for the Method 26 and Method 29 sample trains are presented in Table 5-23. Sample gas volumes were similar to series configuration tests except at the fabric filter inlet. Because particulate loading at the fabric filter inlet in the parallel configuration was similar to that at the ESP inlet and subject to the same filter plugging difficulties, the sample volumes for the Method 29 sample trains were reduced. Accordingly, the overall method detection limits were increased to levels similar to that at the ESP inlet.

TABLE 5-21. FLUE GAS PARAMETERS - PARALLEL CONFIGURATION,
BASELINE TESTS

	Run	Units	Value*				
			GSA inlet	ESP inlet	ESP outlet	Baghouse inlet	Baghouse outlet
Velocity	A	m/sec	19.0	21.7	20.4	13.3	11.3
	B		18.8	21.5	19.8	14.0	11.6
	C		18.4	20.5	19.8	13.8	11.0
	Mean		18.7	21.2	20.0	14.0	11.3
	2.5% CC		0.7	1.6	0.8	0.9	0.8
Flow rate	A	dscm/min	575	633	435	80.8	98.9
	B		568	634	431	81.9	101.2
	C		563	602	431	82.5	95.9
	Mean		569	623	432	81.7	98.7
	2.5% CC		16	46	6	2.1	6.6
Temperature	A	°C	147	133	123	115	112
	B		146	133	123	116	114
	C		142	134	123	119	113
	Mean		145	134	123	117	113
	2.5% CC		6	1	0	6	3
Moisture	A	% Vol.	7.0	7.6	8.0	7.2	6.5
	B		7.4	7.3	7.3	10.5	6.7
	C		7.6	7.6	7.3	8.0	6.7
	Mean		7.3	7.5	7.5	8.6	6.6
	2.5% CC		0.7	0.4	1.1	4.2	0.3
O2 (dry)	A	% Vol.	6.77	7.22	7.89	7.89	8.33
	B		6.43	6.64	7.68	7.68	8.00
	C		6.11	6.81	7.50	7.50	7.85
	Mean		6.44	6.89	7.69	7.69	8.06
	2.5% CC		0.82	0.74	0.48	0.48	0.61
Isokinetic ratio	A	%	98.8	99.2	97.9	96.7	97.5
	B		99.5	99.3	96.4	100.2	97.3
	C		99.7	100.1	96.4	98.2	96.9
	Mean		99.3	99.5	96.9	98.4	97.2
	2.5% CC		1.2	1.2	2.2	4.4	0.8

*All results taken from multiple metals trains data except GSA inlet, where HCl train data were used.

TABLE 5-22. FLUE GAS PARAMETERS - PARALLEL CONFIGURATION, DEMONSTRATION TESTS

	Run	Units	Value*				
			GSA inlet	ESP inlet	ESP outlet	Baghouse inlet	Baghouse outlet
Velocity	A	m/sec	19.2	19.0	-	14.5	11.0
	B		20.1	19.1	18.1	14.1	11.5
	C		19.6	19.5	18.2	14.9	11.2
	Mean		19.6	19.2	18.1	14.0	11.2
	2.5% CC		1.1	0.7	0.8	1.0	0.6
Flow rate	A	dscm/min	585	603	-	96.5	103.6
	B		597	632	431	92.6	107.1
	C		576	631	434	97.5	104.5
	Mean		586	622	433	95.5	105.1
	2.5% CC		27	41	20	6.4	4.5
Temperature	A	°C	140	60	-	58	62
	B		147	63	63	58	62
	C		144	64	64	58	62
	Mean		144	63	64	58	62
	2.5% CC		8	6	4	1	1
Moisture	A	% Vol.	7.6	17.6	-	12.8	12.5
	B		8.0	13.0	13.1	13.5	12.9
	C		9.3	14.7	13.1	13.9	13.1
	Mean		8.3	15.1	13.1	13.4	12.8
	2.5% CC		2.2	5.8	0.1	1.4	0.8
O2 (dry)	A	% Vol.	6.15	6.71	-	7.21	6.95
	B		6.11	6.65	7.16	7.16	7.12
	C		5.81	6.34	6.94	6.94	6.71
	Mean		6.02	6.57	7.05	7.10	6.93
	2.5% CC		0.46	0.49	1.40	0.36	0.51
Isokinetic ratio	A	%	99.9	105.8	-	98.9	100.7
	B		99.5	102.1	99.9	100.1	98.3
	C		100.5	93.7	101.1	99.5	101.2
	Mean		100.0	100.5	100.5	99.5	100.1
	2.5% CC		1.3	15.4	7.6	1.5	3.9

*All results taken from multiple metals trains data.

TABLE 5-23. SUMMARY OF FLUE GAS SAMPLING DURATION AND VOLUMES - PARALLEL CONFIGURATION

Test Condition	Sample Date	Sample Train	GSA Inlet		Baghouse Inlet		Baghouse Outlet		ESP Inlet		ESP Outlet	
			Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)	Time (min)	Volume (scf)
Baseline	10/21/93	Metals	--	--	96	44.5	240	162.4	120	65.8	240	174.8
		HCl	60	40.4	60	30.2	60	39.7	--	--	--	--
		HCl	60	40.4	60	30.2	60	40.9	--	--	--	--
	10/22/93	Metals	--	--	96	46.2	240	165.5	120	65.5	240	168.8
		HCl	60	39.8	60	31.5	60	40.7	--	--	--	--
		Metals	--	--	96	46.8	240	156.2	120	62.7	240	168.8
Demonstration	10/13/93	HCl	60	41.3	60	33.7	60	45.5	--	--	--	--
		Metals	160	111.8	192	119.5	240	173.2	120	66.7	--	--
	10/14/93	HCl	60	41.7	60	35.0	60	46.6	60	37.1	60	41.5
		Metals	160	115.2	96	54.4	240	178.5	72	40.6	240	176.1
	10/15/93	Metals	160	114.8	72	42.4	240	179.0	72	37.2	240	179.2
		HCl	60	41.5	--	--	60	46.4	60	37.7	--	--

5.4.2 Flue Gas Particulate Results - Parallel Configuration

Table 5-24 presents the results of particulate measurements made during parallel configuration tests. Particulate was not measured at the GSA inlet during baseline tests because inlet conditions were otherwise similar to other tests. Also, only two valid test runs were completed at the ESP outlet during demonstration test conditions. The precision of the results at the ESP inlet was low (large confidence interval) for baseline tests compared to measurements at the other locations. Run 1 demonstration test results at the ESP inlet were invalidated because the acetone rinse sample container was broken during shipment to the laboratory and most of the sample was lost; hence, this result was not included in the average. Precision of the ESP inlet and outlet demonstration results was low. One of the runs during demonstration tests at the ESP outlet appears to be much higher than the all others and thus would appear to be suspect, especially since there was no significant difference in opacity observed for that test; however, no definitive reason could be identified to invalidate the result.

Particulate concentration at the ESP inlet and fabric filter inlet was not similar in most cases, but the differences are generally within the confidence intervals of the measurements. ESP outlet results were significantly lower than at the inlet for both baseline and demonstration tests, indicating significant removal in the ESP. ESP inlet concentrations were much greater for demonstration tests compared to baseline, by an average factor of 5; however, concentrations at the fabric filter inlet were only a factor of two greater during demonstration tests compared to baseline. Particulate concentration at the fabric filter outlet was substantially lower than at the inlet, indicating good particulate removal in the ESP. Concentrations of total particulate at the outlet of both the ESP and the fabric filter were well below the federal NSPS of approximately 164 mg/dscm (0.072 gr/dscf) for coal-fired utility boilers built after August 1971 for baseline conditions. However, average ESP outlet results were approximately twice the limit under demonstration conditions. This appears to be driven by the anomalous test run discussed above. Baseline results at the ESP outlet were slightly below the NSPS of approximately 49 mg/dscm (0.021 gr/dscf) for coal-fired utility boilers built after September 1978. Particulate concentrations were considerably below this level at the fabric filter outlet for both baseline and demonstration tests.

Solids concentration the lime slurry, shown for reference in Table 5-24, averaged 31 percent.

TABLE 5-24. PARTICULATE RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1):						
	Run No.	—	2	3	4		
	1 GSA inlet	mg/dscm	—	—	—	—	—
	2 ESP inlet	mg/dscm	2,614	1,237	3,514	2,455	2,849
	3 ESP outlet	mg/dscm	44	52	48	48	10
	12 Fabric filter inlet	mg/dscm	4,244	5,014	5,607	4,955	1,698
	10 Fabric filter outlet	mg/dscm	12.22	11.29	11.07	11.53	1.52
Demonstration	Flue gas (note 1):						
	Run No.	—	1	2	3		
	1 GSA inlet	mg/dscm	3,487	3,320	3,415	3,407	208
	2 ESP inlet	mg/dscm	(3) 1,734	12,068	16,173	14,121	26,075
	3 ESP outlet	mg/dscm	—	676	11	344	4,224
	12 Fabric filter inlet	mg/dscm	6,443	11,642	10,122	9,402	6,641
		10 Fabric filter outlet	mg/dscm	6.76	4.35	8.36	6.49
	7 Lime slurry (note 2)	wt. %	29.2	29.1	35.1	31.13	8.54

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Percent solids, reported as 100-(% moisture)
- (3) Excluded from average; acetone rinse sample destroyed during shipment to laboratory.

5.4.3 Trace Metals Results - Parallel Configuration

Trace metals results for the parallel configuration tests are presented in this section. Trace metals were not measured at the GSA inlet during baseline tests, and only two valid metals runs were achieved at the ESP outlet during demonstration tests. It should be noted that, as with the particulate results, trace metals results at the ESP inlet for Run 1 of the demonstration tests were not included in the averages because the acetone rinse sample was destroyed during shipment from the field to the lab. Results from a single lime slurry sample from Run 1 of the demonstration tests are reported. As discussed earlier for series configuration tests, this sample was analyzed using the most sensitive analytical methods and results are considered representative of other samples. Trim water samples for each demonstration test run were analyzed using less sensitive techniques; however, all results were below detection limits. A single trim water sample, believed to be representative of all demonstration test runs, was analyzed during series configuration tests using more sensitive methods. The results of trim water analysis were presented earlier in the preceding discussion of series configuration results.

A second series of field sample train blanks was analyzed for the parallel configuration tests. The results showed significant concentrations of metals in several of the samples, indicating the possibility of background contamination for several metals. The impact of these results is discussed below and in Section 7.

Antimony

Table 5-25 presents antimony results for parallel configuration tests. Antimony was measured at concentrations above the detection limits in only a few samples. Antimony was detected in 6 of 28 baseline test samples and in 12 of 31 demonstration test samples. Antimony was detected only in the GSA inlet, ESP inlet, and fabric filter inlet samples where total particulate loading was relatively high. Concentrations at the GSA inlet were slightly lower during demonstration tests compared to baseline, but the difference is within the confidence interval of the measurements. Lower concentrations — below the detection limits in all cases — in the ESP outlet samples and most of the fabric filter outlet indicate good removal in the ESP and fabric filter. The low precision of most detected data suggests considerable uncertainty in the results. Antimony was not detected in any sample train blanks and other quality control results were within normal acceptance limits. Antimony was below detection limits in all of the process solids samples, lime

TABLE 5-25. ANTIMONY RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	6.90	8.09	10.84	8.61	5.02
	3 ESP outlet	µg/dscm	ND 0.09	ND 0.09	ND 0.09	ND 0.09	0.00
	12 Fabric filter inlet	µg/dscm	15.12	19.18	34.76	23.02	25.76
	10 Fabric filter outlet	µg/dscm	ND 0.10	ND 0.10	ND 0.10	ND 0.10	0.01
	4 Coal	mg/kg	ND 0.5			ND 0.5	NA
	13 Reinject fly ash	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
	5 Cyclone solids	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
	9a ESP ash field 1	mg/kg	ND 10	ND 10	ND 10	ND 10	0
	9b ESP ash field 2-4	mg/kg	ND 10	ND 10	ND 10	ND 10	0
11 Fabric filter ash	mg/kg	ND 10	ND 10	ND 10	ND 10	0	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	5.19	6.17	7.22	6.20	2.52
	2 ESP inlet	µg/dscm	(3) 5.34	15.89	24.36	20.13	53.80
	3 ESP outlet	µg/dscm	—	ND 0.09	ND 0.08	ND 0.09	0.06
	12 Fabric filter inlet	µg/dscm	11.77	16.67	12.73	13.72	6.45
	10 Fabric filter outlet	µg/dscm	ND 0.09	ND 0.09	ND 0.08	ND 0.09	0.01
	4 Coal	mg/kg	ND 0.5			ND 0.5	NA
	13 Reinject fly ash	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
	7 Lime slurry (note 2)	mg/kg	ND 0.08	—	—	ND 0.08	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	ND 0.08	ND 0.08	ND 0.08	ND 0.08	0.00
9a ESP ash field 1	mg/kg	ND 10	ND 10	ND 10	ND 10	0	
9b ESP ash field 2-4	mg/kg	ND 10	ND 10	ND 10	ND 10	0	
11 Fabric filter ash	mg/kg	ND 10	ND 10	—	ND 10	0	

Notes:

- (1) Dry, corrected to 3% O2.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

slurry, and coal. Given the small number of samples in which antimony was detected and the low precision of the detected results, the antimony results should be used with caution.

Arsenic

Arsenic results are presented in Table 5-26. Arsenic was detected in all of the baseline samples and in 28 of 30 demonstration test samples. The precision of the flue gas measurements ranges from good to fair. Arsenic was detected at low levels in 1 of 5 sample train blanks, indicating samples were relatively free from contamination. Low concentration audit sample results for arsenic indicate reduced accuracy for low level measurements. Arsenic concentrations at the ESP inlet and outlet are higher for demonstration tests compared to baseline, but the confidence interval for these results also is relatively large. Mean baseline concentrations at the fabric filter inlet are somewhat greater than at the ESP inlet for baseline tests but are slightly lower for demonstration tests. These differences are not significant in light of the relatively large confidence intervals. Significantly lower concentrations at the outlets of the ESP and fabric filter compared to the inlets indicates significant removal efficiency. Precision of the solids results was low for baseline test samples but good for demonstration test samples. Arsenic was detected at very low levels in the lime slurry. Arsenic concentration in the reinjected fly ash was similar for baseline and demonstration tests. Arsenic concentrations in process output solid samples collected during demonstration tests were generally lower than those for baseline tests.

Barium

Barium was detected in 16 of 28 baseline test samples and 27 of 30 demonstration test samples (Table 5-27). Barium was not detected in any sample train blanks and other quality control results were within normal acceptance limits. The confidence interval associated with detected results in the flue gas is large, indicating significant scatter in the results. Compared to series configuration results presented earlier, barium concentration in the GSA inlet flue gas is somewhat lower; however, concentrations in the reinjected fly ash and lime slurry are similar. The difference in GSA inlet concentrations thus may not be significant given the large confidence intervals associated with the earlier measurements, particularly given that the other key process inputs show similar concentrations. Barium concentration is below the detection limits at the ESP outlet for baseline tests, but is above detection limits for demonstration tests. Barium results are below detection limits at the fabric filter outlet for all tests. The large confidence intervals associated with most of the results suggests caution should be exercised in applying these results.

TABLE 5-26. ARSENIC RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	252.4	142.1	314.9	236.5	217.4
	3 ESP outlet	µg/dscm	7.65	7.87	9.18	8.23	2.05
	12 Fabric filter inlet	µg/dscm	392.2	535.1	695.7	541.0	377.2
	10 Fabric filter outlet	µg/dscm	1.06	0.75	1.12	0.98	0.49
	4 Coal	mg/kg	5			5	NA
	13 Reinject fly ash	mg/kg	53	55.22	41.9	50.04	17.73
	5 Cyclone solids	mg/kg	23.3	21.2	23.2	22.6	2.9
	9a ESP ash field 1	mg/kg	72	255	145	157.3	228.9
	9b ESP ash field 2-4	mg/kg	245	32.2	116	131.1	266.3
11 Fabric filter ash	mg/kg	321	400	141	287.3	329.8	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	280.4	313.4	257.8	283.9	69.4
	2 ESP inlet	µg/dscm	(3) 75	347.9	427.8	387.8	508.0
	3 ESP outlet	µg/dscm	-	38.03	0.43	19.23	238.8
	12 Fabric filter inlet	µg/dscm	108.3	309.3	264.8	227.5	262.3
	10 Fabric filter outlet	µg/dscm	ND 0.06	ND 0.06	0.29	0.12	0.33
	4 Coal	mg/kg	5			5	NA
	13 Reinject fly ash	mg/kg	33.8	30.6	54.4	39.60	32.09
	7 Lime slurry (note 2)	mg/kg	0.54	-	-	0.54	NA
	14 Trim water	mg/kg	-	-	-	-	-
	5 Cyclone solids	mg/kg	16.6	13.9	20.6	17.03	8.37
9a ESP ash field 1	mg/kg	51	55	51	52.3	5.7	
9b ESP ash field 2-4	mg/kg	41	38	45	41.3	8.7	
11 Fabric filter ash	mg/kg	59	53	-	56.0	38.1	

Notes:

- (1) Dry, corrected to 3% O2.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

TABLE 5-27. BARIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	525.0	425.9	188.2	379.7	430.0
	3 ESP outlet	µg/dscm	ND 5.07	ND 5.11	ND 5.04	ND 5.07	0.09
	12 Fabric filter inlet	µg/dscm	1214	706.2	2718	1546	2599
	10 Fabric filter outlet	µg/dscm	ND 5.70	ND 5.43	ND 5.69	ND 5.60	0.38
	4 Coal	mg/kg	58			58	NA
	13 Reinjecting fly ash	mg/kg	116.1	126.9	122.3	121.8	13.46
	5 Cyclone solids	mg/kg	89.4	86.5	101.0	92.3	19.1
	9a ESP ash field 1	mg/kg	38	ND 3.1	ND 3.1	13.7	50.1
	9b ESP ash field 2-4	mg/kg	56	ND 3.1	44	33.9	68.9
11 Fabric filter ash	mg/kg	ND 3.1	ND 3.1	ND 3.1	ND 3.1	0.0	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	88.66	49.37	52.30	63.44	54.37
	2 ESP inlet	µg/dscm	(3) 219.3	1041	2947	1994	12108
	3 ESP outlet	µg/dscm	—	124	7.79	65.98	739.2
	12 Fabric filter inlet	µg/dscm	587	460	1025	690.6	736.3
	10 Fabric filter outlet	µg/dscm	ND 4.74	ND 4.76	ND 4.60	ND 4.70	0.22
	4 Coal	mg/kg	64			64	NA
	13 Reinjecting fly ash	mg/kg	113.5	124.2	146.1	127.9	41.28
	7 Lime slurry (note 2)	mg/kg	1.38	—	—	1.38	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	55.3	51.6	41.6	49.5	17.61
9a ESP ash field 1	mg/kg	91	84	57	77.3	44.6	
9b ESP ash field 2-4	mg/kg	94	67	72	77.7	35.7	
11 Fabric filter ash	mg/kg	83	63	—	73.0	127.0	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

Nevertheless, the results indicate significant barium removal in the ESP and fabric filter for both baseline and demonstration test conditions.

Beryllium

Beryllium results for parallel configuration tests are shown in Table 5-28. Due to an analytical laboratory error, beryllium was not analyzed in all of the flue gas samples and several of the process solid samples. Similar beryllium concentrations in the coal and reinjected fly ash for all series and parallel configuration tests suggest input levels were relatively constant. Beryllium was below detection limits in the lime slurry and trim water. Beryllium concentration in the GSA solids is lower for demonstration tests compared to baseline, suggesting dilution by other solids.

Cadmium

Table 5-29 presents cadmium results for parallel configuration tests. Cadmium was detected in 26 of 28 baseline test samples and in 28 of 30 demonstration test samples. Significant amounts of cadmium also were detected in 4 of 5 sample train blanks, suggesting the possibility of significant background contamination. Other quality control results for cadmium are within normal acceptance limits. The precision of flue gas results is low for most sampling locations. Cadmium concentrations in the GSA inlet flue gas, coal, and reinjected fly ash are similar to those measured during series configuration tests. Mean ESP inlet concentration is slightly higher for demonstration tests, but the difference is well within the confidence interval of the measurements. Cadmium concentration in the ESP outlet and fabric filter outlet flue gas is lower for demonstration tests compared to baseline, with generally good precision. All flue gas results are above the detection limits. Cadmium concentrations in the process output solids are similar for baseline and demonstration test conditions. The cadmium enrichment of fabric filter ash that was observed in the series configuration results was not observed in the parallel configuration results.

Chromium

Parallel configuration results for chromium are presented in Table 5-30. Chromium was detected in 25 of 28 baseline test samples and in 26 of 30 demonstration test samples. Chromium was detected in all of the flue gas samples except at the fabric filter outlet and in one demonstration

TABLE 5-28. BERYLLIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	1	3	4		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	0.8			0.8	NA
	13 Reinjecting fly ash	mg/kg	1.82	2.06	1.82	1.9	0.34
	5 Cyclone solids	mg/kg	1.03	0.96	0.95	0.98	0.11
	9a ESP ash field 1	mg/kg	-	-	-	-	-
	9b ESP ash field 2-4	mg/kg	-	-	-	-	-
11 Fabric filter ash	mg/kg	-	-	-	-	-	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	1.1			1.1	NA
	13 Reinjecting fly ash	mg/kg	1.81	1.5	2.11	1.8067	0.76
	7 Lime slurry (note 2)	mg/kg	1.1	-	-	1.1	NA
	14 Trim water	mg/kg	-	-	-	-	-
	5 Cyclone solids	mg/kg	0.35	0.27	0.21	0.2767	0.17
9a ESP ash field 1	mg/kg	-	-	-	-	-	
9b ESP ash field 2-4	mg/kg	-	-	-	-	-	
11 Fabric filter ash	mg/kg	-	-	-	-	-	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.

TABLE 5-29. CADMIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	7.76	4.12	11.21	7.70	8.81
	3 ESP outlet	µg/dscm	1.42	1.24	1.52	1.39	0.35
	12 Fabric filter inlet	µg/dscm	5.23	10.21	10.20	8.55	7.14
	10 Fabric filter outlet	µg/dscm	2.73	2.92	3.42	3.02	0.89
	4 Coal	mg/kg	0.09			0.09	NA
	13 Reinjecting fly ash	mg/kg	0.326	0.455	0.465	0.4153	0.19
	5 Cyclone solids	mg/kg	ND 0.004	ND 0.004	0.335	0.113	0.47
	9a ESP ash field 1	mg/kg	1.200	1.400	1.300	1.30	0.25
	9b ESP ash field 2-4	mg/kg	1.000	0.600	1.600	1.07	1.25
	11 Fabric filter ash	mg/kg	3.500	2.700	2.100	2.77	1.74
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	6.41	6.36	7.04	6.61	0.94
	2 ESP inlet	µg/dscm	(3) 4.95	8.56	11.25	9.91	17.09
	3 ESP outlet	µg/dscm	—	0.97	0.20	0.59	4.89
	12 Fabric filter inlet	µg/dscm	1.07	3.74	4.14	2.98	4.15
	10 Fabric filter outlet	µg/dscm	2.24	1.87	1.48	1.86	0.94
	4 Coal	mg/kg	ND 0.05			ND 0.05	NA
	13 Reinjecting fly ash	mg/kg	0.295	0.297	0.405	0.3323	0.16
	7 Lime slurry (note 2)	mg/kg	0.018	—	—	0.02	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	ND 0.004	0.222	0.322	0.182	0.40
	9a ESP ash field 1	mg/kg	1.2	0.9	1.2	1.10	0.43
9b ESP ash field 2-4	mg/kg	0.8	1.6	0.9	1.10	1.08	
11 Fabric filter ash	mg/kg	1.2	0.8	—	1.00	2.54	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

TABLE 5-30. CHROMIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results				Mean	2.5% CC
			A	B	C			
Baseline	Flue gas (note 1): Run No.	—	2	3	4			
	1 GSA inlet	µg/dscm	—	—	—	—	—	
	2 ESP inlet	µg/dscm	305.8	319.9	512.4	379.4	286.8	
	3 ESP outlet	µg/dscm	8.91	10.08	12.12	10.37	4.04	
	12 Fabric filter inlet	µg/dscm	447.3	896.1	998.2	780.5	728.1	
	10 Fabric filter outlet	µg/dscm	ND 3.31	ND 3.15	ND 3.30	ND 3.25	0.22	
	4 Coal	mg/kg	16			16	NA	
	13 Reinjectd fly ash	mg/kg	23.90	26.90	27.80	26.20	5.07	
	5 Cyclone solids	mg/kg	20.90	14.50	24.50	19.97	12.58	
	9a ESP ash field 1	mg/kg	19.00	45.00	38.00	34.00	33.42	
	9b ESP ash field 2-4	mg/kg	55.00	18.00	58.00	43.67	55.35	
	11 Fabric filter ash	mg/kg	50.00	61.00	51.00	54.00	15.11	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3			
	1 GSA inlet	µg/dscm	403.2	349.7	298.3	350.4	130.3	
	2 ESP inlet	µg/dscm	(3) 56.7	410.0	628.2	519.1	1386	
	3 ESP outlet	µg/dscm	—	53.25	ND 2.66	27.29	321.3	
	12 Fabric filter inlet	µg/dscm	150.9	227.4	286.2	221.5	168.6	
	10 Fabric filter outlet	µg/dscm	ND 2.75	ND 2.76	ND 2.67	ND 2.73	0.12	
	4 Coal	mg/kg	17			17	NA	
	13 Reinjectd fly ash	mg/kg	22	32.3	30	28.1	13.43	
	7 Lime slurry (note 2)	mg/kg	3.7			3.70	NA	
	14 Trim water	mg/kg						
	5 Cyclone solids	mg/kg	16.5	15.6	15.2	15.77	1.65	
	9a ESP ash field 1	mg/kg	23	21	18	20.67	6.25	
9b ESP ash field 2-4	mg/kg	32	24	28	28.00	9.94		
11 Fabric filter ash	mg/kg	22	25	—	23.50	19.06		

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

test sample at the ESP outlet. Precision of the flue gas results is generally fair to good. Chromium was detected in 2 of 5 sample train blanks, indicating the slight possibility of background contamination; however, the levels found are significant only to measurements at the outlets of the ESP and fabric filter. Also, the low level chromium audit sample results indicated reduced accuracy of low concentration measurements. Chromium concentrations in the GSA inlet flue gas, reinjected fly ash, coal, and lime slurry are similar to those measured during series configuration tests. Mean chromium concentrations at the ESP inlet and outlet are slightly elevated for demonstration tests compared to baseline. The differences are not statistically significant, however, especially considering that there are only two valid measurements at each of these locations for demonstration test conditions and one of those is below detection limits. Chromium concentrations in the process output solids are lower for demonstration tests compared to baseline.

Cobalt

Table 5-31 presents cobalt results for parallel configuration tests. Cobalt was detected in 25 of 28 baseline test samples and in 25 of 30 demonstration test samples. The precision of flue gas cobalt measurements is generally fair to good. Cobalt was detected in 1 of 5 sample train blanks at a level close to the detection limits, indicating the flue gas samples were free from significant contamination. Other quality control results for cobalt are within normal acceptance limits. Cobalt was detected in all of the flue gas samples except for those at the fabric filter outlet and one ESP outlet demonstration test measurement. Cobalt concentrations in the GSA inlet flue gas, reinjected fly ash, and coal are slightly higher than measurements during series configuration tests. Cobalt was not detected in the lime slurry. Cobalt concentrations in the process output solids are generally higher during demonstration tests compared to baseline, except for the GSA solids which are lower. Measurements across the ESP and fabric filter indicate significant removal across the control devices.

Lead

Lead test results for parallel configuration tests are shown in Table 5-32. Lead was detected in all but one of 28 baseline test samples and in 24 of 30 demonstration test samples. Lead also was detected in 3 of 5 flue gas sample train blanks, indicating the possibility of significant contamination or background bias; however, the average blank level is significant only for the fabric filter outlet samples. Other quality control results for lead were within normal acceptance limits. Lead was detected in all flue gas samples. The precision of the flue gas results is

TABLE 5-31. COBALT RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	65.71	53.41	89.39	69.50	45.43
	3 ESP outlet	µg/dscm	1.69	1.87	1.95	1.84	0.33
	12 Fabric filter inlet	µg/dscm	96.06	147.2	170.5	137.9	94.64
	10 Fabric filter outlet	µg/dscm	ND 1.47	ND 1.40	ND 1.47	ND 1.45	0.10
	4 Coal	mg/kg	4			4	NA
	13 Reinjecting fly ash	mg/kg	6.23	7.64	5.98	6.617	2.22
	5 Cyclone solids	mg/kg	7.43	6.80	5.29	6.507	2.73
	9a ESP ash field 1	mg/kg	8.00	8.00	6.00	7.33	2.87
	9b ESP ash field 2-4	mg/kg	12.00	3.00	8.00	7.67	11.20
	11 Fabric filter ash	mg/kg	11.00	8.00	9.00	9.33	3.79
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	65.34	70.41	66.36	67.37	6.67
	2 ESP inlet	µg/dscm	(5) 8.83	93.47	111.6	102.5	115.0
	3 ESP outlet	µg/dscm	—	11.79	ND 1.18	6.19	67.39
	12 Fabric filter inlet	µg/dscm	31.90	43.79	66.68	47.46	43.92
	10 Fabric filter outlet	µg/dscm	ND 1.22	ND 1.23	ND 1.19	ND 1.21	0.05
	4 Coal	mg/kg	5			5	NA
	13 Reinjecting fly ash	mg/kg	6.02	6.02	7.6	6.547	2.27
	7 Lime slurry (note 2)	mg/kg	ND 0.35	—	—	ND 0.35	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	3.16	2.4	2.34	2.633	1.14
	9a ESP ash field 1	mg/kg	19	16	13	16.00	7.45
9b ESP ash field 2-4	mg/kg	17	16	14	15.67	3.79	
11 Fabric filter ash	mg/kg	15	15		15.00	0.00	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

TABLE 5-32. LEAD RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	193.3	166.1	188.5	182.6	36.10
	3 ESP outlet	µg/dscm	5.74	6.59	6.23	6.19	1.07
	12 Fabric filter inlet	µg/dscm	306.4	412.5	606.9	441.9	378.7
	10 Fabric filter outlet	µg/dscm	1.59	1.09	1.18	1.29	0.66
	4 Coal	mg/kg	5			5	NA
	13 Reinject fly ash	mg/kg	21.10	17.90	15.70	18.23	6.75
	5 Cyclone solids	mg/kg	3.45	2.60	7.69	4.58	6.77
	9a ESP ash field 1	mg/kg	19.00	14.00	16.00	16.33	6.25
	9b ESP ash field 2-4	mg/kg	25.00	ND 4.00	23.00	16.67	28.79
	11 Fabric filter ash	mg/kg	18.00	15.00	20.00	17.67	6.25
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	112.0	153.0	124.3	129.8	52.27
	2 ESP inlet	µg/dscm	(3) 2.61	215.1	300.1	257.6	539.8
	3 ESP outlet	µg/dscm	—	34.97	0.48	17.73	219.1
	12 Fabric filter inlet	µg/dscm	24.05	86.92	147.6	86.19	153.5
	10 Fabric filter outlet	µg/dscm	1.097	0.947	0.407	0.82	0.90
	4 Coal	mg/kg	5			5	NA
	13 Reinject fly ash	mg/kg	10.8	9.96	18.7	13.15	11.98
	7 Lime slurry (note 2)	mg/kg	ND 0.035	—	—	ND 0.035	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	ND 0.04	0.22	0.53	0.257	0.62
	9a ESP ash field 1	mg/kg	ND 2.3	6	6	4.38	5.31
9b ESP ash field 2-4	mg/kg	ND 2.3	6	6	4.38	5.31	
11 Fabric filter ash	mg/kg	ND 2.3	ND 2.3	—	ND 2.30	0.00	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

fairly good in most cases. Lead concentrations in the GSA inlet flue gas, reinjected fly ash, and coal are similar to those measured during series configuration tests. Measurements across the ESP and fabric filter indicate significant lead removal in the control devices. Lead concentrations at the fabric filter inlet and outlet are considerably lower during demonstration tests compared to baseline conditions, although the confidence interval for these measurements is relatively large. Lead concentration in the GSA cyclone solids is lower than that in the ESP and fabric filter solids, and concentrations in all process output solids are lower for demonstration tests compared to baseline.

Manganese

The results of manganese measurements for parallel configuration tests are shown in Table 5-33. Manganese was detected in all of the 28 baseline test samples and in all of the 30 demonstration test samples. Precision of the flue gas results is fair to low at most locations. Manganese was detected in 3 of 5 sample train field blanks, indicating the possibility of significant contamination or background bias. The mean manganese concentration in the field blanks is low, however, and significant only for samples collected at the ESP outlet and fabric filter outlet. Mean manganese concentrations in the flue gas at the GSA inlet, reinjected fly ash, and coal are slightly lower than those for series configuration tests. As with most of the other metals results, manganese concentrations at the ESP inlet and outlet are slightly elevated for demonstration tests compared to baseline; however, this difference may not be significant in light of the number of valid measurements at this location and the large confidence intervals. Manganese concentration in the fabric filter outlet flue gas is similar for demonstration and baseline tests in most instances. The concentration of manganese in the process output solids is slightly lower for demonstration tests compared to baseline.

Mercury

Table 5-34 shows mercury concentrations measured during parallel configuration tests. Mercury was detected in 13 of 28 baseline test samples and in 15 of 30 demonstration test samples, indicating only trace levels of mercury in the system. Nearly all the detected results occurred in the flue gas samples at generally low levels. Mercury was not detected in any of the sample train blanks, indicating the samples were free from any significant contamination, and other quality control results were acceptable. The precision of the flue gas measurements is fair in most instances, considering the low absolute concentrations. Mercury concentrations in the GSA inlet flue gas and coal are similar to series configuration test results; mercury was not detected in the

TABLE 5-33. MANGANESE RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	260.5	235.7	479.1	325.1	332.7
	3 ESP outlet	µg/dscm	7.19	12.64	23.85	14.56	21.10
	12 Fabric filter inlet	µg/dscm	376.3	807.0	878.6	687.3	675.0
	10 Fabric filter outlet	µg/dscm	5.51	4.38	3.36	4.42	2.67
	4 Coal	mg/kg	31			31	NA
	13 Reinject fly ash	mg/kg	68.5	70.8	89.3	76.2	28.33
	5 Cyclone solids	mg/kg	93.1	77.4	89.9	86.8	20.61
	9a ESP ash field 1	mg/kg	27.0	27.0	26.0	26.67	1.43
	9b ESP ash field 2-4	mg/kg	46.0	21.0	44.0	37.00	34.51
	11 Fabric filter ash	mg/kg	39.0	43.0	38.0	40.00	6.57
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	440.5	200.4	194.1	278.3	349.0
	2 ESP inlet	µg/dscm	(3) 45	449.2	580.1	514.6	831.7
	3 ESP outlet	µg/dscm	—	68.12	3.30	35.71	411.7
	12 Fabric filter inlet	µg/dscm	197.4	247.1	436.9	293.8	314.1
	10 Fabric filter outlet	µg/dscm	4.59	11.00	5.54	7.04	8.59
	4 Coal	mg/kg	24			24	NA
	13 Reinject fly ash	mg/kg	75.7	89.1	78.3	81.03	17.65
	7 Lime slurry (note 2)	mg/kg	5.44	—	—	5.44	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	68.4	61.2	51.2	60.27	21.46
	9a ESP ash field 1	mg/kg	23	17	12	17.33	13.68
9b ESP ash field 2-4	mg/kg	28	22	17	22.33	13.68	
11 Fabric filter ash	mg/kg	26	19	—	22.50	44.46	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

TABLE 5-34. MERCURY RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	ND 0.085	0.297	ND 0.086	0.13	0.30
	3 ESP outlet	µg/dscm	0.768	0.725	0.743	0.75	0.05
	12 Fabric filter inlet	µg/dscm	1.133	1.534	1.754	1.47	0.78
	10 Fabric filter outlet	µg/dscm	ND 0.037	1.436	3.125	1.53	3.84
	4 Coal	mg/kg	0.075			0.075	NA
	13 Reinjecting fly ash	mg/kg	ND 0.10	ND 0.10	ND 0.10	ND 0.1	0.00
	5 Cyclone solids	mg/kg	ND 0.10	ND 0.10	ND 0.10	ND 0.1	0.00
	9a ESP ash field 1	mg/kg	0.07	ND 0.03	ND 0.03	0.03	0.06
	9b ESP ash field 2-4	mg/kg	ND 0.03	ND 0.03	ND 0.03	ND 0.03	0.00
	11 Fabric filter ash	mg/kg	0.11	0.08	ND 0.03	0.07	0.10
	Demonstration	Flue gas (note 1): Run No.	—	1	2	3	
1 GSA inlet		µg/dscm	3.80	1.83	0.53	2.06	4.09
2 ESP inlet		µg/dscm	(3) 0.55	2.11	4.59	3.35	15.75
3 ESP outlet		µg/dscm	—	1.77	1.71	1.74	0.38
12 Fabric filter inlet		µg/dscm	2.10	1.51	1.90	1.84	0.75
10 Fabric filter outlet		µg/dscm	0.94	1.66	0.47	1.02	1.49
4 Coal		mg/kg	0.065			0.065	NA
13 Reinjecting fly ash		mg/kg	ND 0.10	ND 0.10	ND 0.10	ND 0.1	0.00
7 Lime slurry (note 2)		mg/kg	ND 0.1	—	—	ND 0.10	NA
14 Trim water		mg/kg	—	—	—	—	—
5 Cyclone solids		mg/kg	ND 0.10	ND 0.10	ND 0.10	ND 0.1	0.00
9a ESP ash field 1		mg/kg	ND 0.03	ND 0.03	ND 0.03	ND 0.03	0.00
9b ESP ash field 2-4		mg/kg	ND 0.03	ND 0.03	ND 0.03	ND 0.03	0.00
11 Fabric filter ash	mg/kg	ND 0.03	ND 0.03	—	ND 0.03	0.00	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

reinjecting fly ash or lime slurry. Mercury concentration at the ESP inlet was much higher for demonstration test conditions; the reason for this is not immediately apparent. The results could indicate a problem with the baseline ESP inlet results, which were below detection limits for two of the three runs in marked contrast to the all of the other measurements at this location and measurements made at the fabric filter inlet. Mean mercury concentrations at the ESP outlet were slightly lower for demonstration tests compared to baseline, and fabric filter outlet were slightly lower. These differences are probably not significant due to the large confidence intervals for these measurements. Mercury was below or slightly above the detection limits in all of the process output solids; there was no significant difference in demonstration and baseline samples that could be measured.

Nickel

Available nickel results for parallel configuration tests are presented in Table 5-35. Due to an analytical laboratory error, nickel was not determined in any of the flue gas samples and in several of the solid samples. Nickel concentrations in the coal and reinjected fly ash are slightly higher than in series configuration samples. Nickel concentration in the GSA solids is similar to the reinjected fly ash for baseline tests, but is considerably higher for demonstration tests. Nickel was detected at low levels in the lime slurry.

Selenium

In Table 5-36, selenium concentrations in parallel configuration test samples are shown. Selenium was detected in 19 of 28 baseline test samples, but in only 7 of 30 demonstration test samples. Selenium was not detected in any flue gas sample train field blanks, indicating the samples were free from significant contamination. Other quality control results are within acceptance limits. The precision of detected flue gas results is fair to low, since most detected levels are less than an order of magnitude above the detection limits. Selenium concentration in the GSA inlet flue gas was markedly lower than that measured during series configuration tests; however, results for the coal and reinjected fly ash are of similar magnitude or slightly higher. Selenium was above detection limits in only a few flue gas samples. Thus, the flue gas results are generally of little use for calculating selenium removal efficiencies across the ESP and fabric filter. In fact, baseline ESP removal efficiency for selenium is strongly negative, due to undetected

TABLE 5-35. NICKEL RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	1	2	4		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	-			-	-
	13 Reinject fly ash	mg/kg	20.10	22.80	17.40	20.1	6.71
	5 Cyclone solids	mg/kg	21.30	20.30	13.40	18.333	10.69
	9a ESP ash field 1	mg/kg	-	-	-	-	-
	9b ESP ash field 2-4	mg/kg	-	-	-	-	-
11 Fabric filter ash	mg/kg	-	-	-	-	-	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	-	-	-	-	-
	2 ESP inlet	µg/dscm	-	-	-	-	-
	3 ESP outlet	µg/dscm	-	-	-	-	-
	12 Fabric filter inlet	µg/dscm	-	-	-	-	-
	10 Fabric filter outlet	µg/dscm	-	-	-	-	-
	4 Coal	mg/kg	12			12	NA
	13 Reinject fly ash	mg/kg	19.1	17.2	22.5	19.6	6.67
	7 Lime slurry (note 2)	mg/kg	0.96			0.96	NA
	14 Trim water	mg/kg	-			-	-
	5 Cyclone solids	mg/kg	68.4	61.2	51.2	60.267	21.46
9a ESP ash field 1	mg/kg	-	-	-	-	-	
9b ESP ash field 2-4	mg/kg	-	-	-	-	-	
11 Fabric filter ash	mg/kg	-	-	-	-	-	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.

TABLE 5-36. SELENIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results						Mean	2.5% CC	
			A		B		C				
Baseline	Flue gas (note 1): Run No.	—	2		3		4				
	1 GSA inlet	µg/dscm	—		—		—		—	—	
	2 ESP inlet	µg/dscm	ND	0.18	ND	0.18	ND	0.19	ND	0.18	0.01
	3 ESP outlet	µg/dscm	20.25		11.43		29.81		20.50		22.84
	12 Fabric filter inlet	µg/dscm	ND	0.28	ND	0.27	17.54		5.94		24.76
	10 Fabric filter outlet	µg/dscm	ND	0.08	ND	0.08	ND	0.08	ND	0.08	0.00
	4 Coal	mg/kg	2						2	NA	
	13 Reinjectd fly ash	mg/kg	3.98		4.11		4.39		4.16		0.52
	5 Cyclone solids	mg/kg	8.10		18.30		10.30		12.23		13.34
	9a ESP ash field 1	mg/kg	5.00		4.90		7.80		5.90		4.09
	9b ESP ash field 2-4	mg/kg	9.00		ND	2.00	11.40		7.13		12.13
11 Fabric filter ash	mg/kg	15.60		14.20		8.40		12.73		9.48	
Demonstration	Flue gas (note 1): Run No.	—	1		2		3				
	1 GSA inlet	µg/dscm	9.85		ND	0.10	21.86		10.59		27.08
	2 ESP inlet	µg/dscm	ND (3)	0.17	ND	0.29	ND	0.30	ND	0.30	0.06
	3 ESP outlet	µg/dscm	—		ND	0.07	ND	0.06	ND	0.07	0.06
	12 Fabric filter inlet	µg/dscm	ND	0.10	ND	0.23	ND	0.28	ND	0.20	0.23
	10 Fabric filter outlet	µg/dscm	ND	0.07	ND	0.07	ND	0.06	ND	0.07	0.01
	4 Coal	mg/kg	2						2	NA	
	13 Reinjectd fly ash	mg/kg	2.73		4.11		3.46		3.43		1.72
	7 Lime slurry (note 2)	mg/kg	1.01		—		—		1.01		NA
	14 Trim water	mg/kg	—		—		—		—		—
	5 Cyclone solids	mg/kg	ND	0.10	ND	0.10	ND	0.10	ND	0.1	0.00
9a ESP ash field 1	mg/kg	ND	0.11	ND	0.11	ND	0.11	ND	0.11	0.00	
9b ESP ash field 2-4	mg/kg	ND	0.11	ND	0.11	ND	0.11	ND	0.11	0.00	
11 Fabric filter ash	mg/kg	ND	0.11	ND	0.11	—		ND	0.11	0.00	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

results at the ESP inlet that are much lower than detected results at the ESP outlet. The data indicate considerable caution should be exercised in applying these results.

Vanadium

Table 5-37 shows vanadium concentrations in samples collected during parallel configuration tests. Vanadium was detected in 20 of 28 baseline test samples and in 21 of 30 demonstration test samples. Vanadium was not detected in any flue gas sample train field blanks, indicating these samples were free from any significant contamination. Other quality control results are acceptable. Precision of the flue gas results is fair for most detected results. Compared to series configuration test results, vanadium concentration is slightly lower in the GSA inlet flue gas, similar in the coal, and slightly higher in the reinjected fly ash (all of these results are above the detection limits). Vanadium was not detected in most of the ESP outlet and fabric filter outlet samples.

5.4.4 HCl and HF Results - Parallel Configuration

HCl and chloride results for the parallel configuration tests are presented in Table 5-38. The precision and quality of the flue gas results is considered good. HCl concentrations in the GSA inlet flue gas, coal, reinjected fly ash, and lime slurry were similar to those measured for series configuration tests. The results of measurements under baseline conditions indicate no significant removal across the system. HCl was below detection limits in flue gas samples collected downstream of the GSA reactor/cyclone during demonstration tests, indicating significant HCl removal. Elevated chloride concentrations in process output solid samples is also seen for demonstration tests compared to baseline results, as expected based on HCl removal from the flue gas.

HF results for parallel configuration tests (Table 5-39) showed trends similar to series configuration tests. The precision of the baseline flue gas HF measurements is fair to low. Several results at the GSA inlet are low compared to the bulk of the measurements. Also, baseline HF concentration at the fabric filter inlet is very low, below the concentration measured at the fabric filter outlet. These measurements are intuitively suspect, although no definitive problems with any of the samples could be identified. The anomalous data indicate the baseline results should be used with considerable caution. HF concentrations in samples collected downstream of the GSA are below the detection limits, indicating significant removal across the GSA/cyclone.

TABLE 5-37. VANADIUM RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1): Run No.	—	2	3	4		
	1 GSA inlet	µg/dscm	—	—	—	—	—
	2 ESP inlet	µg/dscm	590	523	ND 25.70	375.4	766.2
	3 ESP outlet	µg/dscm	ND 9.81	19.5	ND 9.76	NDM 9.81	13.95
	12 Fabric filter inlet	µg/dscm	961	1653	1947	1520	1258
	10 Fabric filter outlet	µg/dscm	ND 11.02	ND 10.50	ND 11.01	ND 10.84	0.74
	4 Coal	mg/kg	30			30	NA
	13 Reinject fly ash	mg/kg	42.7	44.9	48.8	45.47	7.67
	5 Cyclone solids	mg/kg	47.5	43.4	46.6	45.83	5.35
	9a ESP ash field 1	mg/kg	ND 1.7	86.0	101.0	62.62	132.98
	9b ESP ash field 2-4	mg/kg	101.0	ND 1.7	116.0	72.62	154.32
11 Fabric filter ash	mg/kg	110.0	130.0	86.0	108.67	54.73	
Demonstration	Flue gas (note 1): Run No.	—	1	2	3		
	1 GSA inlet	µg/dscm	857	595	453	635.0	509.6
	2 ESP inlet	µg/dscm	(3) 84.99	905	1138	1022	1479
	3 ESP outlet	µg/dscm	—	113	ND 8.86	58.48	658.4
	12 Fabric filter inlet	µg/dscm	282	566	624	491.0	454.9
	10 Fabric filter outlet	µg/dscm	ND 9.180	ND 9.210	ND 8.910	ND 9.10	0.41
	4 Coal	mg/kg	47			47	NA
	13 Reinject fly ash	mg/kg	32.0	47.5	47.7	42.4	22.38
	7 Lime slurry (note 2)	mg/kg	2.21	—	—	2.21	NA
	14 Trim water	mg/kg	—	—	—	—	—
	5 Cyclone solids	mg/kg	23.6	24.4	20.0	22.67	5.82
9a ESP ash field 1	mg/kg	65.0	ND 1.7	ND 1.7	22.23	90.79	
9b ESP ash field 2-4	mg/kg	56.0	ND 1.7	ND 1.7	19.23	77.88	
11 Fabric filter ash	mg/kg	ND 1.7	53.0	—	26.93	325.9	

Notes:

- (1) Dry, corrected to 3% O₂.
- (2) Results of original sample analysis below detection limit. Analysis of single archive sample for test condition using more sensitive test method shown.
- (3) Acetone rinse sample broken during shipment. Excluded from average.

TABLE 5-38. HCL AND CHLORIDE RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results			Mean	2.5% CC
			A	B	C		
Baseline	Flue gas (note 1):						
	Run No.	—	2	3	4		
	1 GSA inlet	mg/dscm	17.9	23.0	25.9	22.3	10.1
	2 ESP inlet	mg/dscm	—	—	—	—	—
	3 ESP outlet	mg/dscm	—	—	—	—	—
	12 Fabric filter inlet	mg/dscm	24.9	34.4	21.5	26.9	16.6
	10 Fabric filter outlet	mg/dscm	24.6	23.7	26.3	24.9	3.3
	4 Coal	wt %	0.02			0.02	NA
	13 Reinjectd fly ash	mg/kg	3.0	5.6	3.9	4.2	3.3
	5 Cyclone solids	mg/kg	4.1	—	2.8	3.5	8.3
	9a ESP ash field 1	mg/kg	17	14	36	22	30
9b ESP ash field 2-4	mg/kg	7.4	5.0	ND 2.0	4.5	6.7	
11 Fabric filter ash	mg/kg	100	340	23	154	411	
Demonstration	Flue gas (note 1):						
	Run No.	—	1	2	3		
	1 GSA inlet	mg/dscm	17.8	24.8	26.7	23.1	11.6
	2 ESP inlet	mg/dscm	—	ND 0.013	ND 0.012	ND 0.012	0.004
	3 ESP outlet	mg/dscm	—	—	0.571	0.571	NA
	12 Fabric filter inlet	mg/dscm	ND 0.015	ND 0.014	—	ND 0.015	0.004
	10 Fabric filter outlet	mg/dscm	ND 0.011	ND 0.010	ND 0.010	ND 0.010	0.001
	4 Coal	wt %	0.02			0.02	NA
	13 Reinjectd fly ash	mg/kg	3.1	3.3	3.3	3.2	0.3
	7 Lime slurry	mg/L	28	28	28	28	0
	14 Trim water	mg/L	240	87	60	129	241
5 Cyclone solids	mg/kg	92	100	210	134	164	
9a ESP ash field 1	mg/kg	730	780	850	787	150	
9b ESP ash field 2-4	mg/kg	770	730	850	783	152	
11 Fabric filter ash	mg/kg	—	720	—	720	NA	

Notes:

(1) Reported as HCl, dry, corrected to 3% O₂.

TABLE 5-39. HF RESULTS - PARALLEL CONFIGURATION

	Location	Units	Run Results				Mean	2.5% CC	
			A	B	C				
Baseline	Flue gas (note 1):								
	Run No.	—	2	3	4				
	1 GSA inlet	mg/dscm	0.79	4.27	4.43	3.16	5.11		
	2 ESP inlet	mg/dscm	—	—	—	—	—		
	3 ESP outlet	mg/dscm	—	—	—	—	—		
	12 Fabric filter inlet	mg/dscm	0.77	0.77	0.49	0.67	0.40		
10 Fabric filter outlet	mg/dscm	1.17	1.17	4.53	2.29	4.82			
Demonstration	Flue gas (note 1):								
	Run No.	—	1	2	3				
	1 GSA inlet	mg/dscm	0.95	0.44	4.93	2.11	6.11		
	2 ESP inlet	mg/dscm	—	ND	0.04	ND	0.04	0.01	
	3 ESP outlet	mg/dscm	—	—	ND	0.03	ND	0.03	NA
	12 Fabric filter inlet	mg/dscm	ND	0.03	ND	0.04	ND	0.03	0.02
10 Fabric filter outlet	mg/dscm	ND	0.03	ND	0.03	ND	0.03	0.00	

Notes:

(1) Dry, corrected to 3% O₂.

6.0 MASS BALANCES, REMOVAL EFFICIENCY, AND EMISSION FACTORS

This section of the report presents results based on the basic measurement data presented in Section 5. The discussion is divided into three major subsections:

- Mass balances across the GSA/cyclone, ESP, fabric filter, and the entire system;
- Emission factors calculated for three conceptual process arrangements.
- Removal efficiency of the GSA process in three conceptual process arrangements;

6.1 Mass Balances

Mass balances across the whole GSA pilot plant and across the GSA reactor/cyclone, ESP, and baghouse were calculated for each of the four test conditions. Mass balances were calculated for total mass, trace metals, and chlorine. If the mass balance closure is within the project objectives, this imparts a degree of confidence to the test results and can be helpful in interpreting the results. In this report, the mass balance closure is defined as the percentage of total mass output to total mass input,

$$\text{Mass balance closure, \%} = 100 \times (\text{total mass output})/(\text{total mass input})$$

A mass balance closure of 100 percent indicates that the amount of mass measured leaving the system equals the amount measured entering the system (i.e., perfect closure). Detailed results of the mass balance calculations, example calculations, and specific assumptions used for data averaging and substitution are provided in Appendix C for each test condition. The following discussion presents a summary of the mass balance procedures and major results.

6.1.1 Mass Balance Procedures

Control Volumes

Mass balances were calculated across four distinct control volumes:

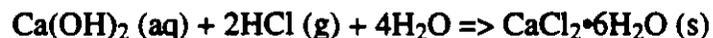
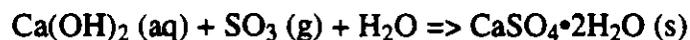
- GSA reactor and cyclone, as a single unit;

- ESP;
- Fabric filter;
- Entire system.

Figure 6-1 defines the control volumes used for series and parallel configurations. All of the streams crossing the control volume boundary were included in the calculations. The only difference between the series configuration and parallel configuration control volumes is in how the ESP balance is handled. Since the fabric filter slipstream take-off is upstream of the ESP outlet sampling point in the series configuration, the fabric filter inlet measurements must be added to the ESP outlet measurements to complete the ESP balance. Similarly for the parallel configuration, the fabric filter inlet measurements must be subtracted from the ESP inlet measurements.

Calculated Mass Flow Rates

It was not possible to directly measure the mass of solids collected in the GSA, ESP, and baghouse. Therefore, these streams were calculated by difference between the measured inputs and outputs. In addition to the amount of solids entering the system directly in the input streams, solids were generated during demonstration tests by the reaction of added lime with SO₂, SO₃, and HCl to form calcium sulfite, calcium sulfate, and calcium chloride, respectively:

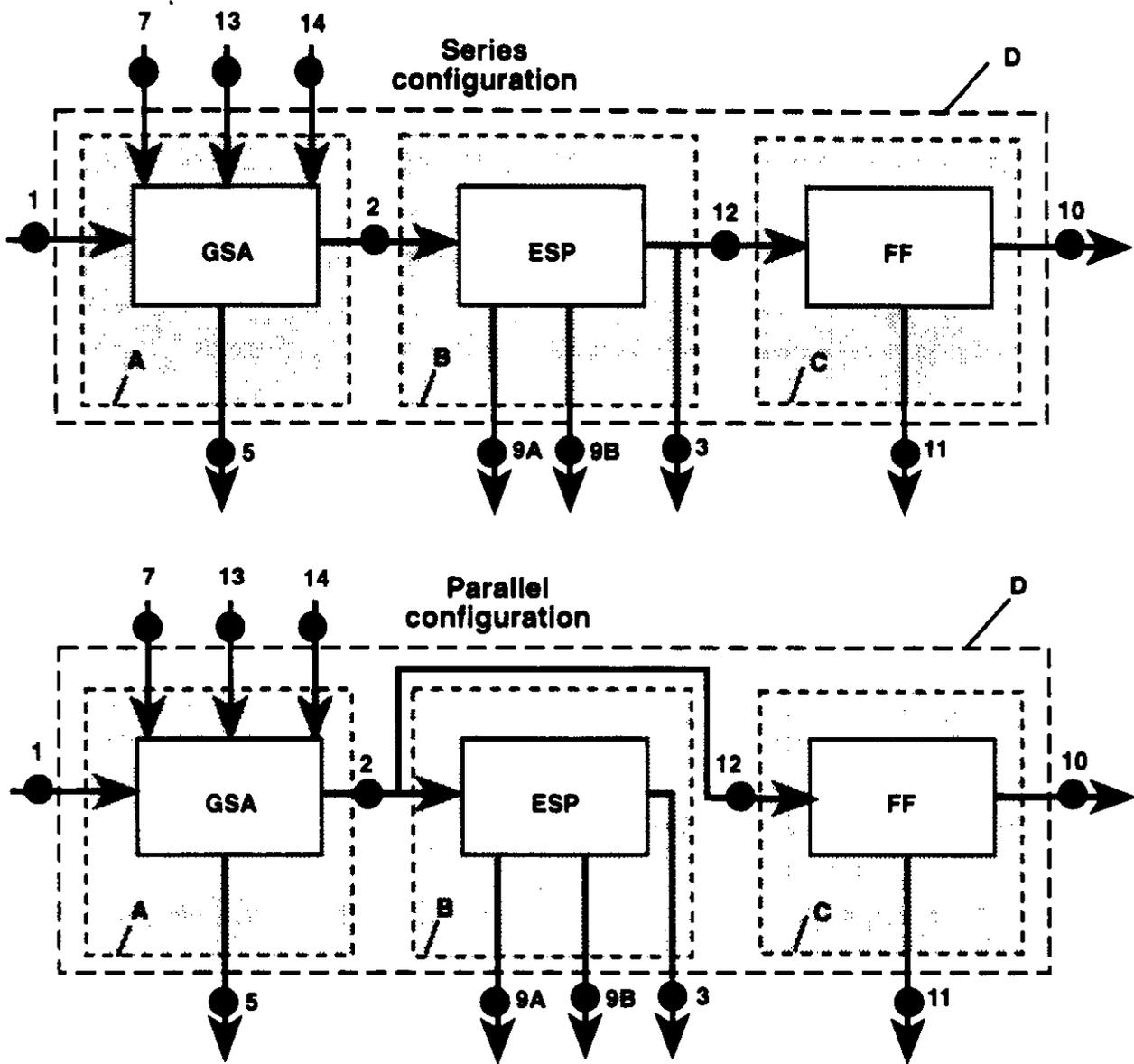


The solids generated by the reaction of SO₂ and lime were calculated based on flue gas flow rate, molecular weight, and SO₂ measurements at the inlet and outlet of the device. Example calculations are provided in Appendix C. First, the number of moles of SO₂ removed were calculated. Then, the incremental solids generated per mole of SO₂ removed was calculated as follows:

Solids input: 1 mole Ca(OH)₂ x 74.1 g/mole = 74.1 g Ca(OH)₂

Solids output: 1 mole CaSO₃•1/2H₂O (s) x 129.15 g/mole = 129.14 g CaSO₃•1/2H₂O

Solids generated: (129.14 g CaSO₃•1/2H₂O) - (74.1 g Ca(OH)₂) = 55.05 g



Legend
 A - GSA reactor/cyclone control volume
 B - ESP control volume
 C - Fabric filter control volume
 D - System control volume

Sampling Locations
 1 - GSA inlet flue gas
 2 - ESP inlet flue gas
 3 - ESP outlet flue gas
 5 - GSA cyclone solids
 7 - Lime slurry
 9A - ESP hopper solids, field 1
 9B - ESP hopper solids, fields 2-4
 10 - Fabric filter outlet flue gas
 11 - Fabric filter hopper solids
 12 - Fabric filter inlet flue gas
 13 - Re-injected fly ash
 14 - Trim water

Figure 6-1. Control volumes used for mass balances.

This amount was added to the difference between solids in the process inputs and measured outputs when calculating the solids removed in the GSA, ESP, and baghouse. SO₃ concentration was not measured during these tests but is typically about 0.25 percent of SO₂ concentration when firing eastern coals. HCl was measured and was found to be less than 1 percent of the SO₂ mass in the system. Because the mass of SO₃ and HCl are much less than that of SO₂, the solids formed by SO₃ and HCl reaction were neglected in this analysis. For baseline conditions, solids generation was neglected even though some flue gas measurements indicated SO₂ removal. This was considered to be measurement error rather than true SO₂ removal; since no lime was added to the system during baseline tests, the calculated solids generation was neglected.

Elemental mass balances — i.e., for trace metals and chlorine — were performed in a similar manner using laboratory results for each stream and measured or calculated stream flow rate to calculate the mass flow of each element. The calculated mass flow rate of each element is presented in Appendix C for each of the process streams.

Data Averaging and Substitution

The final consideration in performing the mass balance calculations is measurements that were not made simultaneously with the remaining measurements in a data set. The following procedures were used in developing the mass balances:

- Averaging of elemental mass flows - When averaging results of individual runs that were all ND, if the average concentration in the sample was flagged NDM, the mass flow rate was also flagged NDM. Average elemental mass flow rates were not flagged NDM unless the average concentration was flagged NDM. If the average mass flow rate was flagged NDM, the normal averaging procedures were used (i.e., one-half of the non-detects was used with detected values in the average).
- If fewer than three full runs were obtained at a particular location:
 - If two valid runs were obtained, the average of the two valid runs was substituted for the missing run;
 - If one valid run was obtained, no data were substituted for the missing runs;

- If a make-up run was performed for a run that was invalidated and the make-up run was performed on the same day as a planned run of the same type at the same location, the make-up run data were substituted for the invalidated run.

For example, for the series configuration demonstration tests, the initial trace metals run at the ESP inlet was invalidated and repeated on the third test day. When this occurred, the data from the repeat measurement was substituted for the original data. For baseline tests with both series and parallel configurations, the first day of testing was invalidated due to process conditions (see Section 5.1). Repeat flue gas measurements were made on both the second and third day of testing. This resulted in two sets of process data that were combined with three sets of flue gas data. SO₂ and O₂ results were taken for test periods corresponding to Method 29 trace metals test runs.

6.1.2 Expected and Measured Element Concentrations at GSA Inlet

Because the GSA pilot plant utilizes a slipstream of the total flue gas generated by Shawnee Unit 9, the coal could not be included directly in the mass balance calculations. To provide an indication of whether the measured concentrations at the GSA inlet are commensurate with the coal characteristics, the coal analyses were used to calculate expected fly ash, trace element, and HCl concentrations at the GSA inlet. Table 6-1 compares the expected concentration to the measured concentration at the GSA inlet, using an average of all four coal analyses and all nine GSA inlet measurements. A portion of the fly ash produced in Unit 9 is removed in the mechanical collector upstream of the slipstream take-off. Some of the fly ash is re-injected into the GSA pilot plant to simulate input conditions corresponding to the boiler air preheater outlet. The table also shows the equivalent concentration of re-injected fly ash and its elements in the GSA inlet flue gas, and the sum of this plus the measured concentration in the GSA inlet flue gas. A pseudo-mass balance closure, defined as the total concentration at the GSA inlet relative to the theoretical concentration from the coal, is also shown on the table.

Table 6-1 shows that total ash entering the GSA system is 78 percent of that expected based on total ash in the coal. This is quite reasonable since typically 10 to 30 percent of mineral matter in the coal exits the boiler as bottom ash (and economizer ash if so equipped) rather than as fly ash. For metals that are not volatile and also end up in the bottom ash, this same degree of closure would be expected. The measured concentrations of arsenic and cadmium fall within 50 to 150 percent of the expected value, which is the elemental mass balance objective. All of the other

TABLE 6-1. COMPARISON OF EXPECTED AND MEASURED ASH, TRACE METALS, AND HCl AT GSA INLET

Parameter	Units (1)	GSA inlet	Reinjected fly ash (2)	Total inlet	Coal (3)	Mass Balance (6)	
Ash (4)	mg/dscm	3503	6653	10156	13078	78%	
Antimony	µg/dscm	2.7	ND	0.5	3.2	64.2	L 5%
Arsenic	µg/dscm	223		340	564	549	103%
Barium	µg/dscm	304		870	1174	25181	L 5%
Beryllium	µg/dscm	-		-	-	107.1	-
Cadmium	µg/dscm	7.0		2.3	9.3	8.4	110%
Chromium	µg/dscm	380		207	588	1913	L 31%
Cobalt	µg/dscm	58		38	97	455	L 21%
Lead	µg/dscm	119		114	234	602	L 39%
Manganese	µg/dscm	456		573	1030	3098	L 33%
Mercury (5)	µg/dscm	1.7	ND	0.7	2.4	8.8	L 27%
Nickel	µg/dscm	-		-	-	1114	-
Selenium	µg/dscm	75		22	98	214	L 46%
Vanadium	µg/dscm	770		256	1025	3916	L 26%
HCl	mg/dscm	22.4		-	22.4	21.7	103%

L = mass balance less than 50%; H = mass balance greater than 150%.

- (1) Concentration on dry basis, 3% O₂.
- (2) Equivalent concentration in flue gas based on average GSA inlet flow.
- (3) Equivalent concentration in flue gas based on average coal heating value and composition.
- (4) Assumes all particulate at GSA inlet is ash.
- (5) Coal analysis by ASTM D3684.
- (6) Total inlet divided by coal.

measured metals concentrations entering the GSA were low relative to expected concentrations based on coal analysis results. Antimony and barium concentrations were 5 percent of the expected value. Average concentrations of chromium, cobalt, lead, manganese, mercury, selenium, and vanadium ranged from 21 to 46 percent. The results suggest either the coal analysis results are biased high, or the GSA inlet measurements are biased low. Except for antimony and mercury, most of the individual GSA inlet flue gas results were above the method detection limits. HCl concentration measured at the GSA inlet is in very close agreement with theoretical levels based on the coal analyses, averaging 103 percent of the expected value.

6.1.3 Mass Balances - Series Configuration

Total Mass Balance - Series Configuration

Table 6-2 presents the total flow rate of flue gas and particulate matter for each of the process streams for baseline and demonstration tests. The basis of each value, i.e., calculated or measured, is indicated on the table. For each stream, the mean value and 2.5 percent confidence coefficient are shown with the results from each run. From these results, a mass balance for total mass entering and leaving the system and its components can be calculated. The mass balance closure for total mass is also shown on Table 6-2. Mass balance closure around the entire GSA system ranges from 86 to 94 percent for all baseline and demonstration test runs. This is considerably better than the objective of 70 to 130 percent for total mass. However, because the solid stream outputs from the GSA, ESP, and baghouse were calculated by difference between inputs and other outputs, the mass balances may be artificially forced towards closure. A true rigorous mass balance might not show the same degree of closure if all of the solids streams were measured directly.

Mass balance closure around the GSA reactor/cyclone control volume ranged from 91 to 108 for all series configuration tests and averaged 106 and 99 percent for baseline and demonstration tests, respectively. Closure around the ESP was generally low, ranging from 84 to 93 for all series configuration tests and averaging 85 and 88 percent for baseline and demonstration tests, respectively. Closure around the fabric filter was generally high, ranging from 108 to 118 percent for all series configuration tests and averaging 115 and 111 percent for baseline and demonstration tests, respectively. Assuming all streams are measured, low closure (i.e., closure less than 100 percent) can be due to either a low bias in the output measurements or a high bias in the input measurements. Conversely, high closure (i.e., closure greater than 100 percent) can be

TABLE 6-2. TOTAL MASS BALANCE, SERIES CONFIGURATION

Process Stream	Units	Run results			Mean	2.5% CC	Basis
		A	B	C			
Baseline							
Flue gas mass flows: Run No.	—						
1 GSA inlet, gas total	kg/hr	45777	46482	45883	46047	944	M
Particulate	kg/hr	134	81.8	130	115	72	M
2 ESP inlet	kg/hr	47350	49821	49807	48993	3534	M
Particulate	kg/hr	123	137	64.7	108	95	M
3 ESP outlet	kg/hr	35391	35624	35392	35469	333	M
Particulate	kg/hr	0.836	0.911	0.919	0.889	0.114	M
12 Fabric filter inlet	kg/hr	6388	6544	6211	6381	414	M
Particulate	kg/hr	0.211	0.213	0.107	0.177	0.150	M
10 Fabric filter outlet	kg/hr	7366	7300	7350	7339	86	M
Particulate	kg/hr	0.056	0.028	0.059	0.048	0.042	M
13 Reinjecting fly ash	kg/hr	183	182	180	182	4	M
5 Cyclone solids	kg/hr	193	127	245	189	147	C
9a ESP ash field 1	kg/hr	109	121	57	96	85	C
9b ESP ash field 2-4	kg/hr	13.1	14.5	6.8	11.5	10.2	C
11 Fabric filter ash	kg/hr	0.154	0.185	0.048	0.129	0.178	C
Mass balance closure							
GSA reactor/cyclone	%	103	107	108	106	7	C
ESP	%	88	85	84	85	6	C
Fabric filter	%	115	112	118	115	8	C
System	%	94	93	93	93	2	C
Demonstration							
Flue gas mass flows:							
1 GSA inlet	kg/hr	46781	47205	46014	46667	1500	M
Particulate	kg/hr	83.2	91.1	96.4	90.3	16.6	M
2 ESP inlet	kg/hr	51603	47267	43690	47520	9844	M
Particulate	kg/hr	378	269	304	317	138	M
3 ESP outlet	kg/hr	36271	33929	33398	34533	3798	M
Particulate	kg/hr	0.398	0.380	0.218	0.332	0.246	M
12 Fabric filter inlet	kg/hr	7654	7404	7335	7464	417	M
Particulate	kg/hr	0.120	0.072	0.048	0.080	0.092	M
10 Fabric filter outlet	kg/hr	8292	8363	8276	8310	115	M
Particulate	kg/hr	0.036	0.029	0.028	0.031	0.010	M
13 Reinjecting fly ash	kg/hr	198	201	198	199	5	M
7 Lime slurry	kg/hr	1056	1129	1149	1111	121	M
14 Trim water	kg/hr	1333	1210	1199	1247	185	M
5 Cyclone solids	kg/hr	335	460	432	409	163	C
9a ESP ash field 1	kg/hr	339	243	273	285	122	C
9b ESP ash field 2-4	kg/hr	40.7	29.1	32.7	34.2	14.7	C
11 Fabric filter ash	kg/hr	0.315	0.086	0.173	0.191	0.287	C
Mass balance closure							
GSA reactor/cyclone	%	106	96	91	98	18	C
ESP	%	85	88	93	89	10	C
Fabric filter	%	108	113	113	111	7	C
System	%	92	86	87	88	7	C

Notes:

M = measured directly

C = calculated

due to either a high bias in the output measurements or a low bias in the input measurements. The fact that the ESP closure is low and the fabric filter closure is high suggests that the fabric filter inlet measurements may be biased low. Thus, series configuration removal efficiencies for the fabric filter also may be biased low. Since the particulate concentration is relatively low and similar at both the ESP outlet and fabric filter inlet, the closure discrepancy is most likely due to errors in the gas flow measurements. High closure can also be caused by another stream entering the system that was not measured, such as infiltrated air resulting from the low pressure in the system. O₂ concentration measurements at various points in the system (see Section 5) indicate air infiltration on the order of 4 percent (of total dry flue gas entering) in the GSA reactor/cyclone, 7 percent in the ESP, and 2 percent in the fabric filter. Therefore, the low closure around the ESP may be underestimated and the high closure around the fabric filter may be slightly overestimated.

Trace Metals and Chlorine Mass Balances - Series Configuration

Tables 6-3 and 6-4 present trace metals mass balance closure for trace metals and chlorine during baseline and demonstration test conditions, respectively. The tables show the mean closure, 2.5 percent confidence coefficient, and individual run results for the GSA reactor/cyclone, ESP, fabric filter, and the whole system. The objective for trace element and chlorine mass balance closure is 50 to 150 percent. Trace metals mass balances across the whole system meet this goal for 33 percent of the results. Barium, cobalt, and manganese closures across the whole system satisfy the mass balance objective. Closure across the whole system of all other metals except antimony is below 50 percent, indicating either a low bias in the output results or a high bias in the input results. Antimony mass balances are very high primarily because most of the analytical results for the ESP ash (locations 9A and 9B), which dominate the output mass flow, are below detection limits. Non-detected results also contribute to many of the other closure results that are outside the desired closure range. Beryllium and nickel are not included in the mass balance analysis because most of the data are missing due to analytical laboratory error (see Section 5). Chlorine closure across the whole system is good for baseline tests, ranging from 92 to 163 percent and averaging 122 percent. Chlorine closure is low for demonstration tests, averaging 45 percent. This is because of the large number of flue gas results downstream of the GSA reactor cyclone below detection limits, discussed later.

The best trace metals mass balances were achieved across the GSA reactor/cyclone, with closure objectives achieved for 73 percent of baseline tests and 76 percent of demonstration tests. This is likely due to the relatively high concentrations of metals in the flue gas, which are generally

TABLE 6-3. MASS BALANCE CLOSURE SUMMARY
FOR SERIES CONFIGURATION, BASELINE TESTS

	Mass balance closure, %						Mean	2.5% CC	
	A		B		C				
GSA reactor/cyclone									
Antimony	146	H	677	H	1476	H	766	1664	
Arsenic	53		107		93		85	69	
Barium	74	H	283		131	H	163	268	
Cadmium	88		119		89		99	44	
Chromium	69	H	163		137		123	120	
Cobalt	133	H	195	H	174	H	168	79	
Lead	61	H	211		108		127	191	
Manganese	144		125		120		129	31	
Mercury	83	H	212		71		122	194	
Selenium	101		92		97		97	10	
Vanadium	94	H	160		111		121	85	
Chlorine (as chloride)	90		107		135		111	56	
ESP									
Antimony	H	1957	H	2387	H	505	H	1616	2450
Arsenic	L	40	L	40	L	15	L	32	36
Barium	L	25	L	28	L	15	L	23	17
Cadmium	L	40	L	44	L	21	L	35	30
Chromium	L	26	L	32	L	13	L	24	25
Cobalt	L	16	L	23	L	9	L	16	18
Lead	L	24	L	22	L	9	L	18	20
Manganese	L	20	L	41	L	12	L	24	38
Mercury	L	26	L	21	L	16	L	21	13
Selenium	L	55	L	39	L	41	L	45	22
Vanadium	L	24	L	30	L	1	L	18	37
Chlorine (as chloride)		121		78	H	209		136	166
Fabric Filter									
Antimony	H	333	H	356		142	H	277	292
Arsenic	L	17	L	42	L	12	L	23	40
Barium	L	12	L	14	L	10	L	12	5
Cadmium	H	374	H	275	H	335	H	328	124
Chromium	L	15	L	17	L	13	L	15	5
Cobalt	L	34	L	29	L	17	L	27	21
Lead	L	37		53	L	48	L	46	21
Manganese	L	37		56	L	29	L	41	35
Mercury		145	H	216	H	170	H	177	89
Selenium	L	19	L	11	L	27	L	19	20
Vanadium		50		67	L	37		51	36
Chlorine (as chloride)		107	H	168	L	15		97	190
Total System									
Antimony	H	2570	H	7486	H	3564	H	4540	6457
Arsenic	L	31		54	L	42	L	42	29
Barium	L	37		116		58		70	101
Cadmium	L	37		54	L	20	L	37	42
Chromium	L	29		69		50	L	49	49
Cobalt	L	44		65		51		53	27
Lead	L	17		52	L	17	L	29	50
Manganese		90		81		79		84	14
Mercury	L	32		57	L	23	L	38	43
Selenium		70	L	47		63		60	29
Vanadium	L	38		60	L	29	L	42	40
Chlorine (as chloride)		110		92	H	163		122	91

L = low closure (less than 50 percent)

H = high closure (greater than 50 percent)

TABLE 6-4. MASS BALANCE CLOSURE SUMMARY
FOR SERIES CONFIGURATION, DEMONSTRATION TESTS

	Mass balance closure, %					
	A	B	C	Mean	2.5% CC	
GSA reactor/cyclone						
Antimony	L 40	87	L 39	55	68	
Arsenic	85	L 33	95	71	83	
Barium	H 217	H 150	H 189	H 185	83	
Cadmium	136	63	96	98	91	
Chromium	123	104	120	116	25	
Cobalt	141	105	144	130	53	
Lead	90	59	80	76	39	
Manganese	H 194	H 190	142	H 175	72	
Mercury	87	L 33	60	60	67	
Selenium	103	128	95	109	42	
Vanadium	97	91	98	95	9	
Chlorine (as chloride)	L 4	L 5	L 7	L 6	4	
ESP						
Antimony	H 13793	H 4668	H 29504	H 15988	31210	
Arsenic	99	141	139	126	59	
Barium	58	L 49	L 4	L 37	72	
Cadmium	88	H 155	91	111	94	
Chromium	L 41	55	60	52	24	
Cobalt	L 10	L 12	L 48	L 23	53	
Lead	L 35	L 46	L 38	L 39	15	
Manganese	L 36	L 39	54	L 43	24	
Mercury	L 21	72	L 19	L 37	75	
Selenium	L 1	L 7	L 44	L 17	58	
Vanadium	L 4	75	63	L 47	94	
Chlorine (as chloride)	H 94068	H 91614	H 106113	H 97265	19278	
Fabric Filter						
Antimony	H 514	H 186	H 336	H 345	408	
Arsenic	H 431	H 1032	H 977	H 813	826	
Barium	57	L 42	L 47	L 49	19	
Cadmium	H 1025	H 276	H 279	H 526	1072	
Chromium	98	L 41	55	65	73	
Cobalt	L 43	L 31	L 38	L 37	15	
Lead	79	L 31	59	56	61	
Manganese	H 467	102	H 450	H 340	512	
Mercury	126	L 8	H 190	108	229	
Selenium	60	L 15	61	L 45	65	
Vanadium	54	L 34	L 47	L 45	25	
Chlorine (as chloride)	H 356	143	93	H 197	347	
Total System						
Antimony	H 1896	H 3127	H 2720	H 2581	1559	
Arsenic	84	L 36	105	75	88	
Barium	H 163	107	72	114	115	
Cadmium	128	98	89	105	52	
Chromium	67	75	85	76	22	
Cobalt	L 33	L 38	97	56	88	
Lead	L 37	L 29	L 32	L 33	11	
Manganese	121	H 158	116	131	57	
Mercury	L 35	L 29	L 26	L 30	12	
Selenium	L 1	L 9	L 42	L 17	54	
Vanadium	L 22	76	71	56	74	
Chlorine (as chloride)	L 47	L 39	L 52	L 46	17	

L = low closure (less than 50 percent)

H = high closure (greater than 50 percent)

well above the method detection limits (except antimony). Average closure for baseline conditions meets the objective for all metals except antimony, barium, and cobalt. For demonstration conditions, average closure meets the objective for all metals except barium and manganese. Chlorine closure around the GSA is excellent for baseline conditions but low for demonstration conditions. This feature of the chlorine results prevails around the ESP and fabric filter also.

Average closure around the ESP for all trace metals except antimony ranges from 13 to 38 percent during baseline tests, with most closures in the range of 18 to 21 percent. Chlorine closure satisfied the mass balance objective for baseline conditions. Demonstration test results were better (except for chlorine which was much worse), with 39 percent of the results meeting the project objectives. Average closure during demonstration tests for arsenic, cadmium, and chromium was between 50 and 150 percent. The average closure around the ESP for other metals ranges from 17 to 47 percent. In almost every case, the mass balance closure around the ESP is low. Since most of the test results are above detection limits in most of the samples and since closure around the GSA reactor/cyclone is generally good, this suggests one or more of the output measurements (hopper ash, ESP outlet flue gas, fabric filter inlet flue gas) may be biased low.

Mass balance closure results for the fabric filter are almost a mirror image of the ESP results, with most of the metals closures greater than 100 percent. Closure is within 50 to 150 percent in 27 percent of baseline metals tests and 30 percent of demonstration metals tests. Average closure around the fabric filter during baseline tests for lead and manganese is between 50 and 150 percent. The average baseline test closure around the fabric filter for other metals ranges from 12 to 51 percent, except for antimony, cadmium, and mercury. Baseline closure for those metals is relatively high. Mercury closure is high for these cases because of two of the three mercury results at the fabric filter inlet were below detection limits, in contrast to results at the ESP outlet (essentially the same flue gas stream and measured simultaneously) which were an order of magnitude higher. This indicates that baseline fabric filter inlet mercury results are very probably biased low. Average closure around the fabric filter satisfied the mass balance objectives for chlorine and vanadium during baseline tests and for chromium, lead, and mercury during demonstration tests.

6.1.4 Mass Balances - Parallel Configuration

Total Mass Balance - Parallel Configuration

Table 6-5 summarizes the balance of total mass for the parallel configuration tests. The overall mass balance closure across the whole system satisfies the mass balance objective in all cases, ranging from 90 to 93 percent. Closure ranges from 105 to 111 percent across the GSA reactor/cyclone, 78 to 83 percent across the ESP, and 107 to 122 percent across the fabric filter. All of the results satisfied the objective for total mass balance closure (70 to 130 percent).

Trace Metals and Chlorine Mass Balances - Parallel Configuration

Tables 6-6 and 6-7 summarize mass balance closures for trace metals and chlorine during parallel configuration tests. Beryllium and nickel are not included in the mass balance analysis because most of the data are missing due to analytical laboratory error (see Section 5). The objective for elemental mass balance closure (50 to 150 percent) is satisfied across the whole system for 75 percent of baseline tests. Those cases that do not meet the objective generally have low closure, except for antimony and arsenic. Average baseline mass balances across the whole system meet the closure objective for all elements except antimony and lead. The baseline mercury balance was only slightly below the objective. Demonstration test results are less satisfactory - 33 percent of demonstration test results meet the mass balance objectives. Average demonstration test closures for chromium, manganese, mercury, and vanadium satisfy the mass balance objective. Average demonstration test closures for arsenic, barium, cadmium, and cobalt are high, ranging from 183 to 236 percent, while those for lead and selenium are low (21 and 4 percent, respectively). Antimony closure is very high in both baseline and demonstration tests primarily because of the high detection limits realized for the ESP ash (locations 9A and 9B), which dominates the output mass flow. Chlorine mass balances were not calculated because not enough data are available.

Mass balance closure across the GSA reactor/cyclone was generally good, with 78 percent of baseline test results and 52 percent of demonstration test results satisfying the mass balance objective. Average baseline mass balance closures satisfied the objective for all metals except antimony and mercury. Average mercury mass balance was only slightly below the objective. The average mass balance closures across the GSA cyclone/reactor for demonstration tests meet the

TABLE 6-5. TOTAL MASS BALANCE, PARALLEL CONFIGURATION

Process Stream	Units	Mass flow rate			Mean	2.5% CC	Basis
		A	B	C			
Baseline							
Flue gas mass flows:							
1 GSA inlet	kg/hr	(3) 44464	(3) 45173	(3) 44732	44790	890	M
Particulate	kg/hr	(1) 100	(1) 100	(1) 100	100	0	C
2 ESP inlet	kg/hr	47388	49821	49849	49019	3510	M
Particulate	kg/hr	99.8	75.9	37.5	71.1	78.2	M
3 ESP outlet	kg/hr	33790	34220	33778	33929	626	M
Particulate	kg/hr	0.937	0.830	0.994	0.920	0.207	M
12 Fabric filter inlet	kg/hr	6498	6321	6557	6459	305	M
Particulate	kg/hr	20.8	14.9	18.2	18.0	7.2	M
10 Fabric filter outlet	kg/hr	7482	7690	7895	7689	513	M
Particulate	kg/hr	0.046	0.051	0.049	0.049	0.006	M
13 Reinjectd fly ash	kg/hr	189	188	182	186	9	M
5 Cyclone solids	kg/hr	189	212	245	216	69	C
9a ESP ash field 1	kg/hr	69.8	53.7	16.3	46.6	68.1	C
9b ESP ash field 2-4	kg/hr	8.36	6.44	1.96	5.58	8.16	C
11 Fabric filter ash	kg/hr	20.7	14.9	18.1	17.9	7.3	C
Mass balance closure							
GSA reactor/cyclone	%	107	110	111	109	6	C
ESP	%	83	79	78	80	6	C
Fabric filter	%	115	122	120	119	9	C
System	%	93	93	93	93	1	C
Demonstration							
Flue gas mass flows:							
1 GSA inlet	kg/hr	46052	46205	47316	46525	1714	M
Particulate	kg/hr	99.4	101	98.3	100	3.2	M
2 ESP inlet	kg/hr	52404	51074	51747	51742	1652	M
Particulate	kg/hr	498	(2) 431	364	431	166	M,C
3 ESP outlet	kg/hr	35538	(2) 35390	35243	35390	366	M,C
Particulate	kg/hr	0.22	(2) 6.83	13.4	6.83	16.4	M,C
12 Fabric filter inlet	kg/hr	8026	7871	7596	7831	541	M
Particulate	kg/hr	46.2	28.5	49.7	41.5	28.1	M
10 Fabric filter outlet	kg/hr	8600	8478	8783	8620	381	M
Particulate	kg/hr	0.042	0.033	0.022	0.032	0.025	M
13 Reinjectd fly ash	kg/hr	194	198	199	197	7	M
7 Lime slurry	kg/hr	1416	1424	1517	1452	140	M
14 Trim water	kg/hr	1034	1036	966	1012	99	M
5 Cyclone solids	kg/hr	329	404	582	438	323	C
9a ESP ash field 1	kg/hr	404	356	271	344	167	C
9b ESP ash field 2-4	kg/hr	48.4	42.7	32.5	41.2	20.0	C
11 Fabric filter ash	kg/hr	47.4	30.2	51.2	42.9	27.9	C
Mass balance closure							
GSA reactor/cyclone	%	109	106	105	107	5	C
ESP	%	80	82	80	81	3	C
Fabric filter	%	107	108	116	110	12	C
System	%	92	91	90	91	3	C

Notes:

M = measured directly

C = calculated

(1) No sampling at this location was performed. Average of all data from other tests at this location substituted.

(2) Average of runs A and C substituted for missing data.

(3) Flows from Method 26A HCl runs at GSA inlet.

TABLE 6-6. MASS BALANCE CLOSURE SUMMARY
FOR PARALLEL CONFIGURATION, BASELINE TESTS

	Mass balance closure, %								
	A	B	C	Mean	2.5% CC				
GSA reactor/cyclone									
Antimony	H	872	H	578	H	709	H	720	366
Arsenic		103		75		86		88	35
Barium		82		116		138		112	69
Cadmium		118		77		71		88	64
Chromium		126		78		103		102	59
Cobalt	H	152		117		116		128	50
Lead		88		99		121		103	42
Manganese		129		97		106		111	40
Mercury	L	46		51	L	46	L	48	7
Selenium	L	47		117		75		80	88
Vanadium	L	30		83		84		66	77
Chlorine (as chloride)		105		111		102		106	12
ESP									
Antimony	H	303		149	H	461	H	304	387
Arsenic		88	L	35	H	522	H	215	663
Barium	L	-8	L	8	L	3	L	1	21
Cadmium	L	36	L	25		148		70	168
Chromium	L	22	L	9		56	L	29	60
Cobalt	L	20	L	14		59	L	31	61
Lead	L	33	L	12	L	32	L	26	30
Manganese	L	19	L	12		56	L	29	59
Mercury	L	-288	L	-578	H	439	L	-142	1301
Selenium	L	-1637	H	11598	H	13131	H	7697	20173
Vanadium	L	-83	L	3		67	L	-4	186
Chlorine (as chloride)		73		72		74		73	2
Fabric Filter									
Antimony	H	161	H	281	H	261	H	234	159
Arsenic		114	H	347	H	374	H	278	355
Barium	L	1	L	2	L	3	L	2	3
Cadmium	H	153	H	345	H	167	H	221	265
Chromium	L	29	L	48	L	34	L	37	24
Cobalt	L	30	L	49	L	28	L	36	29
Lead	L	19	L	25	L	19	L	21	10
Manganese	L	25	L	46	L	27	L	32	28
Mercury	H	207	L	43		139		130	204
Selenium	H	268	H	23318	H	26764	H	16783	35789
Vanadium	L	25	L	49	L	40	L	38	30
Chlorine (as chloride)		119		120	H	155		131	51
Total System									
Antimony	H	2118	H	1065	H	2810	H	1998	2183
Arsenic		98		72	H	242		137	228
Barium		64		67		91		74	37
Cadmium		59	L	40		93		64	67
Chromium		51	L	29		70		50	51
Cobalt		76		64		83		74	24
Lead	L	31	L	22		58	L	37	47
Manganese		84		72		91		83	24
Mercury		82		61		76		73	27
Selenium		83		139		100		107	72
Vanadium		52	L	35		63		50	35
Chlorine (as chloride)		85		91		87		88	8

**TABLE 6-7. MASS BALANCE CLOSURE SUMMARY
FOR PARALLEL CONFIGURATION, DEMONSTRATION TESTS**

	Mass balance closure, %				
	A	B	C	Mean	2.5% CC
GSA reactor/cyclone					
Antimony	H 277	H 292	H 199	H 256	124
Arsenic	126	117	107	117	23
Barium	H 426	H 281	H 170	H 292	319
Cadmium	121	145	H 150	139	39
Chromium	136	95	97	109	58
Cobalt	134	123	108	122	32
Lead	H 161	H 152	82	132	107
Manganese	144	106	146	132	56
Mercury	H 164	64	66	98	142
Selenium	L 2	L 2	L 3	L 2	2
Vanadium	H 190	110	128	143	105
Chlorine (as chloride)	L 4	L 5	L 14	L 8	14
ESP					
Antimony	H 654	H 708	H 743	H 701	112
Arsenic	H 189	H 190	H 175	H 184	21
Barium	L 48	58	69	58	26
Cadmium	H 161	134	H 154	150	34
Chromium	60	59	60	60	1
Cobalt	H 272	H 217	H 160	H 216	139
Lead	L 6	L 13	L 37	L 19	40
Manganese	L 15	52	L 41	L 36	47
Mercury	L 31	L 44	69	L 48	48
Selenium	H 631	H 528	H 453	H 537	221
Vanadium	90	L 5	L 10	L 35	119
Chlorine (as chloride)	-	-	H 111274	-	-
Fabric Filter					
Antimony	H 817	H 580	H 721	H 706	297
Arsenic	H 232	H 333	H 217	H 261	157
Barium	84	74	H 191	116	161
Cadmium	H 340	H 740	H 379	H 486	548
Chromium	80	114	125	106	57
Cobalt	H 235	H 323	H 413	H 323	221
Lead	L 8	L 38	L 17	L 21	37
Manganese	63	68	114	82	70
Mercury	L 35	54	139	76	138
Selenium	H 428	H 800	H 619	H 616	461
Vanadium	L 4	130	58	64	156
Chlorine (as chloride)	-	H 37278	-	-	-
Total System					
Antimony	H 1824	H 2000	H 1425	H 1750	733
Arsenic	H 208	H 193	H 148	H 183	78
Barium	H 249	H 195	H 147	H 197	126
Cadmium	H 206	H 194	H 209	H 203	20
Chromium	95	69	77	80	33
Cobalt	H 306	H 238	H 164	H 236	177
Lead	L 10	L 22	L 32	L 21	26
Manganese	93	87	121	100	46
Mercury	63	L 35	55	51	37
Selenium	L 3	L 4	L 4	L 4	1
Vanadium	H 164	L 35	51	83	175
Chlorine (as chloride)	-	-	-	-	-

objective for all metals except antimony, barium, and selenium. Average closures for selenium and chlorine were very low during demonstration tests.

Closures across the ESP during parallel configuration tests generally were low. Baseline closures for cadmium and chlorine met the objective during baseline tests. Baseline closures for all metals except antimony, chromium, selenium, and lead ranged from 35 to 184 percent. Demonstration test closures were acceptable for barium, cadmium, and chromium. Closures for other metals except antimony, barium, mercury, selenium, and vanadium during demonstration tests range from 26 to 215 percent; the rest were outside this range. Negative closures were calculated in some cases because results were below detection limits in the ESP inlet but much higher in the fabric filter inlet. Since the fabric filter inlet must be subtracted from the ESP inlet, this results in negative closures.

6.1.5 Discussion of Mass Balance Results

The mass balance results were generally good across the whole system and across the GSA reactor/cyclone. This indicates that the reported emission factors and removal efficiencies across the *whole system* should generally be valid. Mass balance results across the ESP and fabric filter suggest that flue gas measurements at the ESP inlet and fabric filter inlet may not be reliable; hence removal efficiencies calculated for the ESP and fabric filter alone may not be reliable. Sampling at the ESP inlet during all tests and at the fabric filter inlet during parallel configuration tests were especially difficult because of the high moisture content of the flue gas, high solids loading, and low stack pressure at these locations. Results were particularly poor for demonstration tests. High calcium and calcium sulfate/sulfite in demonstration test samples may have caused analytical interferences, consequently many results are reported as non-detected.

Mass balances across the whole system were generally low. One possible reason would be a low bias in the output measurements. Since direct measurements of output solid stream flow rates (GSA solids, ESP solids, fabric filter solids) were not performed during these tests, this may be a source of error in the mass balances that does not reflect on the quality of the flue gas emission results used for emission factor and removal efficiency calculations. Subsequent to the toxics characterization program, TVA measured the flow rate of solids from the GSA and ESP while the system was operated under series configuration demonstration test conditions. Fabric filter solids were not measured. Two 45-minute test runs were made to measure the solids flow rate from the GSA reactor/cyclone (location 5) and fields 2-4 of the ESP (location 9B). Two 10-minute test runs

were made to measure solids flow rate from the ESP first field (location 9A). Table 6-8 compares the solids flow rates measured during the toxics characterization program to those measured by TVA after these tests. Based on the TVA data, the 89.3 percent of the total solids is removed in the first field. This value was used throughout all mass balance calculations described earlier. Compared to the TVA test results, the GSA solids flow rate is overestimated and the ESP solids flow rate is underestimated. However, the total measured solids output flow rate is in very good agreement with the estimated value. These results are generally consistent with the observed high mass closures across the GSA and low mass closures across the ESP for total mass and many trace metals. This also points to a possible low bias in the trace metals and particulate measurements at the ESP inlet. Since the ESP inlet measurements (except for total dry gas flow rate) were not used for calculating emission factors or removal efficiencies, those results are not affected.

The poor chlorine closures for demonstration tests suggest the possibility of a low bias in either the flue gas measurement at the ESP inlet or in the GSA solids results. It is thought that Method 26A may introduce a low bias in the flue gas results, due to HCl removal on material trapped on the filter. This may be of particular concern at the ESP inlet location, where the particulate loading and moisture content are high, gas temperature is close to saturation, and where the particulate contains unreacted calcium hydroxide. The filter was not analyzed (per the method) since it is not possible to distinguish between particulate-phase chlorine that formed in the GSA or on the filter. Another possible explanation would be a low bias in the analysis of chlorine in the process output solids, possibly due to an analytical interferant in the matrix (e.g., calcium). That the chlorine balance across the whole system is significantly better than across the individual devices suggests the problem may be associated more with the flue gas measurements than the solids, since the lowest flue gas particulate loadings — hence less bias — are found at the outlet of the ESP and the fabric filter. These are the only outlet flue gas streams considered in the whole system mass balance.

6.2 Removal Efficiency

Removal efficiency of the GSA system was calculated for total particulate matter, trace metals, and HCl as follows:

$$\text{Removal efficiency} = (\text{input mass} - \text{output mass}) / (\text{input mass})$$

TABLE 6-8. COMPARISON OF ESTIMATED AND MEASURED SOLIDS FLOW RATES

Location	Verification test kg/hr	Estimated value (1) kg/hr	Balance (2) %
5 - GSA solids	253	409	162
9A - ESP Ash (Field 1)	407	285	70
9B - ESP Ash (Field 2,3,4)	49.0	34.2	70
Total solids	709	729	103

(1) By difference based on mass balance for series configuration, demonstration tests (average).

(2) EER estimate divided by measured value.

Removal efficiencies were calculated for three conceptual GSA process arrangements, illustrated in Figure 6-2:

- GSA reactor/cyclone followed by an ESP, with normal and increased specific collection area (Arrangements IA and IB, respectively);
- GSA reactor/cyclone followed by a fabric filter (Arrangement II);
- GSA reactor/cyclone followed by an ESP and a fabric filter in series (Arrangement III).

Arrangement I was evaluated using both series and parallel configuration data, since the ESP operates with slightly increased specific collection area (SCA) in the parallel configuration. Since a major portion of the particulate and metals input to the system is by way of the re-injected fly ash, the uncontrolled metals and particulate emission level at the inlet to the GSA was defined as follows:

Uncontrolled emissions mass = mass in GSA inlet flue gas + mass in re-injected fly ash

The output mass flow rates were corrected for slipstreams taken off upstream of the sampling location. For example, in Arrangement IA, the slipstream take-off for the fabric filter is upstream of the ESP outlet sampling location. Therefore, the mass of pollutant in the ESP outlet was multiplied by the ratio of gas flow at the ESP outlet to that at the ESP inlet. This approach assumes that the total flue gas mass balance across the GSA reactor/cyclone is reasonably accurate, which is supported by the data. The same rules as those given in Section 5 were used for handling non-detected values. An example calculation is shown below for Arrangement IA using arsenic results from series configuration demonstration tests, Run 1:

Given:

Arsenic flow rate in GSA inlet flue gas:	5009 mg/hr
Arsenic flow rate in re-injected fly ash:	10227 mg/hr
Arsenic flow rate in ESP outlet flue gas:	4.98 mg/hr
ESP inlet flue gas flow rate:	575.4 dscm/min
ESP outlet flue gas flow rate:	444.1 dscm/min

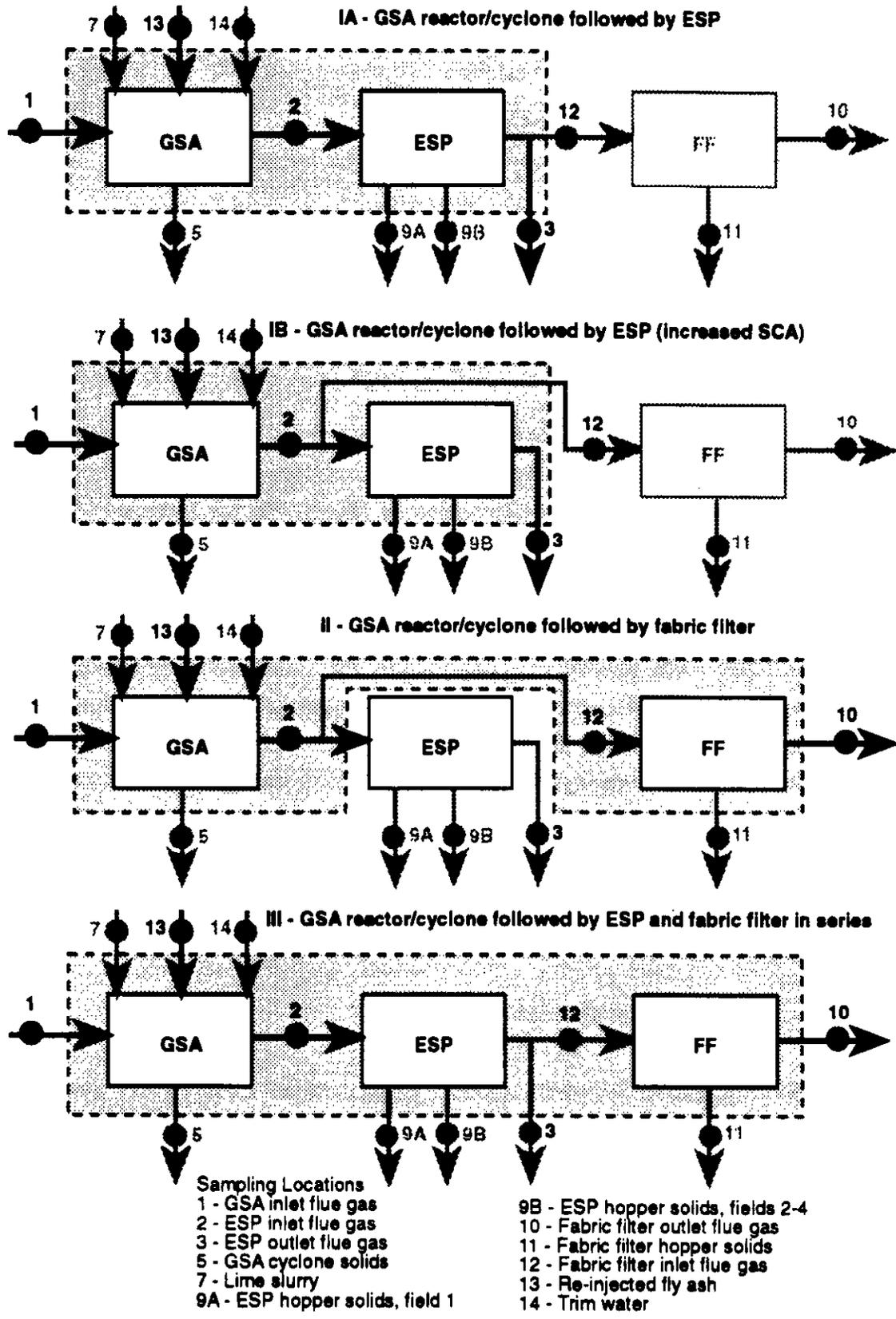


Figure 6-2. Control volumes and streams used for removal efficiency calculations.

Total arsenic entering:

$$(5009 \text{ mg/hr} + 10227 \text{ mg/hr}) = 15236 \text{ mg/hr}$$

Total arsenic leaving Arrangement IA (corrected):

$$(4.98 \text{ mg/hr}) \times (575.4 \text{ dscm/min}) / (444.1 \text{ dscm/min}) = 6.45 \text{ mg/hr}$$

Removal efficiency for arsenic across Arrangement IA:

$$100 \times (15236 \text{ mg/hr} - 6.45 \text{ mg/hr}) / (15236 \text{ mg/hr}) = 99.96 \%$$

6.2.1 Particulate Removal Efficiency

Removal efficiency for total particulate matter across each of the process arrangements is summarized in Table 6-9. The mean value and statistical uncertainty also are presented. See Section 8 for definition and discussion of uncertainty. Except for two tests, particulate removal efficiency is greater than 99 percent for all three process arrangements. Baseline particulate removal efficiency is not significantly different for Arrangements IA and IB. In general, average particulate removal efficiency is slightly improved during demonstration tests for all three process configurations. Particulate removal efficiency is low for Arrangement IB during two of three demonstration tests compared to Arrangement IA demonstration tests; this is the opposite to the expected effect of increased SCA. These results may reflect increased solids buildup on the ESP collectors, since these were among the last tests performed during the project, although ESP operation was normal during these tests. Those process arrangements including the fabric filter (Arrangements II and III) have the highest particulate removal efficiencies, but there does not appear to be a significant increase in particulate removal when the ESP is included upstream of the fabric filter (Arrangement III).

6.2.2 Trace Metals Removal Efficiency

Tables 6-10 through 6-20 present removal efficiencies for all target trace metals except for beryllium and nickel. Removal efficiencies for the latter two metals were not determined due to analytical laboratory error (see Section 5). Removal efficiency for most trace metals is generally above 90 percent. Removal efficiency is low for antimony; however, most of the antimony measurements are below detection limits hence antimony removal efficiency results are not reliable. Two removal efficiencies for mercury are actually negative (during parallel configuration tests), meaning the output was greater than the input. In both cases, this is associated with large variation

TABLE 6-9. PARTICULATE REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)
Baseline	GSA Inlet – Series						
	Flue Gas	kg/hr	83.2	91.1	96.4	90.3	
	Re-Injected Fly Ash	kg/hr	198	201	198	199	
	Total	kg/hr	282	293	294	289	
	GSA Inlet – Parallel						
	Flue Gas (1)	kg/hr	100	100	100	100	
	Re-Injected Fly Ash	kg/hr	189	188	182	186	
	Total	kg/hr	289	288	283	287	
	Configuration Outlet (2)						
	GSA+ESP (Series)	kg/hr	1.11	1.27	1.29	1.22	
	GSA+ESP (Parallel)	kg/hr	1.31	1.21	1.46	1.33	
	GSA+FF (Parallel)	kg/hr	0.291	0.326	0.309	0.309	
	GSA+ESP+FF (Series)	kg/hr	0.357	0.191	0.397	0.315	
	Removal Efficiency						
GSA+ESP (Series)	%	99.61	99.57	99.56	99.5789	10	
GSA+ESP (Parallel)	%	99.55	99.58	99.48	99.5371	10	
GSA+FF (Parallel)	%	99.90	99.89	99.89	99.8922	4	
GSA+ESP+FF (Series)	%	99.87	99.93	99.87	99.891	10	
Demonstration	GSA Inlet – Series						
	Flue Gas	kg/hr	83.2	91.1	96.4	90.3	
	Re-Injected Fly Ash	kg/hr	198	201	198	199	
	Total	kg/hr	282	293	294	289	
	GSA Inlet – Parallel						
	Flue Gas	kg/hr	99.4	101	98.3	99.5	
	Re-Injected Fly Ash	kg/hr	194	198	199	197	
	Total	kg/hr	294	299	298	297	
	Configuration Outlet (2)						
	GSA+ESP (Series)	kg/hr	0.557	0.483	0.257	0.432	
	GSA+ESP (Parallel)	kg/hr	0.327	9.51	19.7	9.84	
	GSA+FF	kg/hr	0.251	0.190	0.127	0.190	
	GSA+ESP+FF	kg/hr	0.216	0.164	0.145	0.175	
	Removal Efficiency						
GSA+ESP (Series)	%	99.80	99.84	99.91	99.85	10	
GSA+ESP (Parallel)	%	99.89	96.82	93.39	96.70	44	
GSA+FF	%	99.91	99.94	99.96	99.94	10	
GSA+ESP+FF	%	99.92	99.94	99.95	99.94	10	

Notes

1. No flue gas data – average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-10. ANTIMONY REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)			
Baseline	GSA Inlet - Series									
	Flue Gas	mg/hr	ND	4	ND	4	43	16		
	Re-Injected Fly Ash	mg/hr	ND	15	ND	15	ND	15		
	Total	mg/hr	ND	18	ND	19	50	23		
	GSA Inlet - Parallel									
	Flue Gas (1)	mg/hr		75		75		75		
	Re-Injected Fly Ash	mg/hr	ND	15	ND	15	ND	15		
	Total	mg/hr		83		83		82		
	Configuration Outlet (2)									
	GSA+ESP (Series)	mg/hr	ND	2.47	ND	2.43	ND	2.31	ND	2.41
	GSA+ESP (Parallel)	mg/hr	ND	3.3	ND	2.62	ND	2.49	ND	2.8
	GSA+FF (Parallel)	mg/hr	ND	2.78	ND	2.72	ND	2.74	ND	2.74
	GSA+ESP+FF (Series)	mg/hr	ND	2.40	ND	2.38	ND	2.71	ND	2.50
	Removal Efficiency									
	GSA+ESP (Series)	%		86.51		87.21		95.41		89.71
GSA+ESP (Parallel)	%		96.01		96.83		96.98		96.61	13.49
GSA+FF (Parallel)	%		96.64		96.71		96.68		96.68	14.17
GSA+ESP+FF (Series)	%		86.93		87.45		94.63		89.67	17.1
Demonstration	GSA Inlet - Series									
	Flue Gas	mg/hr		50		33	ND	4		28
	Re-Injected Fly Ash	mg/hr	ND	16	ND	17	ND	16	ND	16
	Total	mg/hr		58		42	ND	20		37
	GSA Inlet - Parallel									
	Flue Gas	mg/hr		150		183		210		181
	Re-Injected Fly Ash	mg/hr	ND	15	ND	16	ND	16	ND	16
	Total	mg/hr		158		191		218		189
	Configuration Outlet									
	GSA+ESP (Series)	mg/hr		16.7	ND	2.02	ND	2.39		6.3
	GSA+ESP (Parallel)	mg/hr		N/A	ND	2.53	ND	2.47	ND	2.5
	GSA+FF	mg/hr	ND	2.45	ND	2.54	ND	2.53	ND	2.5
	GSA+ESP+FF	mg/hr	ND	2.06	ND	0.181	ND	2.15	ND	1.46
	Removal Efficiency									
	GSA+ESP (Series)	%		71.21		95.16		87.78		84.72
GSA+ESP (Parallel)	%	(3)	98.42		98.68		98.87		98.77	14.24
GSA+FF	%		98.45		98.67		98.84		98.65	14.2
GSA+ESP+FF	%		96.45		99.57		89.00		95.00	18.59

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-11. ARSENIC REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)
Baseline	GSA Inlet – Series						
	Flue Gas	mg/hr	4,835	6,357	6,340	5,844	
	Re-Injected Fly Ash	mg/hr	14,223	5,726	6,437	8,795	
	Total	mg/hr	19,058	12,083	12,777	14,639	
	GSA Inlet – Parallel						
	Flue Gas (1)	mg/hr	6,516	6,516	6,516	6,516	
	Re-Injected Fly Ash	mg/hr	9,953	10,516	7,640	9,370	
	Total	mg/hr	16,469	17,032	14,157	15,886	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	308	161	106	192	
	GSA+ESP (Parallel)	mg/hr	272	221	248	247	30.1
	GSA+FF (Parallel)	mg/hr	28.27	20.47	29.45	26	47.2
	GSA+ESP+FF (Series)	mg/hr	ND 1.69	ND 1.68	5.26	2.32	187.1
	Removal Efficiency						
	GSA+ESP (Series)	%	98.38	98.67	99.17	98.74	8.17
GSA+ESP (Parallel)	%	98.35	98.7	98.25	98.43	8.14	
GSA+FF (Parallel)	%	99.83	99.88	99.79	99.83	8.1	
GSA+ESP+FF (Series)	%	99.991	99.986	99.96	99.98	8.11	
Demonstration	GSA Inlet – Series						
	Flue Gas	mg/hr	5,009	5,111	6,102	5,408	
	Re-Injected Fly Ash	mg/hr	10,151	23,565	5,007	12,907	
	Total	mg/hr	15,160	28,676	11,109	18,315	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	8,108	9,278	7,505	8,297	
	Re-Injected Fly Ash	mg/hr	6,439	6,080	10,956	7,825	
	Total	mg/hr	14,547	15,357	18,461	16,122	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	6	4	7	6	
	GSA+ESP (Parallel)	mg/hr	N/A	1,107	13.00	560	1241.4
	GSA+FF (Parallel)	mg/hr	1.73	ND 1.79	8.62	3.75	239.3
	GSA+ESP+FF (Series)	mg/hr	ND 1.45	ND 0.13	ND 1.52	ND 1.03	13.8
	Removal Efficiency						
	GSA+ESP (Series)	%	99.96	99.99	99.94	99.96	8.37
GSA+ESP (Parallel)	%	(3) 96.15	92.79	99.93	96.36	47.79	
GSA+FF (Parallel)	%	99.99	99.99	99.95	99.98	8.24	
GSA+ESP+FF (Series)	%	99.99	99.9996	99.99	99.99	8.37	

Notes

1. No flue gas data – average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-12. BARIUM REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	6,566	26,469	32,966	22,000	
	Re-Injected Fly Ash	mg/hr	33,407	15,026	17,651	22,028	
	Total	mg/hr	39,973	41,494	50,617	44,028	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	9,616	9,616	9,616	9,616	
	Re-Injected Fly Ash	mg/hr	21,802	24,176	22,301	22,760	
	Total	mg/hr	31,418	33,792	31,917	32,376	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	688	783	651	708	
	GSA+ESP (Parallel)	mg/hr	ND 180	ND 143	ND 136	ND 153	37.3
	GSA+FF (Parallel)	mg/hr	ND 152	ND 149	ND 150	ND 150	11.9
	GSA+ESP+FF (Series)	mg/hr	ND 131	ND 130	ND 148	ND 137	29.5
	Removal Efficiency						
GSA+ESP (Series)	%	98.28	98.11	98.71	98.37	7.81	
GSA+ESP (Parallel)	%	99.43	99.58	99.57	99.52	7.92	
GSA+FF (Parallel)	%	99.52	99.56	99.53	99.54	7.92	
GSA+ESP+FF (Series)	%	99.67	99.69	99.71	99.69	7.77	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	3,235	2,786	8,976	4,999	
	Re-Injected Fly Ash	mg/hr	23,182	37,009	27,557	29,249	
	Total	mg/hr	26,417	39,795	36,533	34,248	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	2,563	1,462	1,522	1,849	
	Re-Injected Fly Ash	mg/hr	21,623	24,676	29,425	25,241	
	Total	mg/hr	24,186	26,138	30,947	27,090	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	ND 125	ND 111	ND 131	ND 122	
	GSA+ESP (Parallel)	mg/hr	N/A	3616	230.00	1923	1117.3
	GSA+FF (Parallel)	mg/hr	ND 134	ND 139	ND 138	ND 137	12.5
	GSA+ESP+FF (Series)	mg/hr	ND 113	ND 10	ND 118	ND 80.1	13.2
	Removal Efficiency						
GSA+ESP (Series)	%	99.53	99.72	99.64	99.63	8.8	
GSA+ESP (Parallel)	%	(3) 92.05	86.17	99.26	92.71	90.19	
GSA+FF (Parallel)	%	99.45	99.47	99.55	99.49	9.44	
GSA+ESP+FF (Series)	%	99.57	99.98	99.68	99.74	8.81	

Notes

1. No flue gas data – average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-13. CADMIUM REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	169	238	3.43	137	
	Re-Injected Fly Ash	mg/hr	54.0	60.0	53.0	55.7	
	Total	mg/hr	223	298	296	272	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	205	205	205	205	
	Re-Injected Fly Ash	mg/hr	61.0	87.0	85.0	77.7	
	Total	mg/hr	266	292	290	283	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	8.75	7.88	3.43	6.69	
	GSA+ESP (Parallel)	mg/hr	50.4	34.7	41.0	42.0	48.3
	GSA+FF (Parallel)	mg/hr	72.7	79.9	90.1	80.9	31.7
	GSA+ESP+FF (Series)	mg/hr	10.6	18.3	20.8	16.5	86.2
	Removal Efficiency						
GSA+ESP (Series)	%	96.07	97.35	98.84	97.42	10.99	
GSA+ESP (Parallel)	%	81.08	88.1	85.85	85.01	11.31	
GSA+FF (Parallel)	%	72.70	72.60	68.91	71.40	13.11	
GSA+ESP+FF (Series)	%	95.24	93.87	92.98	94.03	10.85	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	193	184	241	206	
	Re-Injected Fly Ash	mg/hr	55.0	77.0	47.0	59.7	
	Total	mg/hr	248	261	288	266	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	185	188	205	193	
	Re-Injected Fly Ash	mg/hr	56.0	59.0	82.0	65.7	
	Total	mg/hr	242	247	286	258	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	6.07	ND	0.0832	4.24	3.45
	GSA+ESP (Parallel)	mg/hr	N/A	28.26	5.85	17.05	832
	GSA+FF (Parallel)	mg/hr	63.3	54.6	44.6	54.1	48.9
	GSA+ESP+FF (Series)	mg/hr	10.93	ND	0.53	9.48	6.89
	Removal Efficiency						
GSA+ESP (Series)	%	97.55	99.97	98.53	98.68	10.77	
GSA+ESP (Parallel)	%	(3) 92.94	88.58	97.96	93.27	64.71	
GSA+FF (Parallel)	%	73.81	77.95	84.44	78.73	20.31	
GSA+ESP+FF (Series)	%	95.6	99.8	96.71	97.37	11.73	

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-14 CHROMIUM REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	8,639	13,757	18,146	13,514	
	Re-Injected Fly Ash	mg/hr	17,688	6,072	4,686	9,482	
	Total	mg/hr	26,327	19,829	22,832	22,996	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	11,270	11,270	11,270	11,270	
	Re-Injected Fly Ash	mg/hr	4,488	5,125	5,069	4,894	
	Total	mg/hr	15,758	16,395	16,339	16,164	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	252	48.6	352	218	
	GSA+ESP (Parallel)	mg/hr	317	283	327	309	27.4
	GSA+FF (Parallel)	mg/hr	ND 88.2	ND 86.3	ND 86.9	ND 87.2	12.6
	GSA+ESP+FF (Series)	mg/hr	ND 76.2	ND 75.7	ND 86.1	ND 79.3	29.7
	Removal Efficiency						
GSA+ESP (Series)	%	99.04	99.76	98.46	99.09	8.63	
GSA+ESP (Parallel)	%	97.99	98.27	98	98.09	9.24	
GSA+FF (Parallel)	%	99.44	99.47	99.47	99.46	9.23	
GSA+ESP+FF (Series)	%	99.71	99.62	99.62	99.65	8.47	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	10,205	9,512	10,476	10,064	
	Re-Injected Fly Ash	mg/hr	3,077	4,208	3,477	3,587	
	Total	mg/hr	13,282	13,720	13,952	13,651	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	11,658	10,354	8,684	10,232	
	Re-Injected Fly Ash	mg/hr	4,191	6,417	6,042	5,550	
	Total	mg/hr	15,849	16,771	14,726	15,782	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	ND 72.6	ND 64.2	ND 75.8	ND 70.9	
	GSA+ESP (Parallel)	mg/hr	N/A	1,551	ND 79.0	795	1147.1
	GSA+FF (Parallel)	mg/hr	ND 77.7	ND 80.7	ND 80.2	ND 79.5	13.2
	GSA+ESP+FF (Series)	mg/hr	ND 65.4	ND 5.75	ND 68.3	ND 46.5	13.8
	Removal Efficiency						
GSA+ESP (Series)	%	99.45	99.53	99.46	99.48	9.58	
GSA+ESP (Parallel)	%	(3) 94.98	90.75	99.47	95.11	58.92	
GSA+FF (Parallel)	%	99.51	99.52	99.46	99.50	8.85	
GSA+ESP+FF (Series)	%	99.51	99.96	99.51	99.66	9.6	

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-15. COBALT REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet – Series						
	Flue Gas	mg/hr	1,182	1,880	2,247	1,770	
	Re-Injected Fly Ash	mg/hr	950	877	904	910	
	Total	mg/hr	2,132	2,757	3,152	2,680	
	GSA Inlet – Parallel						
	Flue Gas (1)	mg/hr	1,715	1,715	1,715	1,715	
	Re-Injected Fly Ash	mg/hr	1,170	1,455	1,090	1,238	
	Total	mg/hr	2,885	3,170	2,805	2,953	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	42.9	45.7	37.4	42.0	
	GSA+ESP (Parallel)	mg/hr	60.1	52.5	52.7	55.1	21.9
	GSA+FF (Parallel)	mg/hr	ND 39.2	ND 38.4	ND 38.6	ND 38.7	12.1
	GSA+ESP+FF (Series)	mg/hr	ND 33.8	ND 33.7	ND 38.3	ND 35.3	29.5
	Removal Efficiency						
GSA+ESP (Series)	%	97.99	98.34	98.81	98.38	9.55	
GSA+ESP (Parallel)	%	97.92	98.35	98.12	98.13	9.52	
GSA+FF (Parallel)	%	98.64	98.79	98.62	98.68	9.51	
GSA+ESP+FF (Series)	%	98.41	98.78	98.79	98.66	9.51	
Demonstration	GSA Inlet – Series						
	Flue Gas	mg/hr	1,410	1,224	1,586	1,407	
	Re-Injected Fly Ash	mg/hr	827	1,039	964	943	
	Total	mg/hr	2,237	2,263	2,550	2,350	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	1,889	2,085	1,932	1,969	
	Re-Injected Fly Ash	mg/hr	1,147	1,196	1,531	1,291	
	Total	mg/hr	3,036	3,281	3,462	3,260	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	ND 32.3	ND 28.5	ND 33.7	ND 31.5	
	GSA+ESP (Parallel)	mg/hr	N/A	343	ND 35.0	180	1034.2
	GSA+FF (Parallel)	mg/hr	ND 34.5	ND 35.9	ND 35.7	ND 35.3	12.7
	GSA+ESP+FF (Series)	mg/hr	ND 29.1	ND 2.56	ND 30.4	ND 20.7	13.4
	Removal Efficiency						
GSA+ESP (Series)	%	98.56	98.74	98.68	98.66	9.48	
GSA+ESP (Parallel)	%	(3) 94.06	89.54	98.99	94.27	64.39	
GSA+FF (Parallel)	%	98.86	98.91	98.97	98.91	9.47	
GSA+ESP+FF (Series)	%	98.7	99.89	98.81	99.13	9.62	

Notes

1. No flue gas data – average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-16. LEAD REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)	
Baseline	GSA Inlet - Series							
	Flue Gas	mg/hr	2,058	4,517	5,479	4,018		
	Re-Injected Fly Ash	mg/hr	5,580	1,696	2,024	3,100		
	Total	mg/hr	7,638	6,212	7,503	7,118		
	GSA Inlet - Parallel							
	Flue Gas (1)	mg/hr	3,543	3,543	3,543	3,543		
	Re-Injected Fly Ash	mg/hr	3,962	3,410	2,863	3,412		
	Total	mg/hr	7,506	6,954	6,406	6,955		
	Configuration Outlet (2)							
	GSA+ESP (Series)	mg/hr	57.1	61.4	143	87.1		
	GSA+ESP (Parallel)	mg/hr	204.0	185.0	168.0	185.7	23.8	
	GSA+FF (Parallel)	mg/hr	42.5	30.0	31.0	34.5	48.8	
	GSA+ESP+FF (Series)	mg/hr	21.9	23.8	19.1	21.6	25	
	Removal Efficiency							
GSA+ESP (Series)	%	99.25	99.01	98.1	98.79	9.47		
GSA+ESP (Parallel)	%	97.28	97.34	97.37	97.33	9.16		
GSA+FF (Parallel)	%	99.43	99.57	99.52	99.51	9.16		
GSA+ESP+FF (Series)	%	99.71	99.62	99.74	99.69	9.35		
Demonstration	GSA Inlet - Series							
	Flue Gas	mg/hr	2,581	2,193	3,679	2,818		
	Re-Injected Fly Ash	mg/hr	3,547	5,660	2,484	3,897		
	Total	mg/hr	6,128	7,852	6,162	6,714		
	GSA Inlet - Parallel							
	Flue Gas	mg/hr	3,237	4,529	3,619	3,795		
	Re-Injected Fly Ash	mg/hr	2,058	1,979	3,766	2,601		
	Total	mg/hr	5,294	63,508	7,386	25,396		
	Configuration Outlet							
	GSA+ESP (Series)	mg/hr	19.8	ND	1.1	ND	1.3	7.0
	GSA+ESP (Parallel)	mg/hr	N/A		1,018		14.0	516
	GSA+FF (Parallel)	mg/hr	30.9		27.6		12.2	23.6
	GSA+ESP+FF (Series)	mg/hr	9.37		0.664		12.6	7.56
	Removal Efficiency							
GSA+ESP (Series)	%	99.68	99.99	99.98	99.88	9.08		
GSA+ESP (Parallel)	%	(3) 90.25	84.35	99.81	92.08	107.09		
GSA+FF (Parallel)	%	99.42	99.58	99.83	99.61	9.51		
GSA+ESP+FF (Series)	%	99.85	99.99	99.79	99.88	9.07		

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-17. MANGANESE REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	13,885	27,320	24,658	21,954	
	Re-Injected Fly Ash	mg/hr	12,382	22,247	20,423	18,351	
	Total	mg/hr	26,267	49,566	45,081	40,305	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	13,747	13,747	13,747	13,747	
	Re-Injected Fly Ash	mg/hr	12,864	13,488	16,284	14,212	
	Total	mg/hr	26,610	27,235	30,030	27,958	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	274	317	318	303	
	GSA+ESP (Parallel)	mg/hr	256	355	645	419	127.5
	GSA+FF (Parallel)	mg/hr	147	120	88.5	118	60
	GSA+ESP+FF (Series)	mg/hr	120	51.9	63.8	78.5	110.7
	Removal Efficiency						
GSA+ESP (Series)	%	98.96	99.36	99.29	99.20	9.13	
GSA+ESP (Parallel)	%	99.04	98.7	97.85	98.53	9.36	
GSA+FF (Parallel)	%	99.45	99.56	99.71	99.57	9.24	
GSA+ESP+FF (Series)	%	99.54	99.9	99.86	99.77	9.13	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	10,128	9,547	13,861	11,179	
	Re-Injected Fly Ash	mg/hr	11,170	16,138	23,067	16,792	
	Total	mg/hr	21,298	25,685	36,928	27,970	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	12,737	5,932	5,651	8,107	
	Re-Injected Fly Ash	mg/hr	14,422	17,702	15,770	15,965	
	Total	mg/hr	27,158	23,635	21,420	24,071	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	215	92.1	7,865	2,724	
	GSA+ESP (Parallel)	mg/hr	N/A	1,984	97.0	1,041	1150.6
	GSA+FF (Parallel)	mg/hr	129.4	321.3	166.4	205.7	124
	GSA+ESP+FF (Series)	mg/hr	44.8	3.94	56.9	35.2	27.8
	Removal Efficiency						
GSA+ESP (Series)	%	98.99	99.64	78.7	92.44	33.45	
GSA+ESP (Parallel)	%	(3) 96.17	91.61	99.54	95.58	53.68	
GSA+FF (Parallel)	%	99.52	98.64	99.22	99.13	10.18	
GSA+ESP+FF (Series)	%	99.79	99.98	99.85	99.87	9.67	

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-18. MERCURY REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)	
Baseline	GSA Inlet - Series							
	Flue Gas	mg/hr	31.0	81.0	58.0	56.7		
	Re-Injected Fly Ash	mg/hr	ND	18.0	ND	18.0	ND	18.0
	Total	mg/hr	40.0	90.0	67.0	65.7		
	GSA Inlet - Parallel							
	Flue Gas (1)	mg/hr	51.0	51.0	51.0	51.0		
	Re-Injected Fly Ash	mg/hr	ND	19.0	ND	18.0	ND	15.0
	Total	mg/hr	60.0	60.0	60.0	60.0		
	Configuration Outlet (2)							
	GSA+ESP (Series)	mg/hr	13.2	8.86	13.1	11.7		
	GSA+ESP (Parallel)	mg/hr	27.3	20.4	20.1	22.6	44.4	
	GSA+FF (Parallel)	mg/hr	ND	0.980	39.3	82.2	40.7	249.7
	GSA+ESP+FF (Series)	mg/hr	1.69	8.55	1.91	4.05	235.8	
	Removal Efficiency							
	GSA+ESP (Series)	%	66.89	90.12	80.43	79.15	38.24	
	GSA+ESP (Parallel)	%	54.60	66.24	66.51	62.45	11.71	
GSA+FF (Parallel)	%	98.37	34.80	-37.26	31.97	527.49		
GSA+ESP+FF (Series)	%	99.85	99.86	99.87	99.86	14.26		
Demonstration	GSA Inlet - Series							
	Flue Gas	mg/hr	15.0	34.0	60.0	36.3		
	Re-Injected Fly Ash	mg/hr	ND	20.0	ND	20.0	ND	20.3
	Total	mg/hr	25.0	44.0	70.0	46.3		
	GSA Inlet - Parallel							
	Flue Gas	mg/hr	110	54.0	15.0	59.7		
	Re-Injected Fly Ash	mg/hr	ND	19.0	ND	20.0	ND	19.7
	Total	mg/hr	119	64.0	26.0	69.7		
	Configuration Outlet							
	GSA+ESP (Series)	mg/hr	4.97	2.02	7.30	4.77		
	GSA+ESP (Parallel)	mg/hr	N/A	51.4	50.5	51.0	13.3	
	GSA+FF (Parallel)	mg/hr	26.5	48.4	14.0	29.6	147.6	
	GSA+ESP+FF (Series)	mg/hr	4.48	ND	0.064	7.84	4.13	196.4
	Removal Efficiency							
	GSA+ESP (Series)	%	79.84	95.43	89.55	88.27	24.72	
	GSA+ESP (Parallel)	%	(3)	57.35	19.84	-97.61	-38.89	1918.94
GSA+FF (Parallel)	%	77.85	24.51	45.33	49.23	136.17		
GSA+ESP+FF (Series)	%	81.83	99.86	88.78	90.16	27.34		

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-19. SELENIUM REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	3,550	4,609	3,700	3,953	
	Re-Injected Fly Ash	mg/hr	633	666	584	628	
	Total	mg/hr	4,183	5,274	4,283	4,580	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	2,260	2,260	2,260	2,260	
	Re-Injected Fly Ash	mg/hr	747	783	801	777	
	Total	mg/hr	3,007	3,043	3,060	3,037	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	757	1,600	1,389	1,248	
	GSA+ESP (Parallel)	mg/hr	720	321	806	616	109.1
	GSA+FF (Parallel)	mg/hr	ND 2.12	ND 2.08	ND 2.09	ND 2.10	11.9
	GSA+ESP+FF (Series)	mg/hr	19.0	56.8	48.6	41.5	120.7
	Removal Efficiency						
GSA+ESP (Series)	%	81.91	69.67	67.58	73.05	28.46	
GSA+ESP (Parallel)	%	76.06	89.45	73.67	79.73	35.36	
GSA+FF (Parallel)	%	99.93	99.93	99.93	99.93	9.49	
GSA+ESP+FF (Series)	%	99.54	98.92	98.86	99.11	10.41	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	2,289	2,228	3,040	2,519	
	Re-Injected Fly Ash	mg/hr	333	686	405	475	
	Total	mg/hr	2,622	2,914	3,446	2,994	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	285	ND 3	636	308	
	Re-Injected Fly Ash	mg/hr	520	817	697	678	
	Total	mg/hr	805	818	1,333	985	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	7.83	458	1,839	768	
	GSA+ESP (Parallel)	mg/hr	N/A	ND 1.93	ND 1.89	ND 1.91	14.3
	GSA+FF (Parallel)	mg/hr	ND 1.87	ND 1.94	ND 1.93	ND 1.91	12.5
	GSA+ESP+FF (Series)	mg/hr	ND 1.58	ND 0.138	ND 1.64	ND 1.12	13.2
	Removal Efficiency						
GSA+ESP (Series)	%	99.7	84.29	46.63	76.87	88.86	
GSA+ESP (Parallel)	%	(3) 99.76	99.76	99.86	99.81	10.34	
GSA+FF (Parallel)	%	99.77	99.76	99.86	99.80	10.32	
GSA+ESP+FF (Series)	%	99.94	99.995	99.95	99.96	10.18	

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

TABLE 6-20. VANADIUM REMOVAL EFFICIENCIES

	Stream	Units	Run 2	Run 3	Run 4	Average	Uncertainty (%)
Baseline	GSA Inlet - Series						
	Flue Gas	mg/hr	17,516	28,985	33,149	26,550	
	Re-Injected Fly Ash	mg/hr	5,471	8,096	6,619	6,729	
	Total	mg/hr	22,987	37,081	39,768	33,279	
	GSA Inlet - Parallel						
	Flue Gas (1)	mg/hr	22,754	22,754	22,754	22,754	
	Re-Injected Fly Ash	mg/hr	8,019	8,554	8,899	8,491	
	Total	mg/hr	30,773	31,308	31,653	31,245	
	Configuration Outlet (2)						
	GSA+ESP (Series)	mg/hr	ND 575	ND 257	ND 245	ND 359	
	GSA+ESP (Parallel)	mg/hr	ND 349	ND 548	ND 264	ND 285	195.9
	GSA+FF (Parallel)	mg/hr	ND 294	ND 288	ND 290	ND 291	16.9
	GSA+ESP+FF (Series)	mg/hr	ND 254	ND 252	ND 287	ND 264	31.8
	Removal Efficiency						
GSA+ESP (Series)	%	97.50	99.31	99.38	98.73	13.98	
GSA+ESP (Parallel)	%	98.87	98.25	99.17	98.76	13	
GSA+FF (Parallel)	%	99.04	99.08	99.08	99.07	12.9	
GSA+ESP+FF (Series)	%	98.90	99.32	99.28	99.17	13.74	
Demonstration	GSA Inlet - Series						
	Flue Gas	mg/hr	23,232	21,397	24,928	23,186	
	Re-Injected Fly Ash	mg/hr	4,174	6,396	5,881	5,484	
	Total	mg/hr	27,406	27,794	30,809	28,670	
	GSA Inlet - Parallel						
	Flue Gas	mg/hr	24,782	17,618	13,178	18,526	
	Re-Injected Fly Ash	mg/hr	6,096	9,437	9,607	8,380	
	Total	mg/hr	30,878	27,055	22,785	26,906	
	Configuration Outlet						
	GSA+ESP (Series)	mg/hr	ND 242	ND 214	ND 253	ND 236	
	GSA+ESP (Parallel)	mg/hr	N/A	ND 1.93	ND 1.89	ND 1.91	1081.1
	GSA+FF (Parallel)	mg/hr	ND 259	ND 269	ND 267	ND 265	17.4
	GSA+ESP+FF (Series)	mg/hr	ND 218	ND 19.0	ND 228	ND 155	17.9
	Removal Efficiency						
GSA+ESP (Series)	%	99.12	99.23	99.18	99.18	13.87	
GSA+ESP (Parallel)	%	(3) 94.48	87.89	98.85	93.37	75.62	
GSA+FF (Parallel)	%	99.16	99.01	98.83	99.00	12.5	
GSA+ESP+FF (Series)	%	99.2	99.93	99.26	99.46	13.9	

Notes

1. No flue gas data - average shown is average of all GSA inlet values.
2. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
3. Value shown utilizes average of outlet runs 2 and 3 (not included in average).

in either the input or the output measurements. This is not entirely surprising given that mercury concentrations are generally near the method detection limits.

For Arrangement IA (GSA plus ESP), average removal efficiency is greater than 99 percent for arsenic, barium, chromium, lead, and vanadium. Removal efficiencies are significantly less than 99 percent for manganese, mercury, and selenium. Lower removals for mercury and selenium are expected because of the volatility of these metals. Most trace metals removal efficiencies are slightly higher for demonstration tests compared to baseline; however, in most cases the increase is very small. For Arrangement IB (GSA plus ESP, increased SCA), collection efficiencies are lower than for Arrangement IA except for manganese, mercury, and selenium. This is probably due to the same reasons discussed above for lower particulate removal efficiencies.

Arrangement II (GSA plus fabric filter) results show removal efficiencies greater than 99 percent for arsenic, barium, chromium, lead, manganese, selenium, and vanadium. Cadmium removal is much lower with Arrangement II (69 to 84 percent) than any of the other arrangements for baseline and demonstration tests. Average mercury removal efficiency also was significantly below 99 percent with Arrangement II, 32 percent for baseline tests and 49 percent for demonstration tests. Except for barium, manganese, selenium, and vanadium, Arrangement II removal efficiencies are slightly higher for demonstration tests compared to baseline.

Results for Arrangement III (GSA plus ESP plus fabric filter) show average removal efficiencies greater than 99 percent for arsenic, barium, chromium, cobalt, lead, manganese, selenium, and vanadium. Cadmium removal efficiency is 94 percent during baseline tests and 97 percent during demonstration tests. Arrangement III produced the highest mercury removal efficiencies than the other arrangements, slightly better than 90 percent during demonstration tests and greater than 99 percent during baseline tests.

6.2.3 HCl, HF, and SO₂ Removal Efficiency

Table 6-21 presents removal efficiencies calculated for HCl. Under baseline conditions, calculated removal efficiencies range from -32 to 7 percent. Negative removal efficiencies reflect data where the mass flow of HCl at the outlet of the system is greater than the inlet. Large negative removal efficiencies are most likely due to error in either the input or output measurements. This is further substantiated by large variations in either the input or output measurements in those cases

TABLE 6-21. HCl REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)
Baseline	GSA Inlet – Series						
	Flue Gas	mg/hr	578077	512784	578077	556313	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	578077	512784	578077	556313	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	634288	486986	723567	614947	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	634288	486986	723567	614947	
	Configuration Outlet (1)						
	GSA+ESP (Series)	mg/hr	(2) 713560	(2) 503488	(2) 539099	585382	
	GSA+ESP (Parallel)	mg/hr	(3) 636105	(3) 501711	(3) 700702	612839	
	GSA+FF (Parallel)	mg/hr	662726	643921	696417	667688	
	GSA+ESP+FF (Series)	mg/hr	646347	666082	664343	658924	
	Removal Efficiency						
	GSA+ESP (Series)	%	-23.44	1.81	6.74	-4.96	811
	GSA+ESP (Parallel)	%	-0.29	-3.02	3.16	-0.05	15932
GSA+FF (Parallel)	%	-4.48	-32.23	3.75	-10.99	479	
GSA+ESP+FF (Series)	%	-11.81	-29.90	-14.92	-18.88	371	
Demonstration	GSA Inlet – Series						
	Flue Gas	mg/hr	599580	773169	634214	668988	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	599580	773169	634214	668988	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	484796	691877	747943	641539	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	484796	691877	747943	641539	
	Configuration Outlet (1)						
	GSA+ESP (Series)	mg/hr	ND 318	ND(2) 321	ND(2) 364	335	
	GSA+ESP (Parallel)	mg/hr	-	-	13171	13171	
	GSA+FF	mg/hr	ND 314	ND 303	ND 301	306	
	GSA+ESP+FF	mg/hr	ND 312	ND 306	ND 317	312	
	Removal Efficiency						
	GSA+ESP (Series)	%	99.95	99.96	99.94	99.95	12
	GSA+ESP (Parallel)	%	-	-	98.24	98.24	13
GSA+FF	%	99.94	99.96	99.96	99.95	12	
GSA+ESP+FF	%	99.95	99.96	99.95	99.95	13	

Notes

1. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
2. HCl at ESP outlet was estimated based on HCl concentration at fabric filter inlet and metals train gas flow at ESP outlet.
3. HCl at ESP outlet was estimated based on HCl at GSA inlet and metals train gas flow at ESP inlet.
4. Based on metals train measurements.

with large negative removal efficiencies. For example, calculated removal efficiency is -23 percent during Run 1 for Arrangement IA (GSA + ESP, series). Examining the results shows that one of the measurement is significantly higher than the others. Similarly, Run 2 for Arrangement II has a calculated removal efficiency of -32 percent, which is due to a low HCl measurement at the GSA inlet. Average removal efficiencies during baseline conditions range from 0 to -19 percent for baseline tests. As seen in the table, there are large uncertainties associated with the high negative removal efficiencies. HF results (Table 6-22) exhibited similar behavior.

Demonstration test results show HCl removal efficiencies greater than 99 percent in all but one measurement. All of the arrangements have similar average removal efficiencies, except Arrangement IB which was lower. Since the low result is based on a single test run, confidence in this value is low especially since it is difficult to rationalize why HCl removal should be lower in this arrangement. Uncertainty associated with the measured removal efficiencies is very low. HF removal efficiencies also are generally high, ranging from 94 to greater than 99 percent. The uncertainty of the HF results also is low. There are no significant differences in average HF removal efficiency among the various arrangements, considering the uncertainty associated with the results.

The primary purpose of the GSA process in coal-fired boiler applications is SO₂ emissions control. Table 6-23 presents SO₂ removal efficiencies based on continuous emissions monitoring results reported by TVA/NCER. As expected, SO₂ removal under baseline conditions is low, ranging from 3 to 10 percent. Although uncertainty was not calculated since sufficient data on the plant monitoring system was not available, these differences are probably within the accuracy of the measurement system. SO₂ removal efficiency under demonstration test conditions ranges from an average of 89 percent for Arrangements IA and III to 96 percent for Arrangement II. Since Arrangement II has the highest particulate loading at the fabric filter inlet, the results suggest the best SO₂ removal occurs when the filter cake on the bags is relatively large.

TABLE 6-22. HF REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)
Baseline	GSA Inlet – Series						
	Flue Gas	mg/hr	109042	58686	88434	85387	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	109042	58686	88434	85387	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	117529	21505	123487	87507	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	117529	21505	123487	87507	
	Configuration Outlet (1)						
	GSA+ESP (Series)	mg/hr	(2) 170491	(2) 72179	(2) 67032	103234	
	GSA+ESP (Parallel)	mg/hr	(3) 117865	(3) 22155	(3) 119585	86535	
	GSA+FF (Parallel)	mg/hr	46431	30540	119934	65635	
	GSA+ESP+FF (Series)	mg/hr	118436	156870	174928	150078	
	Removal Efficiency						
GSA+ESP (Series)	%	-56.35	-22.99	24.20	-18.38	-	
GSA+ESP (Parallel)	%	-0.29	-3.02	3.16	-0.05	-	
GSA+FF (Parallel)	%	60.49	-42.01	2.88	7.12	488	
GSA+ESP+FF (Series)	%	-8.62	-167.3	-97.81	-91.24	249	
Demonstration	GSA Inlet – Series						
	Flue Gas	mg/hr	70605	85505	83497	79869	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	70605	85505	83497	79869	
	GSA Inlet – Parallel						
	Flue Gas	mg/hr	25752	12321	137859	58644	
	Re-Injected Fly Ash	mg/hr	0	0	0	0	
	Total	mg/hr	25752	12321	137859	58644	
	Configuration Outlet (1)						
	GSA+ESP (Series)	mg/hr	ND 813	ND (2) 822	ND (2) 1028	888	
	GSA+ESP (Parallel)	mg/hr	-	-	ND 833	833	
	GSA+FF	mg/hr	ND 753	ND 735	ND 756	748	
	GSA+ESP+FF	mg/hr	ND 800	ND 779	ND 816	798	
	Removal Efficiency						
GSA+ESP (Series)	%	98.85	99.04	98.77	98.89	-	
GSA+ESP (Parallel)	%	-	-	99.40	99.40	-	
GSA+FF	%	97.07	94.03	99.45	96.85	15	
GSA+ESP+FF	%	98.87	99.09	99.02	98.99	13	

Notes

1. Values shown corrected for variation in flue gas flow between ESP Inlet and measurement location.
2. HF at ESP outlet was estimated based on HF concentration at fabric filter inlet and metals train gas flow at ESP outlet.
3. HF at ESP outlet was estimated based on HF at GSA inlet and metals train gas flow at ESP inlet.

TABLE 6-23. SO2 REMOVAL EFFICIENCIES

	Stream	Units	Run 1	Run 2	Run 3	Average	Uncertainty (%)
Baseline	GSA Inlet – Series Flue Gas SO2	ppm	2267.25	2297.84	2266.17		
	GSA Inlet – Parallel Flue Gas SO2	ppm	2240.28	2256.19	2184.55		
	Configuration Outlet						
	GSA+ESP (Series)	ppm	2184	2215	2186	2195	
	GSA+ESP (Parallel)	ppm	2149	2165	2065	2126	
	GSA+FF (Parallel)	ppm	2175	2179	2138	2164	
	GSA+ESP+FF (Series)	ppm	2024	2037	2082	2048	
	Removal Efficiency						
	GSA+ESP (Series)	%	3.67	3.60	3.53	3.60177	
	GSA+ESP (Parallel)	%	4.08	4.04	5.47	4.53359	
GSA+FF (Parallel)	%	2.89	3.43	2.11	2.81197		
GSA+ESP+FF (Series)	%	10.73	11.33	8.11	10.0585		
Demonstration	GSA Inlet – Series Flue Gas SO2	ppm	2285.22	2217.88	1970.49		
	GSA Inlet – Parallel Flue Gas SO2	ppm	2206.73	2241.5	2173.32		
	Configuration Outlet						
	GSA+ESP (Series)	ppm	233	239	225	232	
	GSA+ESP (Parallel)	ppm	171	169	167	169	
	GSA+FF (Parallel)	ppm	71	68	82	73	
	GSA+ESP+FF (Series)	ppm	220	233	240	231	
	Removal Efficiency						
	GSA+ESP (Series)	%	89.79	89.24	88.59	89.2054	
	GSA+ESP (Parallel)	%	92.26	92.46	92.31	92.3423	
GSA+FF (Parallel)	%	96.79	96.98	96.24	96.6704		
GSA+ESP+FF (Series)	%	90.38	89.51	87.83	89.2367		

Notes

All SO2 concentrations are corrected to 3 percent O2.

Emission factors for each target substance were calculated for flue gas streams at the ESP outlet (location 3) and fabric filter outlet (location 10). Emission factors also were calculated for the input to the GSA based on the GSA inlet flue gas (location 1) and re-injected fly ash (location 13) to illustrate uncontrolled emissions levels. Emission factors are defined as the mass emission of a substance per unit of gross heat input. Emission factors were calculated based on measured flue gas concentrations and coal composition following the procedures described in EPA Method 19 (Code of Federal Regulations, Title 40, Part 60, Appendix A). The calculation is:

$$E = C \times F_d \times K_1 \times K_2$$

where: E = emission factor

C = concentration in flue gas stream corrected to 3 percent O₂

F_d = dry "F factor" as defined in EPA Method 19 (also see Table 3-3)

K₁ = correction factor for units

K₂ = correction from 3 percent O₂ to 0 percent O₂ = 20.9/17.9 = 1.168

For example, the emission factor for arsenic at the ESP outlet during series configuration baseline tests is calculated as follows:

Given:

Arsenic concentration (3% O₂) = 7.131 µg/dscm (Table 5-7)

F_d = 10151 dscf/MMBtu (Table 3-3)

K₁ = (0.028317 dscf/dscm)/(453 x 10⁶ µg/lb) x (10⁶ MMBtu/E12 Btu)
= 6.252 x 10⁻⁵ dscf-lb-MMBtu/dscm-µg-E12 Btu

Emission factor:

E = (7.131 µg/dscm) x (6.252 x 10⁻⁵ dscf-lb-MMBtu/dscm-µg-E12 Btu)
x (10151 dscf/MMBtu) x (1.168)
= 5.28 lb/E12 Btu

Table 6-24 presents uncontrolled emission factors for trace metals, particulate, HCl, and HF. These are equivalent to the emissions from the boiler if no air pollution controls were

TABLE 6-24. UNCONTROLLED EMISSION FACTORS (GSA INLET)

Pollutant	Emission factor				
	Units	GSA inlet (1)	Re-injected fly ash (2)		Total
Trace Metals					
Antimony	lb/E12 Btu	1.9	ND	0.4	2.3
Arsenic	lb/E12 Btu	166		249	415
Barium	lb/E12 Btu	253		635	888
Beryllium (3)	lb/E12 Btu	--		--	78
Cadmium	lb/E12 Btu	5.3		0.00	5.3
Chromium	lb/E12 Btu	291		2	293
Cobalt	lb/E12 Btu	44		151	195
Lead	lb/E12 Btu	91		28	119
Manganese	lb/E12 Btu	357		83	440
Mercury	lb/E12 Btu	1.3		419	420.3
Nickel (3)	lb/E12 Btu	--		--	612
Selenium	lb/E12 Btu	59	ND	0.00	59
Vanadium	lb/E12 Btu	587		0.00	587
Particulate	lb/E6 Btu	2.6		4.90	7.5
HCl	lb/E12 Btu	16373		0.00	16373
HF	lb/E12 Btu	2011		0.00	2011

(1) Average of all 9 test runs

(2) Average of all 12 test runs, expressed as equivalent concentration in flue gas (see Table 6-1)

(3) Estimated based on coal analysis and assuming metal partitions 100 percent to the fly ash as follows:

$$\frac{\text{lb}}{\text{E12Btu}} = \frac{(\text{concentration in coal, mg/kg})}{(\text{coal heating value, Btu/lb}) \times (2.2046 \text{ lb/kg})} \times \frac{(10^{12} \text{ Btu/E12Btu})}{(454 \text{ g/lb}) \times (1000 \text{ mg/g})}$$

The results for each coal sample were averaged.

installed. Because a portion of the fly ash which normally exits the boiler is removed upstream of the GSA slipstream and later re-injected into the GSA (see Section 3), the equivalent emission factor for the re-injected fly ash is added to the flue gas measurements at the GSA inlet (location 1). Table 6-24 shows the average of all measurements for the GSA inlet flue gas and re-injected fly ash. Uncontrolled emission factors for beryllium and nickel were estimated based on concentration of the metal in the coal and coal heating value, as shown on the table. It was assumed that 100 percent of beryllium and nickel partition to the flue gas as fly ash, since these metals are expected to partially vaporize during combustion and later condense prior to leaving the boiler.

Tables 6-25 to 6-27 present average emission factors for the cleaned flue gas leaving the three conceptual process arrangements. The statistical uncertainty (see Section 8) is also shown for each of the three conceptual arrangements. Emission factors for beryllium and nickel were estimated. The average collection efficiency of all metals except mercury, selenium, and cadmium was calculated for each configuration and applied to the uncontrolled emission factors for beryllium and nickel shown in Table 6-24.

TABLE 6-25. EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT I (GSA + ESP)

Process arrangement		I - GSA + ESP					
Test configuration		IA - Series		IB - Parallel			
Value		Emission factor lb/E12 Btu	Uncertainty %	Emission factor lb/E12 Btu	Uncertainty %		
Baseline	Trace Metals						
	Antimony	ND	0.04	15	ND	0.06	40
	Arsenic		5.28	132		5.08	31
	Barium		19.60	21	ND	3.15	39
	Beryllium (5)		0.97	--		1.25	--
	Cadmium		0.18	102		0.86	49
	Chromium		6.12	182		6.36	27
	Cobalt		1.16	21		1.13	23
	Lead		2.45	148		3.82	25
	Manganese		8.42	28		8.65	126
	Mercury		0.33	59		0.46	46
	Nickel (5)		7.61	--		9.80	--
	Selenium		34.69	88		12.72	109
	Vanadium	ND	7.57	166	NDM	6.12	196
Particulate (2)		0.034	17		0.03	21	
HCl	(3)	16270	48	(3)	17239	22	
HF	(3)	2861	139	(3)	491	60	
Demonstration	Trace Metals						
	Antimony		0.18	334	ND	0.06	23 (1)
	Arsenic		0.16	57		13.83	1242 (1)
	Barium	ND	3.42	17		47.46	1120 (1)
	Beryllium (5)		0.45	--		4.19	--
	Cadmium		0.09	229		0.42	838 (1)
	Chromium	ND	1.98	17		19.62	1149 (1)
	Cobalt	ND	0.88	17		4.45	1038 (1)
	Lead		0.20	382		12.74	1236 (1)
	Manganese		69.36	402		25.68	1152 (1)
	Mercury		0.13	121		1.25	20 (1)
	Nickel (5)		3.51	--		32.85	--
	Selenium		20.21	293	ND	0.05	21 (1)
Vanadium	ND	6.61	21		42.05	1083 (1)	
Particulate (2)		0.012	79		0.25	1230 (1)	
HCl	ND (4)	9.23	18	(4)	141.55	414	
HF	ND (4)	24.46	62	ND (4)	25.90	49	

Notes:

- (1) Uncertainty based on two runs.
- (2) Emission factor in lb/E6 Btu.
- (3) No measurements at ESP outlet made; estimated based on fabric filter inlet results.
- (4) Single run at ESP outlet; estimated including fabric filter inlet results.
- (5) Estimated based on uncontrolled emission factors shown in Table 6-24 and average removal efficiency of all trace metals except mercury, selenium, cadmium, and antimony.

TABLE 6-26. EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT II (GSA + FF)

Process arrangement		II - GSA + FF		
Test configuration		Parallel		
Value	Emission factor lb/E12 Btu	Uncertainty		
		%		
Baseline	Trace Metals			
	Antimony	ND	0.07	17
	Arsenic		0.71	53
	Barium	ND	4.09	14
	Cadmium		2.21	33
	Chromium	ND	2.37	15
	Cobalt	ND	1.05	14
	Lead		0.94	53
	Manganese		3.22	61
	Mercury		1.12	254
	Selenium	ND	0.06	14
	Vanadium	ND	7.91	18
	Particulate (1)		0.008	21
	HCl		18142	18
HF		1534	185	
Demonstration	Trace Metals			
	Antimony	ND	0.06	15
	Arsenic		0.08	238
	Barium	ND	3.39	13
	Cadmium		1.35	52
	Chromium	ND	1.97	13
	Cobalt	ND	0.88	13
	Lead		0.59	111
	Manganese		5.08	122
	Mercury		0.74	146
	Selenium	ND	0.05	13
	Vanadium	ND	6.56	17
	Particulate (1)		0.005	79
	HCl	ND	7.32	16
HF	ND	22.48	17	

Notes:

(1) Emission factor in lb/E6 Btu.

TABLE 6-27. EMISSION FACTORS FOR CONCEPTUAL PROCESS ARRANGEMENT III (GSA + ESP + FF)

Process arrangement		III - GSA + ESP + FF	
Test configuration		Series	
Value	Emission factor lb/E12 Btu	Uncertainty %	
Baseline	Trace Metals		
	Antimony	ND 0.07	30
	Arsenic	0.07	186
	Barium	ND 3.86	28
	Cadmium	0.47	85
	Chromium	ND 2.24	29
	Cobalt	ND 1.00	28
	Lead	0.61	25
	Manganese	2.21	112
	Mercury	0.11	236
	Selenium	1.17	120
	Vanadium	ND 7.48	31
	Particulate (1)	0.009	88
	HCl	18435	16
HF	4208	55	
Demonstration	Trace Metals		
	Antimony	ND 0.06	18
	Arsenic	ND 0.04	16
	Barium	ND 3.18	16
	Cadmium	0.22	80
	Chromium	ND 1.85	16
	Cobalt	ND 0.82	16
	Lead	0.27	60
	Manganese	1.36	283
	Mercury	0.12	196
	Selenium	ND 0.04	16
	Vanadium	ND 6.16	20
	Particulate (1)	0.005	40
	HCl	210	413
HF	ND 22.2	13	

Notes:

(1) Emission factor in lb/E6 Btu.

7.0 QUALITY ASSURANCE/QUALITY CONTROL

7.1 QA/QC Definitions

Quality assurance (QA) and quality control (QC) activities are distinguished in that the former are preventative in nature, while the latter are corrective. QA consists of those activities that are employed before and during a process, method, or measurement activity in order to ensure that the results of those activities are of a consistent quality. QC, on the other hand, consists of those activities that validate and if necessary correct the results of the process, method or measurement. For example, when a chemist makes three independent measurements of a sample, that is QA. When that chemist applies a statistical test for outliers on the set of measurements, and decides whether to retain or reject each measurement, that is QC.

The Category II Quality Assurance Project Plan (QAPP) for this project specified the QA objectives and QA/QC activities needed to ensure data quality is commensurate with the project objectives. In addition, internal audits conducted in the field by EER and the main analytical laboratories further assured data of acceptable quality. Overall, the QA/QC data indicated that most of the key measured data are considered acceptable and defensible.

7.1.1 Quality Assurance Objectives

Quality assurance objectives (QAO's) are either quantitative or qualitative statements defining the quality of data needed to support the program goals. These QAO's are used to support decisions concerning test validity and adequacy with respect to program goals. Quantitative objectives are expressed in terms of accuracy, precision, and completeness. These terms are defined below.

- **Accuracy** The degree of agreement of a measurement (or an average of measurements) of a parameter, X, with an accepted reference or true value, T. It is usually expressed as the difference between two values, X-T, or the difference as a percentage, $100(X-T)/T$. It is also sometimes expressed as a ratio, X/T. Accuracy is a measure of the bias or systematic distortion in a measurement.

- **Precision** A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. Precision is usually expressed in terms of standard deviation, variance or range, in either absolute or relative terms.
- **Completeness** A measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal conditions.

Table 7-1 presents the project objectives for precision, accuracy, and completeness.

7.2 Precision, Accuracy and Completeness Results

Due to the wide variety and scope of measurements made in this program, several methods were employed to determine precision and accuracy from the raw data. The basis for calculations, the approach and the equations used for precision and accuracy are given in Table 7-2. A summary of the precision, accuracy and completeness achieved for each parameter in solid, liquid, and gaseous samples is presented in Table 7-3. Because samples in addition to those planned were collected due to sampling plan changes made in the field, the completeness relative to planned samples is shown separately from the additional samples in Table 7-3. It also should be noted that the accuracy of trace metals results in flue gas samples and liquid samples was assumed to be similar since flue gas samples are reduced to liquid samples for analysis.

7.2.1 Flue Gas Results

Table 7-3 presents the accuracy, precision and completeness achieved for the flue gas sampling locations. In general, accuracy, precision and completeness objectives were achieved for the flue gas sampling locations, except as noted below.

Trace Metals EERs analytical subcontractor inadvertently did not analyze any flue gas samples for beryllium and nickel as specified in the sampling and analysis plan. Since the front-half digests were discarded prior to discovering this error, flue gas samples could not be re-analyzed. This resulted in a completeness of 0 percent for beryllium and nickel in flue gas samples.

TABLE 7-1. QUALITY ASSURANCE OBJECTIVES

Streams	Parameter	Precision	Accuracy	Completeness
		(%)	(%)	(%)
Flue gas, ash coal and lime slurry	Antimony	80 - 120	80 - 120	90
	Arsenic	80 - 120	80 - 120	90
	Barium	80 - 120	80 - 120	90
	Beryllium	80 - 120	80 - 120	90
	Cadmium	80 - 120	80 - 120	90
	Chromium	80 - 120	80 - 120	90
	Cobalt	80 - 120	80 - 120	90
	Lead	80 - 120	80 - 120	90
	Manganese	80 - 120	80 - 120	90
	Mercury	80 - 120	80 - 120	90
	Nickel	80 - 120	80 - 120	90
	Selenium	80 - 120	80 - 120	90
	Vanadium	80 - 120	80 - 120	90
Flue gas, ash, and lime slurry	Chloride	90 - 110	90 - 110	90
	Fluoride	90 - 110	90 - 110	90
Flue gas	Moisture	90 - 110	none	95
	Temperature	90 - 110	97 - 103	95
	Flow rate	90 - 110	none	95
Coal, lime slurry, ash, and flue gas	Flow rate	90 - 110	90 - 110	95
	Total mass balance	70 - 130	70 - 130	90
	Substance mass balance	50 - 150	50 - 150	90

TABLE 7-2. BASIS FOR PRECISION AND ACCURACY RESULTS

		Basis of Calculation	Approach	Equation
Accuracy	Flue gas trace metals	MS/MSD	The percent recovery for the MS and MSD is averaged.	$(MS + MSD)/2$
	Flue gas HCl	Audit	Percent recovery of spiked amount in EPA audit sample.	Based on 90-110 percent recovery criteria.
	Gas temperature	Audit	Comparison of thermocouple (TC) reading against mercury-in-glass thermometer	$100 + 100*((TC - thermometer)/(thermometer))$
	Chlorine in coal	MS	The (RPD) between a known value and the result is the accuracy. In this case the matrix spike was taken as the true value.	$100 + 100*((result - true value)/(true value))$
	Trace metals in process samples	MS	The (RPD) between a known value and the result is the accuracy. In this case the matrix spike was taken as the true value.	$100 + 100*((result - true value)/(true value))$
	Process flowrates	Scale reading	The (RPD) between a known value and the result is the accuracy. In this case the scale reading was taken as the true value.	$100 + 100*((result - true value)/(true value))$
	Precision	Trace metals in flue gas, solid and liquid samples	MS/MSD	The relative percent difference (RPD) between a known value and the result is the accuracy. In this case the matrix spike and matrix spike duplicate were taken as the true value and the result, respectively.
HCl and HF in flue gas samples		Field Dup	Duplicate analysis of the same sample and the relative percent difference between the two results was used for precision.	$100 + ((result 1 - result 2)/((result 1 + result 2)/2)) * 100$
Chloride and fluoride in solid and liquid samples		MS/MSD	The relative percent difference between the MS recovery and the MSD recovery.	$100 + (100 * (MS recovery - MSD recovery) / (MS recovery + MSD recovery) / 2)$
Completeness		...	Calculated as the percentage of valid data to planned data	$(valid data) / (planned data) * 100$

TABLE 7-3. PRECISION, ACCURACY AND COMPLETENESS RESULTS

Streams	Parameter	Flue Gas			Liquid Streams			Solid Streams			
		Precision (%)	Accuracy (%)	Completeness planned additional (% of plan)	Precision (%)	Accuracy (%)	Completeness planned additional (% of plan)	Precision (%)	Accuracy (%)	Completeness planned additional (% of plan)	
Flue gas, ash, coal and lime slurry	Antimony (Sb)	101	109	100	101	109	100	101	99	98	17
	Arsenic (As)	109	104	100	109	104	100	98	96	98	17
	Barium (Ba)	99	100	100	99	100	100	102	98	98	17
	Beryllium (Be)	---	---	0	---	---	33	100	90	29	24
	Cadmium (Cd)	102	97	100	102	97	100	103	116	98	17
	Chromium (Cr)	99	96	100	99	96	100	100	103	98	17
	Cobalt (Co)	101	98	100	101	98	100	99	88	98	17
	Lead (Pb)	101	93	100	101	93	100	92	107	98	17
	Manganese (Mn)	99	98	100	99	98	100	100	90	98	17
	Mercury (Hg)	94	100	100	94	100	100	98	109	98	17
	Nickel (Ni)	---	---	0	---	---	33	98	90	29	24
	Selenium (Se)	97	100	100	97	100	100	95	88	98	17
	Vanadium (V)	100	88	100	100	88	100	101	90	98	17
	Flue gas, ash, and lime slurry	Chloride (Cl)	101	pass	96.9	102	pass	100	N/A	N/A	N/A
Fluoride (F)		99	N/A	96.9	96		100	N/A	N/A	N/A	N/A
Flue gas	Moisture	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Temperature	101	97-103	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Flow rate	102	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coal, lime slurry, ash, and flue gas	Flow rate	102	N/A	N/A	---	---	N/A	116	N/A	N/A	N/A
	Total mass bal.			N/A			N/A		N/A	N/A	N/A
	Sub. mass bal.			N/A			N/A		N/A	N/A	N/A

N/A											

Not determined

Not Applicable

7.2.2 Liquid Process Streams

Table 7-3 presents the accuracy, precision and completeness achieved for lime slurry (SS7) and trim water (SS14). The QA objectives were achieved in all cases, except as noted below.

Trace Metals EER's analytical subcontractor initially did not analyze any samples for beryllium and nickel. The cost of re-analyzing all archived samples was beyond the means of the analytical contractor. Therefore, only selected samples were re-analyzed for beryllium and nickel to provide an indication of metals concentrations and partitioning. Two of six slurry samples were analyzed for beryllium and nickel, resulting in a completeness of 33 percent for beryllium and nickel in slurry samples. Analysis of trim water samples was not planned. A single trim water sample was analyzed which increased the overall completeness for beryllium and nickel in these samples to 50 percent of the planned samples.

7.2.3 Solid Process Streams

Table 7-3 presents the accuracy, precision and completeness achieved for coal (SS4), GSA cyclone solids (SS5), fly-ash reinjection (SS13), ESP field 1 (SS9A), ESP field 2-4 (SS9B) and fabric filter solids (SS11). The QA objectives were achieved in all cases, except as noted below.

Trace Metals EER's analytical subcontractor initially did not analyze any samples for beryllium and nickel. A total of 51 solids samples were planned for beryllium and nickel analysis. The cost of re-analyzing all archived samples was beyond the means of the analytical contractor. Therefore, only selected samples were re-analyzed for beryllium and nickel to provide an indication of metals concentrations and partitioning. A total of 27 samples were re-analyzed for beryllium and nickel, resulting in an overall completeness of 53 percent for beryllium and nickel in solid samples.

7.3 Flue Gas Sampling Quality Assurance

In general, all flue gas sampling QA criteria were satisfied for this test program. All dry gas meters met the ± 5 percent post-test calibration accuracy criterion. As can be seen by Figure 7-1, all isokinetic sample trains were operated within 90-110 percent of the isokinetic velocity ratio, with the exception of runs 2 and 3 conducted at the GSA inlet sampling location during the baseline series configuration. And in this case, as specified in the sampling and analysis plan, the

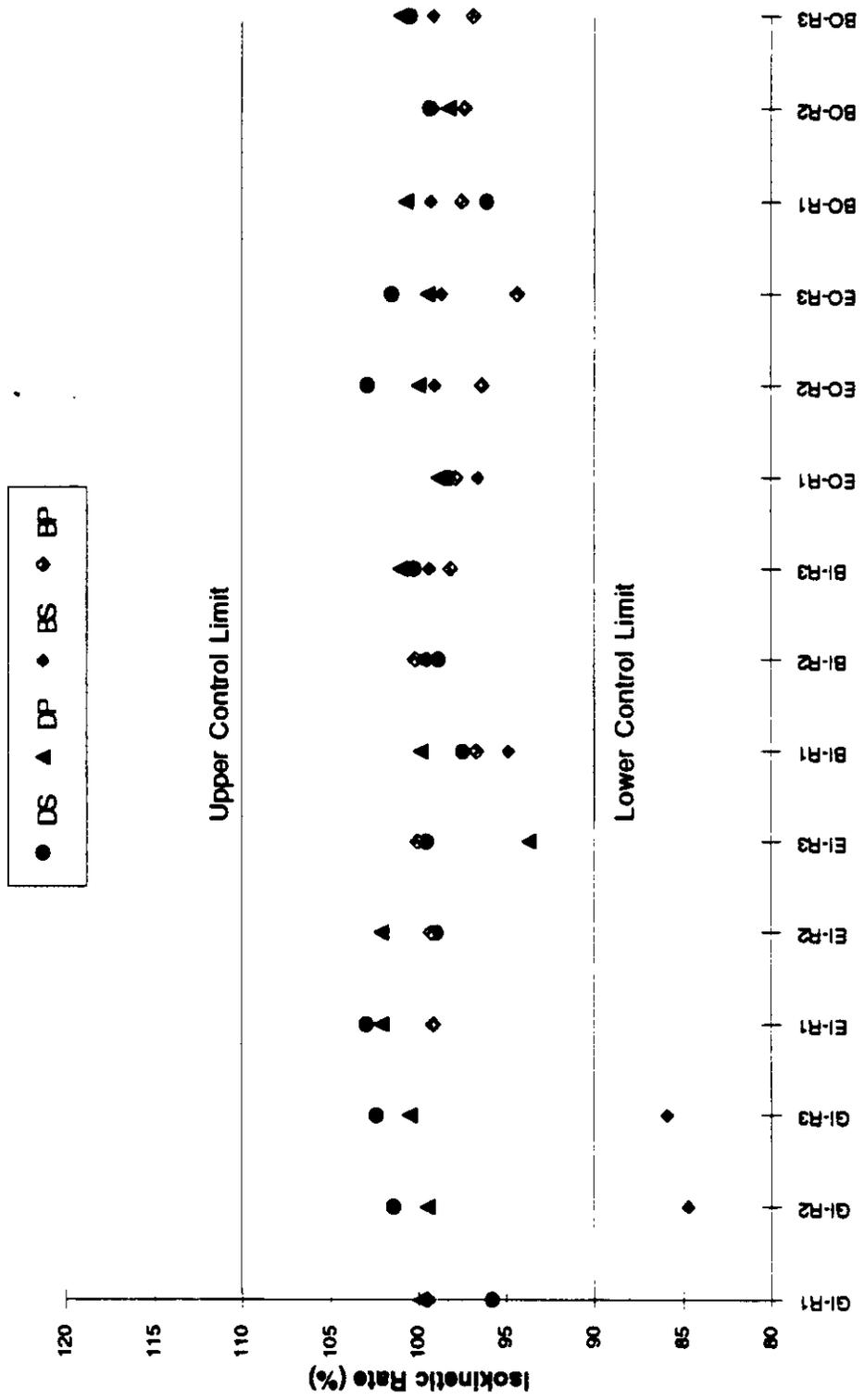


Figure 7-1. Isokinetic sampling rate control chart.

particulate loading was corrected for low isokinetic results. All post-test leak rates were within specified limits.

Figure 7-2 summarizes the moisture contents observed at each sampling location based on multiple metals train results. The moisture content during baseline tests was consistent at approximately 8% for both series and parallel configurations, indicating that there were no large air leaks into the sampling trains or the process. Results for the demonstration tests reflected the moisture added in the GSA in the locations downstream of the GSA, where moisture content increased to approximately 13-14%. The variance in flue gas moisture content at these locations is attributed partly to the variation in the amount of trim water being added to the GSA.

The metals sample train field blank and reagent blank results, presented in Tables 7-4 and 7-5, shows that there were a number of analytes were detected in both sets of field blanks taken during the program, while the reagent blank shows that these detected values can not be attributed to the reagents (filter and impinger contents) used through the program. Tables 7-6BS and 7-6DS compares the average field blank levels as a percentage of the metals found at the individual flue gas sampling locations. These tables indicate that in the series configuration the background levels found in the field blank had no impact on the GSA inlet and the ESP inlet results, while the fabric filter inlet, fabric filter outlet and ESP outlet sampling locations show concentrations similar to those detected in the field blank for most trace metals. This is attributed to the background levels of metals in the filters and the low levels actually present in the flue gas at those locations. The metals field blank results for the parallel configuration, shown in Tables 7-6BP and 7-6DP, show very similar results except that the background levels found in the field blank had no effect on the fabric filter inlet sampling location. Since the trace metals emissions from the process, as a whole, were very low, this is not considered a significant problem. It does indicate a possible high bias in the reported trace metals emissions levels.

The chloride and fluoride field blank and reagent blank results presented in Table 7-7 shows that no analytes were detected in either the field blank or the reagent blank. This is an ideal result suggesting that there is no were no biases in either the chloride or fluoride sampling.

7.4 Analytical Quality Assurance

A number of laboratory QA/QC samples were processed along with the field samples. All of these results showed no biases in reporting the correct value, and support the conclusion that the

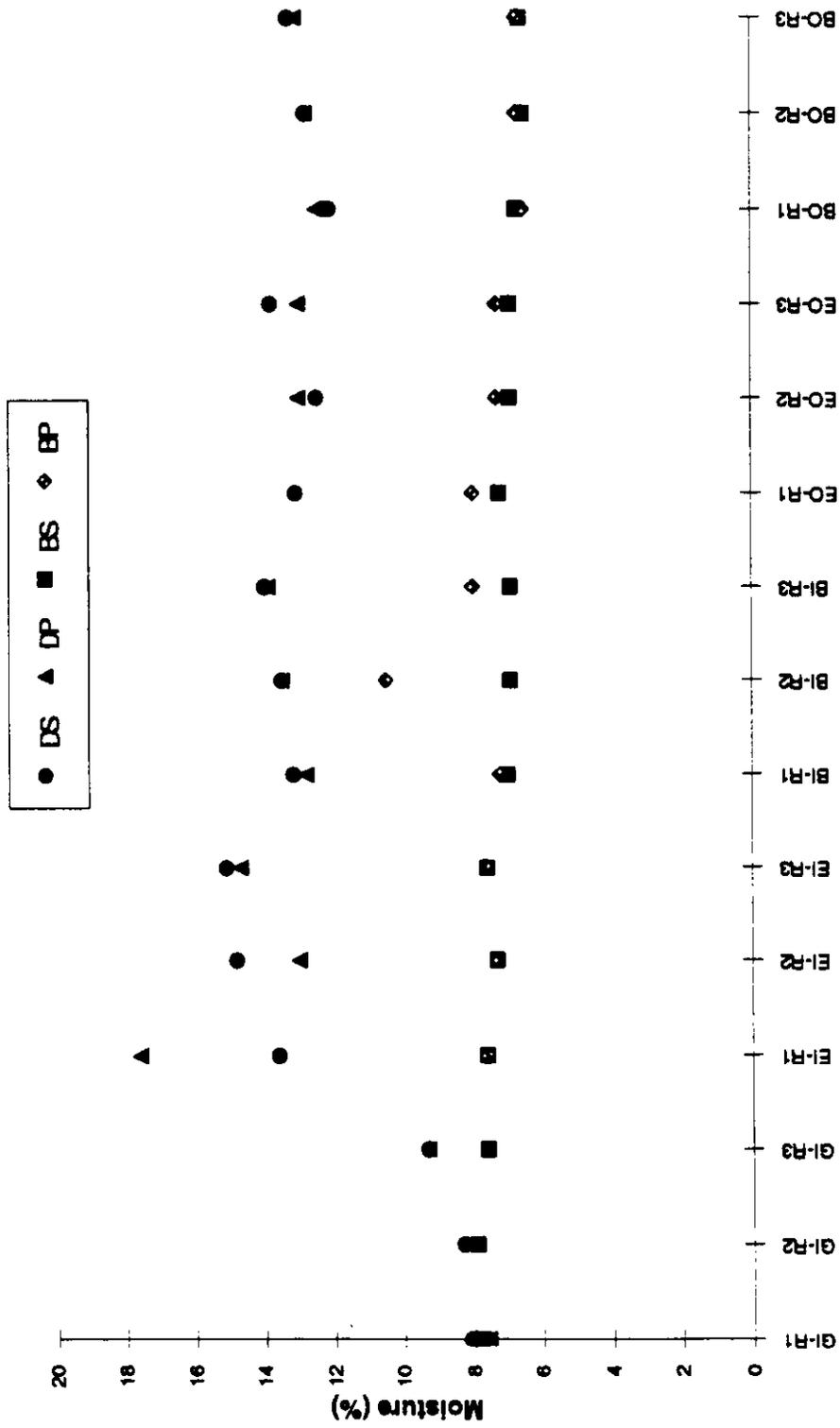


Figure 7-2. Moisture content measured by different sampling trains.

TABLE 7-4. MULTIPLE METALS (METHOD 29) FIELD BLANK RESULTS

		Series Configuration - September 27, 1994				
	units	GSA Inlet	ESP Inlet	Baghouse Inlet	ESP Outlet	Baghouse Outlet
Antimony	µg	ND 0.34	ND 0.34	ND 0.34	ND 0.34	ND 0.34
Arsenic	µg	2.8	ND 0.24	ND 0.24	ND 0.24	ND 0.24
Barium	µg	ND 18.6	ND 18.6	ND 18.6	ND 18.6	ND 18.6
Cadmium	µg	ND 0.014	3.1	ND 0.014	3.1	1.7
Chromium	µg	ND 10.8	ND 10.8	ND 10.8	ND 10.8	ND 10.8
Cobalt	µg	ND 4.8	ND 4.8	ND 4.8	ND 4.8	ND 4.8
Lead	µg	ND 0.188	11	3	ND 0.188	ND 0.188
Mercury	µg	ND 0.12	ND 0.12	ND 0.12	ND 0.12	ND 0.12
Manganese	µg	ND 1.6	ND 1.6	ND 1.6	ND 1.6	69
Selenium	µg	ND 0.26	ND 0.26	ND 0.26	ND 0.26	ND 0.26
Vanadium	µg	ND 36	ND 36	ND 36	ND 36	ND 36
Particulate	mg	3.5	0.4	ND 0.2	0.8	1.4

		Parallel Configuration - October 18, 1994				
	units	GSA Inlet	ESP Inlet	Baghouse Inlet	ESP Outlet	Baghouse Outlet
Antimony	µg	ND 0.34	ND 0.34	ND 0.34	ND 0.34	ND 0.34
Arsenic	µg	ND 0.24	ND 0.24	ND 0.24	10.9	ND 0.24
Barium	µg	ND 18.6	ND 18.6	ND 18.6	ND 18.6	ND 18.6
Cadmium	µg	1.9	4.1	ND 0.014	9.6	4.2
Chromium	µg	ND 10.8	30	ND 10.8	33	ND 10.8
Cobalt	µg	ND 4.8	ND 4.8	ND 4.8	7.6	ND 4.8
Lead	µg	ND 0.188	ND 0.188	1.6	7.2	2.1
Mercury	µg	ND 0.12	ND 0.12	ND 0.12	ND 0.12	ND 0.12
Manganese	µg	ND 1.6	9	ND 1.6	19	9
Selenium	µg	ND 0.26	ND 0.26	ND 0.26	ND 0.26	ND 0.26
Vanadium	µg	ND 36	ND 36	ND 36	ND 36	ND 36
Particulate	mg	9.6	7.5	5	120	6

TABLE 7-5. MULTIPLE METALS (METHOD 29)
REAGENT BLANK RESULTS

	units	Reagent Blank
Antimony	μg	ND 0.34
Arsenic	μg	ND 0.24
Barium	μg	ND 18.6
Cadmium	μg	ND 0.014
Chromium	μg	ND 10.8
Cobalt	μg	ND 4.8
Lead	μg	ND 0.188
Mercury	μg	ND 0.12
Manganese	μg	ND 1.6
Selenium	μg	ND 0.26
Vanadium	μg	ND 36
Particulate	mg	ND 0.2

TABLE 7-6BS. COMPARISON OF METHOD 29 FIELD TRAIN BLANK RESULTS
TO FIELD SAMPLES BASELINE SERIES CONFIGURATION

		Field blank as a percent of field sample											
		FB* (μ g)		GI		EI		BI		EO		BO	
		Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%
Run A	Sb	ND	0.34	ND	100	2.785	12	ND	100	ND	100	ND	100
	As		0.66	439	0	450.06	0	8.46	8	42.36	2	ND	275
	Ba	ND	18.6	595.65	3	2450	1	86.65	21	94.65	20	ND	100
	Cd		1.58	15.3	10	13.3	12	0.9	176	1.2	132	1.5	105
	Cr	ND	10.8	783.7	1	996.7	1	34.7	31	34.7	31	ND	100
	Co	ND	4.80	107.2	4	169.2	3	6.5	74	5.9	81	ND	100
	Pb		2.86	186.7	2	376.5	1	6.45	44	7.85	36	3.1	92
	Mn		14.4	1259.6	1	1300	1	36	40	37.7	38	17	85
	Hg	ND	0.12	2.8	4	3.82	3	ND	100	1.82	7	0.24	50
	Se	ND	0.26	322.07	0	150.07	0	21.2	1	104.07	0	2.7	10
	V	ND	36.0	1590	2	1770	2	ND	100	79	46	ND	100
	Part. (mg)		1.24	7420	0	6690	0	117	1	174	1	27	5
Run B	Sb	ND	0.34	ND	100	6.185	5	ND	100	ND	100	ND	100
	As		0.66	491.06	0	365.06	0	5.56	12	22.56	3	ND	275
	Ba	ND	18.6	2040	1	1744.7	1	68.65	27	109.65	17	ND	100
	Cd		1.58	18.4	9	11.9	13	0.6	263	1.1	144	2.6	61
	Cr	ND	10.8	1060	1	843.7	1	31.7	34	6.8	159	ND	100
	Co	ND	4.80	145.2	3	173.2	3	9.1	53	6.4	75	ND	100
	Pb		2.86	348.9	1	302.9	1	5.05	57	8.6	33	3.4	84
	Mn		14.4	2110.4	1	1020	1	23.4	62	44.4	32	7.4	195
	Hg	ND	0.12	6.22	2	2.52	5	0.44	27	1.24	10	1.22	10
	Se	ND	0.26	356	0	142.07	0	18.4	1	224	0	8.1	3
	V	ND	36.0	2240	2	1350	3	ND	100	ND	100	ND	100
	Part. (mg)		1.24	10100	0	3160	0	62	2	180	1	57	2
Run C	Sb	ND	0.34	3.39	10	3.09	11	ND	100	ND	100	ND	100
	As		0.66	497.06	0	378.06	0	7.06	9	15.56	4	0.66	100
	Ba	ND	18.6	2590	1	1590	1	76.65	24	95.65	19	ND	100
	Cd		1.58	19	8	12.3	13	0.9	176	0.5	316	2.6	61
	Cr	ND	10.8	1420	1	929.7	1	42.7	25	51.7	21	ND	100
	Co	ND	4.80	176.2	3	161.2	3	6.2	77	5.5	87	ND	100
	Pb		2.86	429.6	1	307.1	1	7.85	36	21	14	2.4	119
	Mn		14.4	1930	1	1190	1	31.9	45	46.7	31	8	180
	Hg	ND	0.12	4.52	3	2.24	5	ND	100	1.92	6	0.24	50
	Se	ND	0.26	290.07	0	143.07	0	25.2	1	204	0	6.1	4
	V	ND	36.0	2600	1	1350	3	ND	100	ND	100	ND	100
	Part. (mg)		1.24	10500	0	6090	0	121	1	163	1	45	3

* - Average of all five field train blank results

ND - non-detect

NDM - non-detect maximum

TABLE 7-6DS. COMPARISON OF METHOD 29 FIELD TRAIN BLANK RESULTS
TO FIELD SAMPLES DEMO SERIES CONFIGURATION

		Field blank as a percent of field sample											
		FB* (µg)	GI		EI		BI		EO		BO		
			Sample	FB%									
Run A	Sb	ND	0.34	4.39	8	1.99	17	ND	100	2.49	14	ND	100
	As		0.66	438	0	85.5	1	0.56	118	0.96	69	ND	275
	Ba	ND	18.6	283	7	1140	2	ND	100	ND	100	ND	100
	Cd		1.58	16.9	9	5.8	27	0.5	316	0.9	176	1.8	88
	Cr	ND	10.8	892	1	417	3	ND	100	ND	100	ND	100
	Co	ND	4.80	123	4	59.2	8	ND	100	ND	100	ND	100
	Pb		2.86	226	1	146	2	3.8	75	2.95	97	1.55	185
	Mn		14.4	885	2	553	3	4.1	351	32	45	7.4	195
	Hg	ND	0.12	1.3	9	0.34	35	0.44	27	0.74	16	0.74	16
	Se	ND	0.26	200	0	198	0	ND	100	1.17	22	ND	100
	V	ND	36.0	2030	2	639	6	ND	100	ND	100	ND	100
	Part. (mg)		1.24	7270	0	9160	0	60	2	77	2	33	4
Run B	Sb	ND	0.34	3.09	11	ND	100	ND	100	ND	100	ND	100
	As		0.66	473	0	109	1	ND	275	0.66	100	ND	275
	Ba	ND	18.6	258	7	1520	1	ND	100	ND	100	ND	100
	Cd		1.58	17	9	9.6	16	0.5	316	ND	15800	ND	158
	Cr	ND	10.8	880	1	551	2	ND	100	ND	100	ND	100
	Co	ND	4.80	113	4	82.2	6	ND	100	ND	100	ND	100
	Pb		2.86	203	1	158	2	4.7	61	ND	1505	1.25	229
	Mn		14.4	883	2	794	2	8	180	15.5	93	7.4	195
	Hg	ND	0.12	3.12	4	1.82	7	0.74	16	0.34	35	ND	100
	Se	ND	0.26	206	0	161	0	0.97	27	77	0	ND	100
	V	ND	36.0	1980	2	792	5	ND	100	ND	100	ND	100
	Part. (mg)		1.24	8300	0	9950	0	37	3	74	2	28	4
Run C	Sb	ND	0.34	ND	100	ND	100	ND	100	ND	100	ND	100
	As		0.66	570	0	155	0	ND	275	0.96	69	ND	275
	Ba	ND	18.6	839	2	883	2	ND	100	ND	100	ND	100
	Cd		1.58	22.5	7	6	26	0.9	176	0.6	263	1.5	105
	Cr	ND	10.8	979	1	419	3	ND	100	ND	100	ND	100
	Co	ND	4.80	148	3	68.2	7	ND	100	ND	100	ND	100
	Pb		2.86	344	1	121	2	4	72	ND	1505	2	143
	Mn		14.4	1300	1	737	2	4	360	1120	1	9	160
	Hg	ND	0.12	5.6	2	1.24	10	0.44	27	1.04	12	1.24	10
	Se	ND	0.26	284	0	105	0	ND	100	262	0	ND	100
	V	ND	36.0	2330	2	558	6	ND	100	ND	100	ND	100
	Part. (mg)		1.24	8840	0	9260	0	26	5	43	3	27	5

* - Average of all five field train blank results

ND - non-detect

NDM - non-detect maximum

TABLE 7-6BP. COMPARISON OF METHOD 29 FIELD TRAIN BLANK RESULTS TO FIELD SAMPLES BASELINE PARALLEL CONFIGURATION

		Field blank as a percent of field sample											
		FB* (μ g)		GI		EI		BI		EO		BO	
		Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%
Run A	Sb	ND	0.34	-	-	9.785	3	13.885	2	ND	100	ND	100
	As		2.28	-	-	358	1	360.1	1	28.06	8	3.46	66
	Ba	ND	18.6	-	-	744.65	2	1110	2	ND	100	ND	100
	Cd		3.96	-	-	11	36	4.8035	82	5.2	76	8.9	44
	Cr		15.8	-	-	433.7	4	410.7	4	32.7	48	ND	146
	Co	NDM	4.80	-	-	93.2	5	88.2	5	6.2	77	ND	100
	Pb		2.22	-	-	274.2	1	281.3	1	21.05	11	5.2	43
	Mn		7.7	-	-	369.5	2	345.5	2	26.4	29	18	43
	Hg	ND	0.12	-	-	ND	100	1.04	12	2.82	4	ND	100
	Se	ND	0.26	-	-	ND	100	ND	100	74.3	0	ND	100
	V	ND	36.0	-	-	837	4	882	4	ND	100	ND	100
	Part. (mg)		1.24	-	-	3710	0	3900	0	163	1	39.9	3
Run B	Sb	ND	0.34	-	-	11.985	3	18.785	2	ND	100	ND	100
	As		2.28	-	-	271.06	1	524.06	0	28.66	8	2.56	89
	Ba	ND	18.6	-	-	630.65	3	691.65	3	ND	100	ND	100
	Cd		3.96	-	-	6.1	65	10	40	4.5	88	10	40
	Cr		15.8	-	-	473.7	3	877.7	2	36.7	43	ND	146
	Co	NDM	4.80	-	-	79.1	6	114.2	4	6.8	71	ND	100
	Pb		2.22	-	-	246.05	1	404.05	1	24	9	3.75	59
	Mn		7.7	-	-	349	2	790.4	1	46	17	15	51
	Hg	ND	0.12	-	-	0.44	27	1.502	8	2.64	5	4.92	2
	Se	ND	0.26	-	-	ND	100	ND	100	41.6	1	ND	100
	V	ND	36.0	-	-	775	5	1620	2	71	51	ND	100
	Part. (mg)		1.24	-	-	1830	0	4910	0	189	1	38.7	3
Run C	Sb	ND	0.34	-	-	15.185	2	34.085	1	ND	100	ND	100
	As		2.28	-	-	568.06	0	682.06	0	33.86	7	3.66	62
	Ba	ND	18.6	-	-	263.65	7	2664	1	ND	100	ND	100
	Cd		3.96	-	-	15.7	25	10.004	40	5.6	71	11.2	35
	Cr		15.8	-	-	717.7	2	978.7	2	44.7	35	ND	146
	Co	NDM	4.80	-	-	125.2	4	167.2	3	7.2	67	ND	100
	Pb		2.22	-	-	264.05	1	595.05	0	23	10	3.85	58
	Mn		7.7	-	-	671	1	861.4	1	88	9	11	70
	Hg	ND	0.12	-	-	ND	100	1.72	7	2.74	4	10.22	1
	Se	ND	0.26	-	-	ND	100	17.2	2	110	0	ND	100
	V	ND	36.0	-	-	ND	100	1910	2	ND	100	ND	100
	Part. (mg)		1.24	-	-	4920	0	5500	0	179	1	36.2	3

* - Average of all five field train blank results

ND - non-detect

NDM - non-detect maximum

- No test conducted

TABLE 7-6DP. COMPARISON OF METHOD 29 FIELD TRAIN BLANK RESULTS TO FIELD SAMPLES DEMO PARALLEL CONFIGURATION

		Field blank as a percent of field sample											
		FB* (μ g)	GI		EI		BI		EO		BO		
			Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	Sample	FB%	
Run A	Sb	ND	0.34	13.7	2	7.99	4	29.8	1	-	-	ND	100
	As		2.28	739	0	112	2	274	1	-	-	ND	950
	Ba	ND	18.6	234	8	328	6	1480	1	-	-	ND	100
	Cd		3.96	16.9	23	7.4	54	2.7	147	-	-	8.8	45
	Cr		15.8	1060	1	84.7	19	382	4	-	-	ND	146
	Co	NDM	4.80	172	3	13.2	36	80.7	6	-	-	ND	100
	Pb		2.22	295	1	3.9	57	60.8	4	-	-	4.3	52
	Mn		7.7	1160	1	67.6	11	499	2	-	-	18	43
	Hg	ND	0.12	10	1	0.82	15	5.32	2	-	-	3.68	3
	Se	ND	0.26	26	1	ND	100	ND	100	-	-	ND	100
	V	ND	36.0	2260	2	127	28	714	5	-	-	ND	100
	Part. (mg)		1.24	9190	0	2590	0	16300	0	-	-	26.5	5
Run B	Sb	ND	0.34	16.6	2	14.5	2	19.2	2	ND	100	ND	100
	As		2.28	842	0	317	1	356	1	149	2	ND	950
	Ba	ND	18.6	133	14	949	2	530	4	487	4	ND	100
	Cd		3.96	17.1	23	7.8	51	4.3	92	3.8	104	7.3	54
	Cr		15.8	940	2	374	4	262	6	209	8	ND	146
	Co	NDM	4.80	189	3	85.2	6	50.4	10	49.2	10	ND	100
	Pb		2.22	411	1	196	1	100	2	137	2	3.7	60
	Mn		7.7	538	1	409	2	284	3	267	3	43	18
	Hg	ND	0.12	4.92	2	1.92	6	1.74	7	6.92	2	6.48	2
	Se	ND	0.26	ND	100	ND	100	ND	100	ND	100	ND	100
	V	ND	36.0	1600	2	825	4	652	6	441	8	ND	100
	Part. (mg)		1.24	8920	0	11000	0	13400	0	2650	0	17	7
Run C	Sb	ND	0.34	19.3	2	20.8	2	11.7	3	ND	100	ND	100
	As		2.28	689	0	365	1	243	1	1.76	130	1.16	197
	Ba	ND	18.6	140	13	2510	1	941	2	31.7	59	ND	100
	Cd		3.96	18.8	21	9.6	41	3.8	104	0.8	495	6	66
	Cr		15.8	797	2	536	3	263	6	ND	146	ND	146
	Co	NDM	4.80	177	3	95.2	5	61.2	8	ND	100	ND	100
	Pb		2.22	332	1	256	1	135	2	1.95	114	1.65	135
	Mn		7.7	518	1	495	2	401	2	13.4	57	22.4	34
	Hg	ND	0.12	1.42	8	3.92	3	1.74	7	6.94	2	1.88	6
	Se	ND	0.26	58.4	0	ND	100	ND	100	ND	100	ND	100
	V	ND	36.0	1210	3	971	4	573	6	ND	100	ND	100
	Part. (mg)		1.24	9120	0	13800	0	6580	0	44.9	3	33.8	4

* - Average of all five field train blank results

ND - non-detect

NDM - non-detect maximum

- No test conducted

TABLE 7-7. METHOD 26 (HCl and HF) FIELD AND REAGENT BLANK RESULTS

Sample Type	Test Condition	Sample Location	Chloride mg	Fluoride mg
Field Blank	Demonstration Parallel	GSA Inlet	ND 0.01	ND 0.03
		ESP Inlet	ND 0.01	ND 0.03
		Baghouse Inlet	ND 0.01	ND 0.03
		ESP Outlet	ND 0.01	ND 0.03
		Baghouse Outlet	ND 0.01	ND 0.03
Reagent Blank		Recovery Area	ND 0.01	ND 0.03

QA objectives were essentially achieved for the program. Summaries of the analytical quality assurance results are shown in Tables 7-8 to 7-11.

7.5 Audit Results

Performance evaluation audits (PEAs) and internal technical systems audits (TSA) were conducted by the EER QA coordinator to ensure proper procedures and representative measurement systems were used. A performance audit involves the performance of a measurement device compared to a reference. A number of performance evaluation audits (PEAs) were conducted during the program. Table 7-12 lists the equipment, a description of the performance evaluation audit, and the result of the PEAs that were conducted during the course of the test program.

Table 7-13, summarizes the results of the EPA performance evaluation audit samples which were analyzed by the appropriate laboratories for trace metals and for HCl. As can be seen from this table, APCL failed the initial PEA for specific multi-metals (arsenic, chromium, nickel and selenium). APCL was able to pass the trace metals audit during with the second EPA filter except for arsenic and chromium. The laboratory performed further quality assurance and quality control checks, summarized in Table 7-14, to determine any possible sources of bias which might account for chromium and arsenic failing the PEA. The results on table 7-14 show that there were no biases being introduced by APLC in the handling of the EPA audit sample.

The dry gas meter audit results, outlined in Table 7-15, show that all dry gas meters passed the critical orifice audit with the exception of Apex #1. Apex #1 was checked after the first complete test was performed (demonstration series run 1 for multi-metals and HCl). The dry gas meter was promptly switched with an audited control box, and this control box was used throughout the remainder of the program. The audit dry gas meter calibration value 'Y' was used to correct the results of the affected tests.

It was not possible to perform process flowrate verifications during the field campaign; however, a verification of the solids flows from the cyclone and ESP was performed during subsequent demonstration tests on December 18, 1993. The results of this testing are summarized in Table 7-16 and compared to estimated values developed for mass balances, as described in Section 6. The results of these tests were used to establish the split between the two ESP streams for the mass balance calculations. The verification tests demonstrates an excellent agreement

TABLE 7-8. MULTI-METALS TRAIN (METHOD 29) QUALITY CONTROL RESULTS

Parameter	Analysis Date	Matrix Spikes				Control Standards		Method Blank (mg/L)
		Spike Amount (mg/L)	MS Recovery (%)	MSD Recovery (%)	RPD %	Spike Amount (mg/L)	Recovery (%)	
Antimony	11/12/93	0.1	106	103	1.4	0.1	90	ND
		0.1	117	119	0.8	0.1	108	ND
		0.05	108	112	1.8	0.1	96	ND
		0.05	107	101	2.9	0.1	110	ND
Arsenic	11/12/93	0.05	100	99	0.5	0.05	95	ND
		0.05	108	103	2.4	0.05	104	ND
		0.05	116	105	5.0	0.05	97	ND
		0.05	112	92	9.8	0.05	93	ND
Barium	11/12/93	10	93	95	1.1	10	100	ND
		10	92	92	0.0	10	98.6	ND
		10	108	109	0.5	10	94.2	ND
		10	104	103	0.5	10	91.3	ND
Cadmium	11/12/93	0.5	98	97	0.5	0.5	98.4	ND
		0.003	93	89	2.2	0.003	105	ND
		0.5	97	97	0.0	0.5	95.6	ND
		0.5	101	100	0.5	0.003	103	ND
Chromium	11/12/93	5	93	95	1.1	5	95	ND
		5	98	97	0.5	5	94	ND
		5	96.4	96	0.2	5	92	ND
		5	94	96	1.1	5	99.4	ND
Cobalt	11/12/93	1	98	99	0.5	1	103	ND
		1	100	98.4	0.8	1	93	ND
		1	95	93	1.1	1	100	ND
		1	101	102	0.5	1	96.5	ND
Lead	11/12/93	3.5	96	96	0.0	3.5	97.7	ND
		0.03	85.7	82.3	2.0	0.03	90	ND
		3.5	99	100	0.5	3.5	95.4	ND
		0.03	92	90	1.1	0.03	93	ND
Manganese	11/12/93	1	98.5	98.3	0.1	1	99.3	ND
		1	105	105	0.0	1	98.1	ND
		1	91.2	92.6	0.8	1	98.4	ND
		1	97.4	99.6	1.1	1	99.1	ND
Mercury	11/12/93	0.005	99	104	2.5	0.005	106	ND
		0.005	98	98	0.0	0.005	107	ND
		0.005	99	104	2.5	0.005	97	ND
		0.005	93	106	6.5	0.005	96.8	ND
Selenium	11/12/93	0.05	93.6	91.4	1.2	0.05	110	ND
		0.05	107	97.2	4.8	0.05	109	ND
		0.05	103	109	2.8	0.05	106	ND
		0.05	89	108	9.6	0.05	95	ND
Vanadium	11/12/93	25	90	91	0.6	50	102	ND
		25	86.8	86.4	0.2	50	100	ND
		25	88	87	0.6	50	94.4	ND
		25	87.6	86.5	0.6	50	96.8	ND

TABLE 7-9. SOLIDS MULTI-METALS QUALITY CONTROL RESULTS

Parameter	Analysis Date	Matrix Spikes				Control Standards		Method Blank (mg/kg)
		Spike Amount (mg/kg)	MS Recovery (%)	MSD Recovery (%)	RPD %	Spike Amount (mg/kg)	Calibration Recovery (%)	
Antimony	22/06/94	5	102	101	0.5	0.1	111	ND 0.08
		5	97	96	0.5	0.1	111	ND 0.08
Arsenic	22/06/94	2.5	96	97	0.5	0.05	105	ND 0.06
		2.5	94	97	1.6	0.05	105	ND 0.06
Barium	22/06/94	200	99	96	1.5	20	100.5	ND 0.11
		200	99	99	0.0	20	100.5	ND 0.11
Beryllium	22/06/94	20	89	88	0.6	0.5	99.6	ND 0.015
		20	90	91	0.6	0.5	99.6	ND 0.015
Cadmium	22/06/94	12.5	127	126	0.4	5	96.4	ND 0.004
		12.5	107	102	2.4	5	96.4	ND 0.004
Chromium	22/06/94	30	99	99	0.0	0.01	98	ND 0.02
		30	107	106	0.5	0.01	98	ND 0.02
Cobalt	22/06/94	50	89	87	1.1	5	99.7	ND 0.35
		50	85	89	2.3	5	99.7	ND 0.35
Lead	22/06/94	30	94	101	3.6	0.03	95.7	ND 0.035
		30	110	121	4.8	0.03	95.7	ND 0.035
Manganese	22/06/94	50	93	90	1.6	5	99.8	ND 0.05
		50	87	90	1.7	5	99.8	ND 0.05
Mercury	22/06/94	2.5	109	115	2.7	0.005	106	ND 0.10
		2.5	107	105	0.9	0.005	106	ND 0.10
Nickel	22/06/94	50	87	88	0.6	0.05	98.4	ND 0.05
		50	91	94	1.6	0.05	98.4	ND 0.05
Selenium	22/06/94	5	89	89	0.0	0.1	101	ND 0.1
		5	82	90	4.7	0.1	101	ND 0.1
Vanadium	22/06/94	250	89	87	1.1	10	99.8	ND 0.4
		250	91	92	0.5	10	99.8	ND 0.4

TABLE 7-10. CHLORIDE AND FLUORIDE QUALITY CONTROL RESULTS

CHLORIDE		Matrix Spikes				Control Standards		Method Blank (mg/L)
RUN	Matrix	Spike Amount (ppm)	MS Recovery (%)	MSD Recovery (%)	RPD (%)	Spike Amount (ppm)	LCS Recovery (%)	
DS-R1-EI	gas	20	99	101	-2.0	10.0	100	ND
BP-R2-BI	gas	100	107	105	1.9	10.0	106	ND
DP-R2-BO	gas	20	91	94	-3.2	10.0	95	ND
BP-R1-BI	gas	20	109	103	5.7	10.0	96	ND
AVERAGE			102	101	0.7		99	
BP-R3-SS13	solid	50	87	88	-1.1	10.0	89	ND
BP-R1-SS13	solid	50	98	99	-1.0	10.0	97	ND
DS-R1-SS13	solid	50	97	97	0.0	10.0	101	ND
BP-R1-SS13	solid	50	80	78	2.5	10.0	85	ND
DP-R1-SS4	solid	50	84	84	0.0	10.0	92	ND
AVERAGE			89	89	0.0		93	
DS-R3-SS7	liquid	100	102	103	-1.0	10.0	106	ND
BP-R1-SS7	liquid	100	89	85	4.6	10.0	96	ND
AVERAGE			96	94	1.6		101	

FLUORIDE		Matrix Spikes				Control Standards		Method Blank (mg/L)
RUN	Matrix	Spike Amount (ppm)	MS Recovery (%)	MSD Recovery (%)	RPD (%)	Spike Amount (ppm)	LCS Recovery (%)	
DS-R1-EI	gas	20	84	87	-3.5	10.0	95	ND
BP-R2-BI	gas	100	95	96	-1.0	10.0	99	ND
DP-R2-BO	gas	20	95	94	1.1	10.0	98	ND
BP-R1-BI	gas	20	105	104	1.0	10.0	98	ND
AVERAGE			95	95	-0.5		98	

TABLE 7-11. COAL QUALITY CONTROL RESULTS

Parameter	Certified Standard			Duplicate Analysis		
	Certified Amount ($\mu\text{g/g}$)	Reported Value ($\mu\text{g/g}$)	Recovery (%)	BP 1st run ($\mu\text{g/g}$)	BP 2nd run ($\mu\text{g/g}$)	RPD (%)
Antimony	6.8	6.7	99	0.6	0.6	100
Arsenic	3.72	2.32	62	5	6	82
Barium	0.15	0.14	93	64	64	100
Beryllium	12	8	67	0.9	0.9	100
Cadmium	0.057	0.06	105	0.09	0.12	71
Chromium	196	179	91	18	17	106
Cobalt	46	43	93	4	4	100
Lead	72	71	99	5	6	82
Manganese	179	175	98	35	35	100
Mercury (DGAA)	0.25	0.25	100	0.09	0.08	112
Mercury (D3684)	0.25	0.21	84	0.08	0.08	100
Nickel	127	118	93	8	10	78
Selenium	1.3	1	77	2	2	100
Vanadium	297	299	101	33	33	100
Chloride (wt. %, dry)	1260	1160	92	0.02	0.02	100

TABLE 7-12. SUMMARY OF PERFORMANCE EVALUATION AUDITS

Equipment	Description	Results
APCL Analytical Procedure	Analysis of blind EPA audit filter for metals	Metals - APCL performed analysis on two audit samples eventually meeting all standards except for arsenic and chromium (Table 7-12). APCL then conducted an internal QC check on these metals with recoveries between 82.9% - 108% (Table 7-13).
Pyramid Analytical Procedures	Analysis of blind EPA audit solution for HCl	HCl - passed audit sample ($\pm 10\%$ of EPA value). No audit sample available for HF.
Dry Gas Meters	Critical orifice check for all dry gas meters	All but one dry gas meter passed within 5%. The dry gas meter was switched out after two tests and the audit 'Y' value was used for the affected tests.
Analytical balances	Comparison against known weight	Triple beam balance was within 0.04%.
Stack pitot tubes	Verification of pitot tube dimensions	Met all method criteria
Stack TC	Comparison against mercury-in-glass thermometer	All TCs were within $\pm 3\%$ of thermometer

TABLE 7-13. FLUE GAS PERFORMANCE EVALUATION AUDIT RESULTS

		Units	Low Level	Pass/Fail	High Level	Pass/Fail
First Sample Multi-Metals Train (EPA Method 29) Sample No. 375	Antimony	µg	3.12	Pass	4.93	Pass
	Arsenic	µg	7.78	Fail	18	Fail
	Cadmium	µg	5.46	Pass	49.3	Pass
	Chromium	µg	5.76	Fail	48	Pass
	Lead	µg	23.3	Pass	249	Pass
	Manganese	µg	6.4	Pass	49.1	Pass
	Nickel	µg	10.3	Fail	215	Pass
	Mercury	µg	0.5	Pass	0.5	Pass
	Selenium	µg	2.75	Fail	10.1	Pass
Second Sample Multi-Metals Train (EPA Method 29) Sample No. 378	Arsenic	µg	10.9	Fail	16.9	Pass
	Chromium	µg	7.89	Fail		
	Nickel	µg	16	Pass		
	Selenium	µg	3.75	Pass		
HCl Train (EPA Method 26) Samples J1531, and J1705	HCl	mg/L	47	Pass	688	Pass

TABLE 7-14. LABORATORY QC CHECK FOR METALS

QC Check		Chromium	Arsenic
Sample Spike	Spike (µg)	7.89	10.9
	Duplicate (µg)	7.9	11.7
Post Digest Spike	Spike (µg)	10	1.5
	Recovery (%)	94.5	108
	Recovery (%)	96	-
Filter Spike	Spike (µg)	5	2.5
	Recovery (%)	108	89.4
	Recovery (%)	107	82.9
ERA Reference Standards	Recovery (%)	98	95.8
	Recovery (%)	103	96.8

Note: 1) Duplicate analysis conducted at a different dilution.

2) Post Digest Spike: the metal is spiked directly into digestate

3) Filter Spike: metals are spiked onto a quartz filter which is then digested by using the same procedures as audit samples.

4) Calculations for the spike filter are blank corrected.

TABLE 7-15. DRY GAS METER AUDIT RESULTS

Dry Gas Meter Identification	Sampling Location	Pretest Y	Audit Y	Deviation (%)	Affected Tests
NU1	GSA Inlet	1.017	1.012	0.49	DS Run 1
Apex #1	ESP Inlet	1.047	0.970	-7.95	
Orange	ESP Inlet	0.971	0.970	-1.38	
NU2	FF Inlet	0.993	1.000	0.7	
Green	ESP Outlet	0.989	0.960	-2.97	
ST2	FF Outlet	1.009	1.000	0	

* Audit Y must be in range of pretest Y \pm 5%.

TABLE 7-16. PROCESS FLOWRATE VERIFICATION

	Start & Stop Time	Units	GSA Solids (SS5)	ESP Field 1 (SS9A)	ESP Field 2-4 (SS9B)	Total Solids
As weighed by AirPol	09:35-10:30	kg/hr	250.0	432.5	49.0	731.5
Dec. 18, 1993	12:44-13:40	kg/hr	255.0	381.0	52.0	688.0
Estimated EER	Average	kg/hr	252.5	406.8	50.5	709.8
	Demonstration Series Average	kg/hr	409	285	34.2	728.2
Relative Percent Difference			(%)	65	62	103

between the estimated and measured total solids flow rate. The verification test showed that GSA solids flow rates may be over-estimated, and ESP solids flow rates under-estimated. This difference does not significantly affect the emission or removal efficiency results reported earlier, but may indicate a low bias in the ESP inlet measurements. This also is evident in the mass balances presented in Section 6.

A technical systems audit involves observation and documentation of a procedure. A summary of the TSAs that were performed are shown in Table 7-17. As shown in the table, system audits were conducted for the flue gas sampling trains, process sampling procedures, and the data reduction activities. It should be noted that if any problems were recognized during the systems audit, corrective action was implemented immediately at that time. Most TSAs were performed before and during the first two days of sampling to avoid any errors being carried through the program. A follow up systems audit was performed if necessary to ensure any difficulties observed in the initial audit were corrected.

7.6 Deviations to the Sampling and Analysis Plan

Deviations to the Sampling and Analysis Plan dated September 9, 1993 include:

- The mercury analytical procedure was modified during analysis of the parallel configurations to reflect proposed changes in EPA Method 101A analytical procedures. The modification consisted of filtering the potassium permanganate solutions and separately analyzing the filtered solids.
- Front-half and back-half EPA Method 29 final digest volumes reduced from 300 and 150 mls down to 100 mls each for better detection limits.
- Expanded sampling matrix to include new sampling locations (SS13 and SS14), and added number of samples at the planned locations. Table 2-1 summarized the original and final field sampling program.
- Use of ultra-high purity (HPLC grade) reagents in the flue gas metals sampling trains to reduce background contamination.

TABLE 7-17. SUMMARY OF INTERNAL SYSTEM AUDITS

Date	Test Phase	Measurement System	Result
20/09/93	Before Testing	Archive reagent and recovery blanks for EPA Method 29	performed
20/09/93		Archive reagent and recovery blanks for EPA Method 26	performed
20/09/93		EPA Method 29 proof blanks	completed
20/09/93		EPA Method 26 proof blanks	completed
22/09/93		Verify that all equipment has been calibrated	satisfactory
22/09/93		Verify all data reduction and data collection activities	performed
22/09/93		Pretest TSA for EPA method 29 trains	completed
22/09/93		Pretest TSA for EPA method 26 trains	completed
22/09/93		PEA of meter box orifice checks	completed *1
20/09/93		Verification of coal feed and sample location representativeness	satisfactory
20/09/93		Verification of lime slurry feed and sample location representativeness	satisfactory
20/09/93		Verification of cyclone solids stream and sample location representativeness	satisfactory
20/09/93		Verification of ESP ash stream and sample location representativeness	satisfactory
20/09/93		Verification of fabric filter ash stream and sample location representativeness	satisfactory
22/09/93		During Testing	EPA Method 29 sample train preparation
22/09/93	EPA Method 29 sample train operation		satisfactory
22/09/93	EPA Method 29 sample train recovery		satisfactory
22/09/93	EPA Method 26 sample train preparation		satisfactory
22/09/93	EPA Method 26 sample train operation		satisfactory
22/09/93	EPA Method 26 sample train recovery		satisfactory
22/09/93	Solid process sample collection, handling and splitting		satisfactory
22/09/93	Liquid process sample collection, handling and splitting		satisfactory
22/09/93	Sample storage and custody	satisfactory	
25/10/93	Post Test	Sample shipping	satisfactory

*1 - Apex #1 meter box failed the dry gas meter critical orifice audit. The meter box was changed out and the critical orifice meter box calibration value was used for the affected runs - ESP Inlet Run #1 for HCl and multimetals during the demonstration series testing.

- **Modification of the EPA Method 29 impinger contents by increasing the quantity of HNO₃/H₂O₂ from 100 ml to 500 ml and by the use of jumbo (2-L) impingers to compensate for high SO₂ concentration in the flue gas.**
- **High negative pressure (-30 in. H₂O) required that the sampling trains be drawing sample as they were entering and exiting the sampling port.**
- **Coal samples were provided by TVA personnel to EER.**
- **Lime slurry samples were collected from a sampling valve in the feed line at 1-hour intervals. The samples were composited at the end of each test for individual run results.**
- **Separate ESP ash samples were collected from conveyers for ESP field 1 (SS9A) and ESP fields 2-4 (SS9B). Each location was sampled at 1-hour intervals during the flue gas testing, and the samples from each conveyer were composited at the end of the test to form two independent results.**
- **Fabric filter solids samples were collected at one hour intervals using a Tedlar-lined sample thief. The samples were combined in a larger container to form a run composite.**
- **The trim water (SS14) sampling location was added to the program. Samples were collected from a valve installed in the feed line into a clean 250 ml amber sample jar.**
- **The fly ash reinjection (SS13) sampling location was added to the program. Samples were collected at one hour intervals. The samples were combined and composited at the end of each run to form individual run results.**

7.7 Quality Assurance Organization

The QA/QC organization is shown in Figure 7-3. The test program was organized to provide internal QA functions which were independent of the program performance. The EER QA Manager was Mr. Jerry Cole. Mr. Cole was responsible for defining and monitoring QA/QC activities according to the QA plan. The EER QA Coordinator was Mr. Greg Rooney. Mr.

Rooney's responsibilities included internal QA audit activities, QA checks, documentation and reporting, and approval of all project QA.

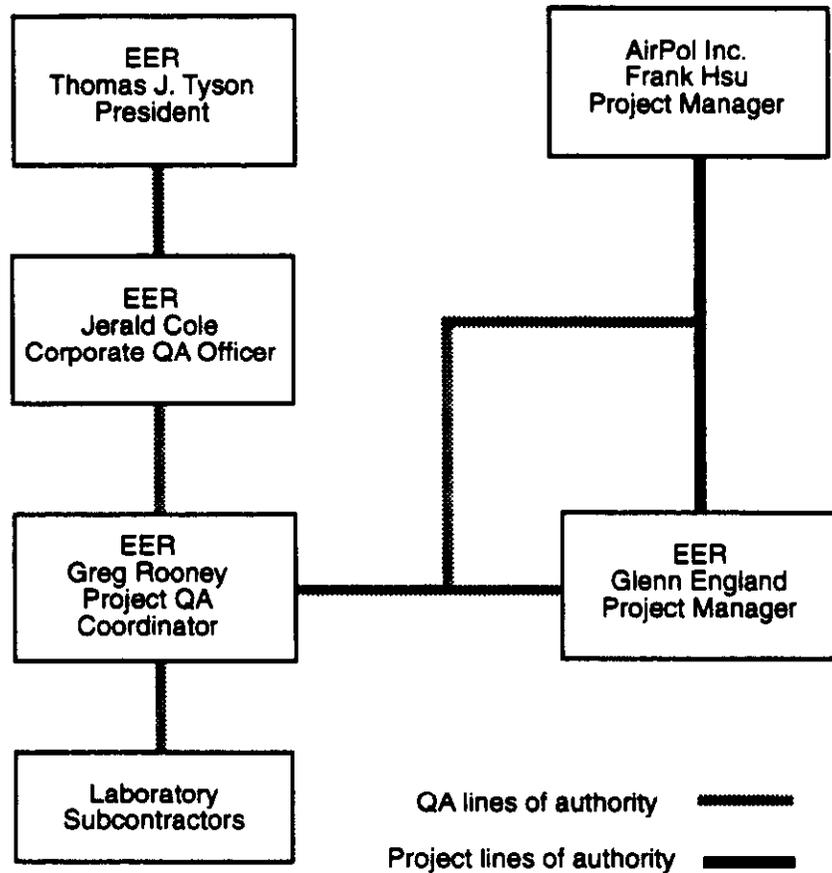


Figure 7-3. QA organization.

8.0 UNCERTAINTY ANALYSIS

8.1 Objective

An uncertainty analysis provides the following key aspects when evaluating the data:

- Identifies corrective action required to achieve test objectives;
- Provides test validation;
- Reduces risks of making erroneous decisions; and
- Demonstrates compliance with agreements.

For this program, an uncertainty analysis provides the end users with a 95% confidence interval for the data and an estimate of an upper limit in the measured emissions. An uncertainty analysis was performed on the following parameters generated from this program:

- Flue gas concentrations of trace metals, particulate, and acid gases for all flue gas streams venting to the atmosphere during each test condition;
- Flue gas mass emission rates for trace metals, particulate, and acid gases for all flue gas streams venting to the atmosphere during each test condition;
- Emission factors for trace metals, particulate, and acid gases for all flue gas streams venting to the atmosphere during each test condition;
- Achieved removal efficiencies during the baseline and demonstration tests, for trace metals, particulate, and acid gases for three different configurations (1) GSA + ESP (parallel + series), (2) GSA + FF, (3) GSA + ESP + FF.

In the tables that follow, the reported results, the total uncertainty, and a 95% confidence upper bound is given for each of the compounds of interest. The total uncertainty represents the 95% confidence interval, two-tailed, based on a students "t" distribution. The 95% confidence upper bound estimate is based on the single-tailed students "t" distribution at the 95% confidence level.

Interpretation of the reported uncertainties can be clarified with a specific example from the results. Mercury has been reported for the demonstration tests at the ESP Outlet (Table 8-1) with a concentration of 1.74 ug/dscm. The total uncertainty is reported at 21.7%. This implies that the measured concentration of 1.74 ug/dscm will be between $\pm 21.7\%$ of 1.74 ug/dscm 95% of the

time when the unit is run under the same operating conditions. The upper bound is reported as 1.95 ug/dscm. This can be interpreted as follows: 95% of the time, for the unit run under the same operating conditions, the flue gas concentration for mercury will be less than 1.95 ug/dscm. A discussion and example calculations are presented in Section 8.6. Results for each of the parameters listed above are discussed in the following sections.

8.2 Flue Gas Concentrations

The uncertainty analysis results for the measured pollutant flue gas concentrations are shown in Table 8-1. This table presents concentrations from all of the streams venting to the atmosphere during the baseline and demonstration tests. In general, most of the calculated uncertainties were within reasonable limits. When high uncertainties did occur, these were generally the result of data scatter rather than a bias associated with the measured result. HCl and HF were not measured at the ESP outlet during parallel tests, therefore uncertainties are not presented. All pollutants for the ESP Outlet during the demonstration tests have elevated uncertainties associated with the reported results. This is due the limited data of only two test runs, resulting in t factors that are extremely conservative.

8.3 Flue Gas Mass Emission Rates

The uncertainty results for the pollutant mass emission rates are shown in Table 8-2.

8.4 Emission Factors

The uncertainty results for the pollutant emission factors at each of the flue gas locations vented to the atmosphere are given in Table 8-3. Emission factors were determined from a Fd factor computed from a fuel analysis. The bias associated with the fuel analysis and the known bias from the flue gas concentrations were combined to calculate the emission factor uncertainties. All calculated uncertainties were within reasonable limits, except for the ESP Outlet emissions during the demonstration parallel tests. These uncertainties are elevated due to the limited data of only two test runs.

sampled. We chose to limit the bias of the sample collection to only the errors associated with the measured amount of volume collected.

The equation for the dry standard volume collected is given in Equation 8-1.

Equation 8-1

$$V_m(\text{std}) = V_m * Y * \frac{T_{\text{std}}}{T_m} * \left[\frac{P_{\text{bar}} + \frac{\Delta H}{13.6}}{P_{\text{std}}} \right]$$

Where:

$V_m(\text{std})$	= Standard Volume
V_m	= Measured Volume
Y	= Meter Correction Factor
T_{std}	= Standard Temperature
T_m	= Meter Temperature
P_{bar}	= Barometric Pressure
ΔH	= Meter Pressure
13.6	= Factor from in H ₂ O to in Hg
P_{std}	= Standard Pressure

The following relative bias can be assigned to each of the measurement parameters:

<u>Parameter</u>	<u>Relative Bias</u> (%B)	<u>Notes</u>
$V_m(\text{std})$	5%	EER calibrates dry gas meters using a secondary dry gas meter as a standard. The secondary is calibrated from an NBS standard to $\pm 3\%$ and the field dry gas meter is calibrated from the secondary standard to $\pm 2\%$, giving a total accuracy of $\pm 5\%$.
T_m	1.5%	Taken from EPA QA Handbook, Volume III
P_{bar}	4%	Taken from EPA QA Handbook, Volume III
ΔH	2%	Estimated from operator error.

Equation 8-2 (Equation 3.10 of the referenced document¹), presents the total relative bias associated with a result.

Equation 8-2

$$\text{Total Bias} = \left[\sum_{i=1}^j \left(\theta_i \frac{B_{-P_i}}{P_i} \right)^2 \right]^{1/2}$$

Where

Note:

Substituting the % Bias stated above results in a total volume bias error of:

$$\%B_{Vm(std)} = 6.5 \%$$

We will assume this to be the total sampling bias error.

Flue Gas Concentrations

Stack gas uncertainties were calculated using the spreadsheet presented in Tables 8-6a through Table 8-6l. The following information is contained in the spreadsheet.

- The reported concentration and reported units;
- The sampling bias: calculated above to be 6.5%;
- The analytical bias: obtained from matrix spikes, lab spikes, and/or surrogate spikes performed during the program. These are the achieved accuracy quality assurance objectives presented in Table 7-3 of this report.;
- The total bias: This is computed using Equation 8-2 above. The equation used to calculate flue gas concentrations for this program is given in Equation 8-4:

Equation 8-4

$$\text{Concentration} = \frac{M}{Vm(std)}$$

Where: M = Amount of analyte captured in sample train
 Vm(std) = Standard Volume collected through the sample train

Computing the relative partial derivatives of the volume equation (Eq. 8-4) with respect to each of the parameters (θ_i), multiplying by the individual bias ($B_{\frac{P_i}{P_i}}$), and dividing by the value

of each parameter ($\overline{P_i}$), the relative bias indexes ($\theta_i \frac{B_{\frac{P_i}{P_i}}}{\overline{P_i}}$) can be computed as follows:

TABLE 8-6a. BASELINE PARALLEL-ESP OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.079	ug/dscm	6.5	9.0	11.1	15.1	39.1	0.101
ARSENIC	6.962	ug/dscm	6.5	4.0	7.6	11.2	28.8	8.379
BARIUM	4.317	ug/dscm	6.5	0.0	6.5	15.1	38.0	5.450
CADMIUM	1.185	ug/dscm	6.5	3.0	7.2	19.3	48.4	1.580
CHROMIUM	8.716	ug/dscm	6.5	4.0	7.6	9.3	24.2	10.231
COBALT	1.552	ug/dscm	6.5	2.0	6.8	8.0	20.9	1.785
LEAD	5.232	ug/dscm	6.5	7.0	9.6	8.7	23.7	6.151
MANGANESE	11.843	ug/dscm	6.5	2.0	6.8	50.1	124.5	21.874
MERCURY	0.636	ug/dscm	6.5	0.0	6.5	18.0	45.3	0.834
SELENIUM	17.425	ug/dscm	6.5	0.0	6.5	43.3	107.7	30.195
VANADIUM	7.947	ug/dscm	6.5	12.0	13.6	78.8	196.1	18.557
PARTICULATE	40.752	mg/dscm	6.5	1.0	6.6	8.2	21.5	47.018
HCl	---	mg/dscm	---	---	---	---	---	---
HF	---	mg/dscm	---	---	---	---	---	---

- (1) Determined from discussion in Section 8.6
 - (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-6b. BASELINE PARALLEL-FABRIC FILTER OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.102	ug/dscm	6.5	9.0	11.1	2.7	13.0	0.115
ARSENIC	0.975	ug/dscm	6.5	4.0	7.6	20.5	51.5	1.320
BARIUM	5.603	ug/dscm	6.5	0.0	6.5	2.7	9.4	6.050
CADMIUM	3.023	ug/dscm	6.5	3.0	7.2	12.0	30.5	3.669
CHROMIUM	3.254	ug/dscm	6.5	4.0	7.6	2.7	10.2	3.544
COBALT	1.446	ug/dscm	6.5	2.0	6.8	2.7	9.6	1.565
LEAD	1.287	ug/dscm	6.5	7.0	9.6	20.8	52.4	1.755
MANGANESE	4.417	ug/dscm	6.5	2.0	6.8	24.3	60.8	6.254
MERCURY	1.526	ug/dscm	6.5	0.0	6.5	101.9	253.1	4.150
SELENIUM	0.078	ug/dscm	6.5	0.0	6.5	2.7	9.4	0.085
VANADIUM	10.845	ug/dscm	6.5	12.0	13.6	2.7	15.2	12.407
PARTICULATE	11.527	mg/dscm	6.5	1.0	6.6	5.3	14.7	12.803
HCl	24.871	mg/dscm	6.5	1.0	6.6	5.3	14.7	27.636
HF	2.452	mg/dscm	6.5	5.0	8.2	74.0	183.9	5.518

- (1) Determined from discussion in Section 8.6
- (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

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TABLE 8-6c. BASELINE SERIES-FABRIC FILTER OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.095	ug/dscm	6.5	9.0	11.1	10.6	28.5	0.115
ARSENIC	0.090	ug/dscm	6.5	4.0	7.6	112.6	279.6	0.262
BARIUM	5.222	ug/dscm	6.5	0.0	6.5	10.6	27.0	6.213
CADMIUM	0.634	ug/dscm	6.5	3.0	7.2	34.0	84.8	1.000
CHROMIUM	3.032	ug/dscm	6.5	4.0	7.6	10.6	27.3	3.620
COBALT	1.348	ug/dscm	6.5	2.0	6.8	10.6	27.1	1.605
LEAD	0.823	ug/dscm	6.5	7.0	9.6	8.4	22.9	0.963
MANGANESE	2.987	ug/dscm	6.5	2.0	6.8	44.8	111.4	5.252
MERCURY	0.153	ug/dscm	6.5	0.0	6.5	94.7	235.2	0.398
SELENIUM	1.588	ug/dscm	6.5	0.0	6.5	48.1	119.6	2.880
VANADIUM	10.108	ug/dscm	6.5	12.0	13.6	10.6	29.6	12.376
PARTICULATE	12.052	mg/dscm	6.5	1.0	6.6	35.2	87.7	19.257
HCl	24.918	mg/dscm	6.5	1.0	6.6	4.7	13.3	27.476
HF	5.689	mg/dscm	6.5	5.0	8.2	21.7	54.5	7.821

(1) Determined from discussion in Section 8.6

(2) Determined from average achieved quality assurance objectives shown in Table 7-3.

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

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TABLE 8-6d. DEMONSTRATION PARALLEL-ESP OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.085	ug/dscm	6.5	9.0	11.1	2.5	25.2	0.099
ARSENIC	19.232	ug/dscm	6.5	4.0	7.6	138.2	1241.4	137.937
BARIUM	65.978	ug/dscm	6.5	0.0	6.5	124.7	1120.0	433.385
CADMIUM	0.584	ug/dscm	6.5	3.0	7.2	93.5	839.9	3.024
CHROMIUM	27.289	ug/dscm	6.5	4.0	7.6	134.5	1208.1	191.207
COBALT	6.189	ug/dscm	6.5	2.0	6.8	127.9	1148.8	41.539
LEAD	17.723	ug/dscm	6.5	7.0	9.6	137.6	1235.7	126.610
MANGANESE	35.711	ug/dscm	6.5	2.0	6.8	128.4	1152.7	240.371
MERCURY	1.737	ug/dscm	6.5	0.0	6.5	2.3	21.7	1.949
SELENIUM	0.065	ug/dscm	6.5	0.0	6.5	2.5	23.5	0.074
VANADIUM	58.474	ug/dscm	6.5	12.0	13.6	130.7	1173.8	399.790
PARTICULATE	343.587	mg/dscm	6.5	1.0	6.6	136.9	1229.2	2443.316
HCl	---	mg/dscm	---	---	---	---	---	---
HF	---	mg/dscm	---	---	---	---	---	---

- (1) Determined from discussion in Section 8.6
 - (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=12.706$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=6.314$ *
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TABLE 8-6c. DEMONSTRATION PARALLEL-FABRIC FILTER OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.086	ug/dscm	6.5	9.0	11.1	1.9	12.0	0.096
ARSENIC	0.116	ug/dscm	6.5	4.0	7.6	127.5	316.5	0.366
BARIUM	4.701	ug/dscm	6.5	0.0	6.5	1.9	8.0	5.040
CADMIUM	1.866	ug/dscm	6.5	3.0	7.2	20.4	51.1	2.520
CHROMIUM	2.730	ug/dscm	6.5	4.0	7.6	1.9	8.9	2.955
COBALT	1.213	ug/dscm	6.5	2.0	6.8	1.9	8.2	1.304
LEAD	0.817	ug/dscm	6.5	7.0	9.6	44.4	110.6	1.433
MANGANESE	7.045	ug/dscm	6.5	2.0	6.8	49.1	122.1	12.897
MERCURY	1.021	ug/dscm	6.5	0.0	6.5	58.9	146.3	2.035
SELENIUM	0.066	ug/dscm	6.5	0.0	6.5	1.9	8.0	0.070
VANADIUM	9.100	ug/dscm	6.5	12.0	13.6	1.9	14.4	10.374
PARTICULATE	6.490	mg/dscm	6.5	1.0	6.6	31.1	77.5	9.921
HCl	0.010	mg/dscm	6.5	1.0	6.6	4.5	12.9	0.011
HF	0.031	mg/dscm	6.5	5.0	8.2	4.5	13.8	0.035

(1) Determined from discussion in Section 8.6

(2) Determined from average achieved quality assurance objectives shown in Table 7-3.

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

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TABLE 8-6f. DEMONSTRATION SERIES-FABRIC FILTER OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.079	ug/dscm	6.5	9.0	11.1	2.9	13.2	0.089
ARSENIC	0.056	ug/dscm	6.5	4.0	7.6	2.9	10.5	0.061
BARIUM	4.347	ug/dscm	6.5	0.0	6.5	2.9	9.7	4.701
CADMIUM	0.299	ug/dscm	6.5	3.0	7.2	55.4	137.8	0.580
CHROMIUM	2.524	ug/dscm	6.5	4.0	7.6	2.9	10.5	2.753
COBALT	1.122	ug/dscm	6.5	2.0	6.8	2.9	9.9	1.216
LEAD	0.374	ug/dscm	6.5	7.0	9.6	24.6	61.9	0.534
MANGANESE	1.854	ug/dscm	6.5	2.0	6.8	11.9	30.4	2.248
MERCURY	0.160	ug/dscm	6.5	0.0	6.5	86.6	215.0	0.395
SELENIUM	0.061	ug/dscm	6.5	0.0	6.5	2.9	9.7	0.066
VANADIUM	8.414	ug/dscm	6.5	12.0	13.6	2.9	15.4	9.634
PARTICULATE	6.875	mg/dscm	6.5	1.0	6.6	13.4	33.9	8.490
HCl	0.293	mg/dscm	6.5	1.0	6.6	169.8	421.5	1.133
HF	0.030	mg/dscm	6.5	5.0	8.2	2.9	10.8	0.033

- (1) Determined from discussion in Section 8.6
 - (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
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TABLE 8-6g. BASELINE PARALLEL-FABRIC FILTER INLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	23.596	mg/dscm	6.5	1.0	6.6	7.8	20.5	27.080
HF	0.673	mg/dscm	6.5	5.0	8.2	23.9	59.9	0.949

- (1) Determined from discussion in Section 8.6
- (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

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TABLE 8-6h. BASELINE SERIES FABRIC FILTER INLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	21.948	mg/dscm	6.5	1.0	6.6	18.6	46.7	28,994
HF	3.858	mg/dscm	6.5	5.0	8.2	55.5	137.9	7,480

- (1) Determined from discussion in Section 8.6
- (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

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TABLE 8-6i. BASELINE SERIES-ESP OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.090	ug/dscm	6.5	9.0	11.1	1.3	11.5	0.100
ARSENIC	7.131	ug/dscm	6.5	4.0	7.6	52.8	131.3	13.502
BARIUM	26.490	ug/dscm	6.5	0.0	6.5	7.1	18.9	30.110
CADMIUM	0.248	ug/dscm	6.5	3.0	7.2	40.5	100.9	0.419
CHROMIUM	8.274	ug/dscm	6.5	4.0	7.6	73.1	181.6	18.488
COBALT	1.572	ug/dscm	6.5	2.0	6.8	6.8	18.1	1.781
LEAD	3.311	ug/dscm	6.5	7.0	9.6	59.4	147.8	6.643
MANGANESE	11.376	ug/dscm	6.5	2.0	6.8	10.3	26.4	13.494
MERCURY	0.441	ug/dscm	6.5	0.0	6.5	23.0	57.6	0.614
SELENIUM	46.897	ug/dscm	6.5	0.0	6.5	35.4	88.1	75.035
VANADIUM	10.224	ug/dscm	6.5	12.0	13.6	66.0	164.5	21.690
PARTICULATE	45.680	mg/dscm	6.5	1.0	6.6	4.5	13.0	50.265
HCl	#DIV/0!	mg/dscm	6.5	1.0	6.6	#DIV/0!	#DIV/0!	#DIV/0!
HF	#DIV/0!	mg/dscm	6.5	5.0	8.2	#DIV/0!	#DIV/0!	#DIV/0!

(1) Determined from discussion in Section 8.6

(2) Determined from average achieved quality assurance objectives shown in Table 7-3.

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

* American Society of Mechanical Engineers Performance Test Cycle 19.1-1985 Reaffirmed 1990

TABLE 8-6j. DEMONSTRATION PARALLEL-FABRIC FILTER INLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	0.195	mg/dscm	6.5	1.0	6.6	166.8	414.1	0.744
HF	0.036	mg/dscm	6.5	5.0	8.2	19.1	48.1	0.048

- (1) Determined from discussion in Section 8.6
 - (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-6k. DEMONSTRATION SERIES - FABRIC FILTER INLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	0.012	mg/dscm	6.5	1.0	6.6	8.2	21.3	0.014
HF	0.034	mg/dscm	6.5	5.0	8.2	10.6	27.6	0.041

NOTE: includes all runs from BI and EO

- (1) Determined from discussion in Section 8.6
- (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-6I. DEMONSTRATION SERIES-ESP OUTLET FLUE GAS CONCENTRATION UNCERTAINTIES

PARAMETER	Reported Concentration	Units	Sampling Bias (1) (%)	Analytical Bias (2) (%)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.243	ug/dscm	6.5	9.0	11.1	133.3	331.2	0.789
ARSENIC	0.216	ug/dscm	6.5	4.0	7.6	22.0	55.2	0.298
BARIUM	4.663	ug/dscm	6.5	0.0	6.5	3.0	9.9	5.049
CADMIUM	0.129	ug/dscm	6.5	3.0	7.2	90.8	225.6	0.326
CHROMIUM	2.708	ug/dscm	6.5	4.0	7.6	3.0	10.7	2.956
COBALT	1.203	ug/dscm	6.5	2.0	6.8	3.0	10.1	1.306
LEAD	0.270	ug/dscm	6.5	7.0	9.6	153.4	381.0	0.969
MANGANESE	96.662	ug/dscm	6.5	2.0	6.8	162.4	403.2	361.369
MERCURY	0.178	ug/dscm	6.5	0.0	6.5	49.6	123.4	0.327
SELENIUM	28.047	ug/dscm	6.5	0.0	6.5	118.8	294.9	84.226
VANADIUM	9.026	ug/dscm	6.5	12.0	13.6	3.0	15.6	10.341
PARTICULATE	16.265	mg/dscm	6.5	1.0	6.6	29.9	74.5	24.531
HCl	#DIV/0!	mg/dscm	6.5	1.0	6.6	#DIV/0!	#DIV/0!	#DIV/0!
HF	#DIV/0!	mg/dscm	6.5	5.0	8.2	#DIV/0!	#DIV/0!	#DIV/0!

- (1) Determined from discussion in Section 8.6
 - (2) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

<u>Parameter</u>	<u>Relative Bias Index</u>
Vm(std)	$-(B_{p(Vm(std))}/P_{(Vm(std))}) = \%B_{Vm(std)} = 6.5\%$, calculated above
M	$B_{p(M)}/P_{(M)} = \%B_M$

The final equation used to propagate the individual measurement biases to a total flue gas concentration bias is given by in Equation 8-5:

Equation 8-5
$$(\%B_{\text{Concentration}})^2 = (\%B_{Vm(std)})^2 + (\%B_M)^2$$

- Total Precision: Determined from the relative standard deviation of the measured data from the test runs;
- The Total Uncertainty: Calculated from Equation 8-6 (Equation 2.26 of the referenced document)¹, shown below:

Equation 8-6
$$U_{\text{Total}} = \sqrt{(B_{\text{Total}})^2 + (t * S_{\text{Total}})^2}$$

Where:

- U_{total} = Total Uncertainty
- B_{total} = Total Bias
- t = Students t factor, 95% two-tailed confidence
- S_{total} = Total Precision/SQRT(number of samples)

- The 95% Upper Bound: Calculated from Equation 8-7 (Equation 2.29B from the referenced document)¹ Shown below:

Equation 8-7
$$95\% \text{ Upper Bound} = \left[\left(\frac{\sqrt{(B_{\text{Total}})^2 + (t * S_{\text{Total}})^2}}{100} \right) + 1 \right] * \text{Reported Concentration}$$

Where:

- 95% Upper Bound = 95% Upper Bound Confidence
- B_{total} = Total Bias
- t = Students t factor, 95% single-tailed confidence

$$S_{\text{total}} = \text{Total Precision}/\text{SQRT}(\text{number of samples})$$

Mass Emission Rates

Mass emission rate uncertainties were calculated using the spreadsheets presented in Table 8-7a through Table 8-7l. The calculation procedures are identical to that described for flue gas concentration. The bias of the flue gas flowrate were added to the spreadsheet.

Emission Factors

Emission factor uncertainties were calculated using the spreadsheets presented in Table 8-8a through Table 8-8l. The calculation procedures are identical to that described for flue gas concentration. Since emission factors were calculated using an Fd analysis, the analytical bias of the Fd analysis was added to the concentration bias. The analytical bias for the Fd analysis was estimated at 10%.

ESP Removal Efficiency

Removal efficiencies were calculated for the baseline tests using the spreadsheet given in Tables 8-9a through 8-9d. The removal efficiency is a function of the total inlet to the system and the total outlet to the system. For all of the tests, the GSA inlet flue gas location and the reinjected fly ash served as the inlet to the system and the outlet flue gas served as the outlet to the system. As seen from the working spreadsheet, the removal uncertainties are not only an function of the biases associated with each of the measurements but also the individual biases are weighted to the total amount of input to the system. As discussed earlier, large removal efficiencies usually result in low uncertainties. The uncertainties for the demonstration test removal efficiencies are presented in Table 8-10a through 8-10d.

REFERENCES

¹American Society of Mechanical Engineers Performance Test Code 19.1, Reaffirmed 1990

TABLE 8-7a. BASELINE PARALLEL-ESP OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	1.944	mg/hr	11.1	10.0	14.9	14.2	38.3	2.493
ARSENIC	171.604	mg/hr	7.6	10.0	12.6	11.0	30.1	210.094
BARIUM	106.331	mg/hr	6.5	10.0	11.9	14.2	37.3	134.797
CADMIUM	29.202	mg/hr	7.2	10.0	12.3	18.8	48.3	39.140
CHROMIUM	214.920	mg/hr	7.6	10.0	12.6	9.8	27.4	259.578
COBALT	38.242	mg/hr	6.8	10.0	12.1	7.4	21.9	44.869
LEAD	128.901	mg/hr	9.6	10.0	13.8	7.8	23.8	153.470
MANGANESE	292.940	mg/hr	6.8	10.0	12.1	51.1	127.5	547.952
MERCURY	15.666	mg/hr	6.5	10.0	11.9	17.2	44.4	20.584
SELENIUM	429.978	mg/hr	6.5	10.0	11.9	43.7	109.1	750.860
VANADIUM	195.622	mg/hr	13.6	10.0	16.9	78.6	195.9	457.046
PARTICULATE	1.004	Kg/hr	6.6	10.0	12.0	7.2	21.6	1.176
HCl	---	mg/hr	---	---	---	---	---	---
HF	---	mg/hr	---	---	---	---	---	---

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
 - (7) From EPA QA Handbook, Volume III
 - (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-7b. BASELINE PARALLEL-FABRIC FILTER OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.435	mg/hr	11.1	10.0	14.9	0.3	15.0	0.500
ARSENIC	4.127	mg/hr	7.6	10.0	12.6	18.3	47.2	5.502
BARIUM	23.785	mg/hr	6.5	10.0	11.9	0.3	11.9	26.625
CADMIUM	12.833	mg/hr	7.2	10.0	12.3	11.8	31.7	15.826
CHROMIUM	13.811	mg/hr	7.6	10.0	12.6	0.3	12.6	15.550
COBALT	6.138	mg/hr	6.8	10.0	12.1	0.3	12.1	6.881
LEAD	5.452	mg/hr	9.6	10.0	13.8	18.8	48.8	7.340
MANGANESE	18.747	mg/hr	6.8	10.0	12.1	23.7	60.0	26.569
MERCURY	6.491	mg/hr	6.5	10.0	11.9	100.5	249.7	17.512
SELENIUM	0.332	mg/hr	6.5	10.0	11.9	0.3	11.9	0.372
VANADIUM	46.036	mg/hr	13.6	10.0	16.9	0.3	16.9	53.828
PARTICULATE	0.063	Kg/hr	6.6	10.0	12.0	4.6	16.6	0.072
HCl	106,006	mg/hr	6.6	10.0	12.0	9.1	25.6	126,639
HF	10,658	mg/hr	8.2	10.0	12.9	78.1	194.2	24,751

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(7) From EPA QA Handbook, Volume III

(8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-7c. BASELINE SERIES-FABRIC FILTER OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.379	mg/hr	11.1	10.0	14.9	10.9	30.8	0.468
ARSENIC	0.359	mg/hr	7.6	10.0	12.6	112.8	280.3	1.044
BARIUM	20.724	mg/hr	6.5	10.0	11.9	10.9	29.5	25.250
CADMIUM	2.518	mg/hr	7.2	10.0	12.3	34.4	86.2	4.010
CHROMIUM	12.033	mg/hr	7.6	10.0	12.6	10.9	29.7	14.705
COBALT	5.348	mg/hr	6.8	10.0	12.1	10.9	29.5	6.521
LEAD	3.266	mg/hr	9.6	10.0	13.8	8.4	25.0	3.911
MANGANESE	11.836	mg/hr	6.8	10.0	12.1	44.3	110.7	20.791
MERCURY	0.609	mg/hr	6.5	10.0	11.9	94.9	235.8	1.585
SELENIUM	6.310	mg/hr	6.5	10.0	11.9	48.4	120.7	11.510
VANADIUM	40.111	mg/hr	13.6	10.0	16.9	10.9	31.8	50.106
PARTICULATE	0.048	Kg/hr	6.6	10.0	12.0	35.6	89.1	0.077
HCl	106,875	mg/hr	6.6	10.0	12.0	4.6	16.5	122,100
HF	24,430	mg/hr	8.2	10.0	12.9	22.1	56.5	34,084

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
 - (7) From EPA QA Handbook, Volume III
 - (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-7d. DEMONSTRATION PARALLEL-ESP OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	1.712	mg/hr	11.1	10.0	14.9	0.9	16.9	1.977
ARSENIC	382.033	mg/hr	7.6	10.0	12.6	138.2	1241.4	2739.067
BARIUM	1312.082	mg/hr	6.5	10.0	11.9	124.3	1117.3	8598.103
CADMIUM	11.646	mg/hr	7.2	10.0	12.3	92.6	832.0	59.813
CHROMIUM	542.234	mg/hr	7.6	10.0	12.6	134.4	1207.3	3795.977
COBALT	123.049	mg/hr	6.8	10.0	12.1	127.6	1146.6	824.298
LEAD	352.068	mg/hr	9.6	10.0	13.8	137.5	1235.5	2514.046
MANGANESE	709.951	mg/hr	6.8	10.0	12.1	128.1	1150.6	4770.048
MERCURY	34.898	mg/hr	6.5	10.0	11.9	0.7	13.3	39.188
SELENIUM	1.309	mg/hr	6.5	10.0	11.9	0.9	14.3	1.474
VANADIUM	1162.274	mg/hr	13.6	10.0	16.9	130.5	1172.2	7934.928
PARTICULATE	6.826	Kg/hr	6.6	10.0	12.0	136.8	1228.8	48.514
HCl	---	mg/hr	---	---	---	---	---	---
HF	---	mg/hr	---	---	---	---	---	---

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=12.706$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=6.314$ *

(7) From EPA QA Handbook, Volume III

(8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

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TABLE 8-7e. DEMONSTRATION PARALLEL-FABRIC FILTER OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.423	mg/hr	11.1	10.0	14.9	1.6	15.4	0.487
ARSENIC	0.575	mg/hr	7.6	10.0	12.6	128.0	318.1	1.819
BARIUM	23.125	mg/hr	6.5	10.0	11.9	1.6	12.5	25.950
CADMIUM	9.161	mg/hr	7.2	10.0	12.3	19.1	48.9	12.315
CHROMIUM	13.427	mg/hr	7.6	10.0	12.6	1.6	13.2	15.153
COBALT	5.968	mg/hr	6.8	10.0	12.1	1.6	12.7	6.706
LEAD	4.006	mg/hr	9.6	10.0	13.8	43.5	109.0	6.998
MANGANESE	34.728	mg/hr	6.8	10.0	12.1	49.7	124.0	64.121
MERCURY	5.019	mg/hr	6.5	10.0	11.9	59.2	147.6	10.067
SELENIUM	0.323	mg/hr	6.5	10.0	11.9	1.6	12.5	0.363
VANADIUM	44.758	mg/hr	13.6	10.0	16.9	1.6	17.4	52.422
PARTICULATE	0.032	Kg/hr	6.6	10.0	12.0	31.4	79.0	0.049
HCl	52	mg/hr	6.6	10.0	12.0	0.9	12.2	58
HF	159	mg/hr	8.2	10.0	12.9	0.9	13.1	179

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- (7) From EPA QA Handbook, Volume III
- (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

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TABLE 8-7I. DEMONSTRATION SERIES-FABRIC FILTER OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.357	mg/hr	11.1	10.0	14.9	2.3	16.0	0.412
ARSENIC	0.252	mg/hr	7.6	10.0	12.6	2.3	13.8	0.285
BARIUM	19.540	mg/hr	6.5	10.0	11.9	2.3	13.2	21.992
CADMIUM	1.338	mg/hr	7.2	10.0	12.3	54.8	136.6	2.585
CHROMIUM	11.346	mg/hr	7.6	10.0	12.6	2.3	13.8	12.840
COBALT	5.043	mg/hr	6.8	10.0	12.1	2.3	13.4	5.683
LEAD	1.677	mg/hr	9.6	10.0	13.8	22.8	58.2	2.360
MANGANESE	8.324	mg/hr	6.8	10.0	12.1	10.1	27.8	10.062
MERCURY	0.713	mg/hr	6.5	10.0	11.9	85.9	213.6	1.749
SELENIUM	0.273	mg/hr	6.5	10.0	11.9	2.3	13.2	0.307
VANADIUM	37.819	mg/hr	13.6	10.0	16.9	2.3	17.9	44.385
PARTICULATE	0.031	Kg/hr	6.6	10.0	12.0	13.2	35.0	0.039
HCl	1.348	mg/hr	6.6	10.0	12.0	169.8	421.8	5.210
HF	137	mg/hr	8.2	10.0	12.9	9.0	25.8	165

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(7) From EPA QA Handbook, Volume III

(8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

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TABLE 8-7g. BASELINE PARALLEL-FABRIC FILTER INLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	439,886	mg/hr	6.6	10.0	12.0	4.5	16.4	502,195
HF	12,494	mg/hr	8.2	10.0	12.9	21.0	53.8	17,207

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- (7) From EPA QA Handbook, Volume III
- (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

TABLE 8-7h. BASELINE SERIES - FABRIC FILTER INLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate (11)	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	427,131	mg/hr	6.6	10.0	12.0	19.2	49.1	574,397
HF	75,054	mg/hr	8.2	10.0	12.9	55.6	138.6	146,049

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- (7) From EPA QA Handbook, Volume III
- (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990
- (11) Corrected to ESP outlet flow rate.

TABLE 8-7i. BASELINE SERIES-ESP OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	1.753	mg/hr	11.1	10.0	14.9	1.3	15.3	2.018
ARSENIC	138.906	mg/hr	7.6	10.0	12.6	53.2	132.7	264.708
BARIUM	515.254	mg/hr	6.5	10.0	11.9	7.5	22.1	604.862
CADMIUM	4.839	mg/hr	7.2	10.0	12.3	41.0	102.5	8.234
CHROMIUM	160.488	mg/hr	7.6	10.0	12.6	72.7	180.9	358.154
COBALT	30.588	mg/hr	6.8	10.0	12.1	7.4	21.9	35.889
LEAD	64.221	mg/hr	9.6	10.0	13.8	58.6	146.2	128.330
MANGANESE	221.167	mg/hr	6.8	10.0	12.1	9.8	27.1	266.328
MERCURY	8.568	mg/hr	6.5	10.0	11.9	22.7	57.6	12.000
SELENIUM	911.479	mg/hr	6.5	10.0	11.9	35.3	88.3	1463.956
VANADIUM	199.253	mg/hr	13.6	10.0	16.9	66.5	165.9	425.034
PARTICULATE	0.889	Kg/hr	6.6	10.0	12.0	5.2	17.5	1.020
HCl	#DIV/0!	mg/hr	6.6	10.0	12.0	#DIV/0!	#DIV/0!	#DIV/0!
HF	#DIV/0!	mg/hr	8.2	10.0	12.9	#DIV/0!	#DIV/0!	#DIV/0!

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(7) From EPA QA Handbook, Volume III

(8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-7). DEMONSTRATION PARALLEL-FABRIC FILTER INLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	4,519	mg/hr	6.6	10.0	12.0	165.8	411.9	17,163
HF	911	mg/hr	8.2	10.0	12.9	22.2	56.7	1,271

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(7) From EPA QA Handbook, Volume III

(8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-7k. DEMONSTRATION SERIES - FABRIC FILTER INLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate (11)	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	259	mg/hr	6.6	10.0	12.0	5.8	18.8	300
HF	515	mg/hr	8.2	10.0	12.9	64.9	161.7	1,083

NOTE: includes all runs from BI and EO

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
- (7) From EPA QA Handbook, Volume III
- (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990
- (11) Corrected to ESP outlet flow rate.

TABLE 8-71. DEMONSTRATION SERIES-ESP OUTLET FLUE GAS MASS EMISSION RATE UNCERTAINTIES

PARAMETER	Reported Mass Emission Rate	Units	Flue Gas Concentration Measurement Bias (3) (%)	Flue Gas Flowrate Bias (7) (%)	Total Bias (8) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	4.873	mg/hr	11.1	10.0	14.9	132.3	328.7	15.764
ARSENIC	4.399	mg/hr	7.6	10.0	12.6	20.2	51.7	5.995
BARIUM	95.153	mg/hr	6.5	10.0	11.9	1.4	12.4	106.728
CADMIUM	2.589	mg/hr	7.2	10.0	12.3	90.4	224.7	6.545
CHROMIUM	55.250	mg/hr	7.6	10.0	12.6	1.4	13.1	62.325
COBALT	24.556	mg/hr	6.8	10.0	12.1	1.4	12.6	27.583
LEAD	5.414	mg/hr	9.6	10.0	13.8	152.8	379.7	19.385
MANGANESE	1964.952	mg/hr	6.8	10.0	12.1	162.4	403.4	7350.187
MERCURY	3.608	mg/hr	6.5	10.0	11.9	48.9	121.9	6.612
SELENIUM	573.725	mg/hr	6.5	10.0	11.9	117.8	292.6	1714.922
VANADIUM	184.166	mg/hr	13.6	10.0	16.9	1.4	17.3	215.636
PARTICULATE	0.332	Kg/hr	6.6	10.0	12.0	29.8	74.9	0.503
HCl	#DIV/0!	mg/hr	6.6	10.0	12.0	#DIV/0!	#DIV/0!	#DIV/0!
HF	#DIV/0!	mg/hr	8.2	10.0	12.9	#DIV/0!	#DIV/0!	#DIV/0!

- (3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
 - (6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *
 - (7) From EPA QA Handbook, Volume III
 - (8) Calculated using concentration bias, flowrate bias, mass emission rate equation, partial derivatives, and Taylor Series *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8a. BASELINE PARALLEL-ESP OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.058	lb/10 ¹² Btu	11.1	10.0	14.9	14.9	39.9	0.074
ARSENIC	5.078	lb/10 ¹² Btu	7.6	10.0	12.6	11.2	30.6	6.233
BARIUM	3.148	lb/10 ¹² Btu	6.5	10.0	11.9	14.9	38.9	4.024
CADMIUM	0.864	lb/10 ¹² Btu	7.2	10.0	12.3	19.2	49.3	1.164
CHROMIUM	6.358	lb/10 ¹² Btu	7.6	10.0	12.6	9.5	26.7	7.652
COBALT	1.132	lb/10 ¹² Btu	6.8	10.0	12.1	7.9	23.0	1.335
LEAD	3.816	lb/10 ¹² Btu	9.6	10.0	13.8	8.5	25.3	4.577
MANGANESE	8.646	lb/10 ¹² Btu	6.8	10.0	12.1	50.4	125.7	16.067
MERCURY	0.464	lb/10 ¹² Btu	6.5	10.0	11.9	17.9	46.0	0.614
SELENIUM	12.716	lb/10 ¹² Btu	6.5	10.0	11.9	43.5	108.6	22.157
VANADIUM	5.791	lb/10 ¹² Btu	13.6	10.0	16.9	78.6	195.9	13.530
PARTICULATE	0.030	lb/10 ⁶ Btu	6.6	10.0	12.0	7.0	21.1	0.035
HCl	---	---	---	---	---	---	---	---
HF	---	---	---	---	---	---	---	---

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8b. BASELINE PARALLEL-FABRIC FILTER OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.075	lb/10 ¹² Btu	11.1	10.0	14.9	3.1	16.8	0.086
ARSENIC	0.711	lb/10 ¹² Btu	7.6	10.0	12.6	20.6	52.8	0.975
BARIUM	4.087	lb/10 ¹² Btu	6.5	10.0	11.9	2.9	13.9	4.614
CADMIUM	2.205	lb/10 ¹² Btu	7.2	10.0	12.3	12.3	32.9	2.736
CHROMIUM	2.373	lb/10 ¹² Btu	7.6	10.0	12.6	2.9	14.5	2.693
COBALT	1.055	lb/10 ¹² Btu	6.8	10.0	12.1	2.9	14.0	1.192
LEAD	0.939	lb/10 ¹² Btu	9.6	10.0	13.8	20.6	53.0	1.290
MANGANESE	3.221	lb/10 ¹² Btu	6.8	10.0	12.1	24.1	61.0	4.586
MERCURY	1.115	lb/10 ¹² Btu	6.5	10.0	11.9	102.1	253.7	3.039
SELENIUM	0.057	lb/10 ¹² Btu	6.5	10.0	11.9	3.0	14.1	0.064
VANADIUM	7.911	lb/10 ¹² Btu	13.6	10.0	16.9	2.9	18.4	9.303
PARTICULATE	0.008	lb/10 ⁶ Btu	6.6	10.0	12.0	6.9	21.0	0.010
HCl	18.142	lb/10 ¹² Btu	6.6	10.0	12.0	5.6	18.4	20.909
HF	1.534	lb/10 ¹² Btu	8.2	10.0	12.9	74.3	185.0	3.466

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8c. BASELINE SERIES-FABRIC FILTER OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.071	lb/10 ¹² Btu	11.1	10.0	14.9	10.3	29.6	0.087
ARSENIC	0.067	lb/10 ¹² Btu	7.6	10.0	12.6	112.4	279.3	0.194
BARIUM	3.863	lb/10 ¹² Btu	6.5	10.0	11.9	10.3	28.2	4.678
CADMIUM	0.469	lb/10 ¹² Btu	7.2	10.0	12.3	33.8	84.9	0.743
CHROMIUM	2.243	lb/10 ¹² Btu	7.6	10.0	12.6	10.3	28.5	2.724
COBALT	0.997	lb/10 ¹² Btu	6.8	10.0	12.1	10.3	28.3	1.208
LEAD	0.609	lb/10 ¹² Btu	9.6	10.0	13.8	8.6	25.4	0.731
MANGANESE	2.211	lb/10 ¹² Btu	6.8	10.0	12.1	44.9	112.2	3.906
MERCURY	0.113	lb/10 ¹² Btu	6.5	10.0	11.9	94.8	235.7	0.295
SELENIUM	1.175	lb/10 ¹² Btu	6.5	10.0	11.9	48.1	120.0	2.137
VANADIUM	7.478	lb/10 ¹² Btu	13.6	10.0	16.9	10.3	30.7	9.291
PARTICULATE	0.009	lb/10 ⁶ Btu	6.6	10.0	12.0	35.2	88.2	0.014
HCl	18,435	lb/10 ¹² Btu	6.6	10.0	12.0	4.4	16.2	21,035
HF	4,208	lb/10 ¹² Btu	8.2	10.0	12.9	21.5	54.9	5,825

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8d. DEMONSTRATION PARALLEL-ESP OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.062	lb/10 ¹² Btu	11.1	10.0	14.9	2.0	23.2	0.072
ARSENIC	13.829	lb/10 ¹² Btu	7.6	10.0	12.6	138.2	1241.8	99.181
BARIUM	47.459	lb/10 ¹² Btu	6.5	10.0	11.9	124.6	1119.5	311.531
CADMIUM	0.421	lb/10 ¹² Btu	7.2	10.0	12.3	93.2	837.6	2.172
CHROMIUM	19.624	lb/10 ¹² Btu	7.6	10.0	12.6	134.5	1208.3	137.474
COBALT	4.452	lb/10 ¹² Btu	6.8	10.0	12.1	127.8	1148.5	29.862
LEAD	12.744	lb/10 ¹² Btu	9.6	10.0	13.8	137.6	1236.1	91.036
MANGANESE	25.685	lb/10 ¹² Btu	6.8	10.0	12.1	128.3	1152.4	172.800
MERCURY	1.254	lb/10 ¹² Btu	6.5	10.0	11.9	1.8	19.9	1.433
SELENIUM	0.047	lb/10 ¹² Btu	6.5	10.0	11.9	2.0	21.4	0.054
VANADIUM	42.055	lb/10 ¹² Btu	13.6	10.0	16.9	130.6	1173.7	287.419
PARTICULATE	0.247	lb/10 ⁶ Btu	6.6	10.0	12.0	136.8	1229.5	1.757
HCl	---	lb/10 ¹² Btu	---	---	---	---	---	---
HF	---	lb/10 ¹² Btu	---	---	---	---	---	---

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=12.706$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=6.314$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8e. DEMONSTRATION PARALLEL-FABRIC FILTER OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.062	lb/10 ¹² Btu	11.1	10.0	14.9	1.5	15.4	0.071
ARSENIC	0.084	lb/10 ¹² Btu	7.6	10.0	12.6	127.7	317.3	0.265
BARIUM	3.391	lb/10 ¹² Btu	6.5	10.0	11.9	1.5	12.5	3.804
CADMIUM	1.345	lb/10 ¹² Btu	7.2	10.0	12.3	20.1	51.5	1.831
CHROMIUM	1.969	lb/10 ¹² Btu	7.6	10.0	12.6	1.5	13.1	2.222
COBALT	0.875	lb/10 ¹² Btu	6.8	10.0	12.1	1.5	12.6	0.983
LEAD	0.589	lb/10 ¹² Btu	9.6	10.0	13.8	44.2	110.5	1.035
MANGANESE	5.078	lb/10 ¹² Btu	6.8	10.0	12.1	48.8	121.8	9.301
MERCURY	0.735	lb/10 ¹² Btu	6.5	10.0	11.9	58.6	145.9	1.466
SELENIUM	0.047	lb/10 ¹² Btu	6.5	10.0	11.9	1.5	12.5	0.053
VANADIUM	6.563	lb/10 ¹² Btu	13.6	10.0	16.9	1.5	17.3	7.686
PARTICULATE	0.005	lb/10 ⁶ Btu	6.6	10.0	12.0	31.5	79.0	0.007
HCl	7	lb/10 ¹² Btu	6.6	10.0	12.0	4.2	16.0	8
HF	22	lb/10 ¹² Btu	8.2	10.0	12.9	4.2	16.7	26

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8f. DEMONSTRATION SERIES-FABRIC FILTER OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.058	lb/10 ¹² Btu	11.1	10.0	14.9	4.3	18.3	0.068
ARSENIC	0.041	lb/10 ¹² Btu	7.6	10.0	12.6	4.3	16.4	0.047
BARIUM	3.183	lb/10 ¹² Btu	6.5	10.0	11.9	4.3	15.9	3.626
CADMIUM	0.220	lb/10 ¹² Btu	7.2	10.0	12.3	56.1	139.9	0.429
CHROMIUM	1.848	lb/10 ¹² Btu	7.6	10.0	12.6	4.3	16.4	2.116
COBALT	0.822	lb/10 ¹² Btu	6.8	10.0	12.1	4.3	16.1	0.937
LEAD	0.273	lb/10 ¹² Btu	9.6	10.0	13.8	23.3	59.5	0.387
MANGANESE	1.356	lb/10 ¹² Btu	6.8	10.0	12.1	10.3	28.3	1.643
MERCURY	0.117	lb/10 ¹² Btu	6.5	10.0	11.9	85.4	212.4	0.286
SELENIUM	0.044	lb/10 ¹² Btu	6.5	10.0	11.9	4.3	15.9	0.051
VANADIUM	6.161	lb/10 ¹² Btu	13.6	10.0	16.9	4.3	19.9	7.294
PARTICULATE	0.005	lb/10 ⁶ Btu	6.6	10.0	12.0	15.2	39.7	0.006
HCl	210	lb/10 ¹² Btu	6.6	10.0	12.0	169.6	421.3	812
HF	21	lb/10 ¹² Btu	8.2	10.0	12.9	0.8	13.1	24

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

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TABLE 8-8g. BASELINE PARALLEL-FABRIC FILTER INLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	17,239	lb/10 ⁴ 12 Btu	6.6	10.0	12.0	7.6	22.3	20,253
HF	491	lb/10 ⁴ 12 Btu	8.2	10.0	12.9	23.6	60.1	697

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8h. BASELINE SERIES - FABRIC FILTER INLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	16,270	lb/10 ¹² Btu	6.6	10.0	12.0	18.7	48.0	21,762
HF	2,861	lb/10 ¹² Btu	8.2	10.0	12.9	55.6	138.6	5,569

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8i. BASELINE SERIES-ESP OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.067	lb/10 ¹² Btu	11.1	10.0	14.9	1.5	15.4	0.077
ARSENIC	5.283	lb/10 ¹² Btu	7.6	10.0	12.6	53.1	132.4	10.055
BARIUM	19.607	lb/10 ¹² Btu	6.5	10.0	11.9	7.0	21.1	22.897
CADMIUM	0.184	lb/10 ¹² Btu	7.2	10.0	12.3	40.7	101.7	0.312
CHROMIUM	6.126	lb/10 ¹² Btu	7.6	10.0	12.6	73.0	181.7	13.705
COBALT	1.164	lb/10 ¹² Btu	6.8	10.0	12.1	6.8	20.7	1.357
LEAD	2.450	lb/10 ¹² Btu	9.6	10.0	13.8	59.3	147.8	4.921
MANGANESE	8.420	lb/10 ¹² Btu	6.8	10.0	12.1	10.1	27.7	10.173
MERCURY	0.326	lb/10 ¹² Btu	6.5	10.0	11.9	23.1	58.6	0.459
SELENIUM	34.693	lb/10 ¹² Btu	6.5	10.0	11.9	35.2	88.2	55.695
VANADIUM	7.580	lb/10 ¹² Btu	13.6	10.0	16.9	66.3	165.6	16.153
PARTICULATE	0.034	lb/10 ⁶ Btu	6.6	10.0	12.0	4.6	16.5	0.039
HCl	0	lb/10 ¹² Btu	6.6	10.0	12.0	#DIV/0!	#DIV/0!	#DIV/0!
HF	0	lb/10 ¹² Btu	8.2	10.0	12.9	#DIV/0!	#DIV/0!	#DIV/0!

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-8j. DEMONSTRATION PARALLEL-FABRIC FILTER INLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	142	lb/10 ¹² Btu	6.6	10.0	12.0	166.8	414.3	540
HF	26	lb/10 ¹² Btu	8.2	10.0	12.9	18.8	48.5	35

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

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TABLE 8-8k. DEMONSTRATION SERIES - FABRIC FILTER INLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
HCl	9	lb/10 ¹² Btu	6.6	10.0	12.0	5.3	17.8	11
HF	24	lb/10 ¹² Btu	8.2	10.0	12.9	24.5	62.1	35

NOTE: includes all runs from BI and EO

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-81. DEMONSTRATION SERIES-ESP OUTLET EMISSION FACTOR UNCERTAINTIES

PARAMETER	Reported Emission Factor	Units	Flue Gas Concentration Measurement Bias (3) (%)	Fd Analysis Bias (9) (%)	Total Bias (10) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)	95% Confidence Upper Bound (6) (in reported units)
ANTIMONY	0.181	lb/10 ¹² Btu	11.1	10.0	14.9	134.4	333.9	0.592
ARSENIC	0.159	lb/10 ¹² Btu	7.6	10.0	12.6	22.3	56.7	0.221
BARIUM	3.422	lb/10 ¹² Btu	6.5	10.0	11.9	4.7	16.7	3.912
CADMIUM	0.095	lb/10 ¹² Btu	7.2	10.0	12.3	91.9	228.6	0.242
CHROMIUM	1.987	lb/10 ¹² Btu	7.6	10.0	12.6	4.7	17.2	2.282
COBALT	0.883	lb/10 ¹² Btu	6.8	10.0	12.1	4.7	16.8	1.011
LEAD	0.202	lb/10 ¹² Btu	9.6	10.0	13.8	153.9	382.4	0.726
MANGANESE	69.490	lb/10 ¹² Btu	6.8	10.0	12.1	162.0	402.4	259.479
MERCURY	0.130	lb/10 ¹² Btu	6.5	10.0	11.9	48.6	121.1	0.237
SELENIUM	20.243	lb/10 ¹² Btu	6.5	10.0	11.9	117.9	292.9	60.541
VANADIUM	6.622	lb/10 ¹² Btu	13.6	10.0	16.9	4.7	20.6	7.860
PARTICULATE	0.012	lb/10 ⁶ Btu	6.6	10.0	12.0	31.5	79.1	0.018
HCl	0	lb/10 ¹² Btu	6.6	10.0	12.0	#DIV/0!	#DIV/0!	#DIV/0!
HF	0	lb/10 ¹² Btu	8.2	10.0	12.9	#DIV/0!	#DIV/0!	#DIV/0!

(3) Calculated using sampling bias, analytical bias, concentration equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

(6) From ASME PTC 19.1 Eq 2.29B. Single Tailed 95% Confidence. $t=2.92$ *

(9) Estimated Analytical Fd Analysis Accuracy

(10) Calculated using flue gas concentration bias, Fd Analysis bias, emission factor equation, partial derivatives, and Taylor Series *

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TABLE 8-9a. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (BASELINE - GSA + ESP SERIES)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias (1)	Reinjected Fly Ash Flowrate Bias (2)	Reinjected Fly Ash Concentration Bias (1)	Outlet Flue Gas Flowrate Bias (2)	Outlet Flue Gas Concentration Bias (1)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)
ANTIMONY	89.71	23	16	15	2,405	10	11.10	10	1	10	11.10	12.2	5.52	18.38
ARSENIC	98.74	14639	5844	8795	192	10	7.61	10	4	10	7.63	8.1	0.40	8.17
BARIUM	98.37	44028	22000	22028	708	10	6.50	10	2	10	6.50	7.8	0.31	7.81
CADMIUM	97.42	272	216	56	7	10	7.16	10	16	10	7.16	10.4	1.42	10.99
CHROMIUM	99.09	22996	13514	9482	218	10	7.63	10	3	10	7.63	8.5	0.66	8.63
COBALT	98.38	2680	1770	911	42	10	6.80	10	12	10	6.80	9.5	0.42	9.55
LEAD	98.79	7118	4018	3100	87	10	9.55	10	7	10	9.55	9.4	0.61	9.47
MANGANESE	99.20	40305	21954	18350	303	10	6.80	10	10	10	6.80	9.1	0.22	9.13
MERCURY	79.15	65	56	18	11.7	10	6.50	10	9	10	6.50	11.0	14.74	38.24
SELENIUM	73.05	4580	3953	627	1248	10	6.50	10	10	10	6.50	10.8	10.60	28.46
VANADIUM	98.73	33279	26350	6729	359	10	13.65	10	12	10	13.65	13.7	1.08	13.98
PARTICULATE	99.99	298	115	199	1.22	10	6.58	10	10	10	6.58	10.4	0.07	10.41
HCl (6)	-4.963333	556313	556313	0	585382	10	6.58	10	10	10	6.58	20.9	-326	811
HF (6)	-18.38	83387	83387	0	103234	10	8.20	10	10	10	8.20	21.4	-220	547

- (1) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (2) Estimated bias in the reinjected flyash flowrate measurement.
- (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $b=4.3$ *
- (6) No ESP outlet measurements made; estimated based on fabric filter inlet measurement.

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-9b. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (BASELINE - GSA + ESP PARALLEL)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	Outlet Flue Gas Mass Flowrate Bias	GSA Inlet Concentration Bias	Reinjected Fly Ash Flowrate Bias	Outlet Flue Gas Concentration Bias	GSA Inlet Concentration Bias	Reinjected Fly Ash Concentration Bias	Outlet Flue Gas Concentration Bias	Total Bias (%)	Total Precision (%)	Total Uncertainty (%)
ANTIMONY	96.91	83	75	15	2.8	10	11.10	10	10	10	11.10	1	10	13.5	0.11	13.49
ARSENIC	98.48	15886	6516	9370	247	10	7.63	10	10	10	7.63	4	10	8.1	0.32	8.14
BARIUM	99.58	32376	9616	22760	153	10	6.50	10	10	10	6.50	2	10	7.9	0.01	7.92
CADMIUM	86.98	283	205	78	42	10	7.16	10	10	10	7.16	16	10	10.4	1.83	11.31
CHROMIUM	98.14	16164	11270	4894	309	10	7.63	10	10	10	7.63	3	10	9.2	0.19	9.24
COBALT	98.24	2954	1715	1239	55	10	6.80	10	10	10	6.80	12	10	9.5	0.17	9.52
LEAD	97.36	6955	3543	3412	186	10	9.55	10	10	10	9.55	7	10	9.2	0.02	9.16
MANGANESE	98.28	27958	13747	14212	418	10	6.80	10	10	10	6.80	10	10	9.2	0.61	9.36
MERCURY	66.38	60	51	19	22.5	10	6.50	10	10	10	6.50	9	10	11.7	0.29	11.71
SELENIUM	81.56	3037	2260	777	616	10	6.50	10	10	10	6.50	12	10	9.8	13.68	35.36
VANADIUM	98.71	31244	22754	8490	285	10	13.65	10	10	10	13.65	10	10	12.9	0.66	13.00
PARTICULATE	99.52	288	101	186	1.448	10	6.58	10	10	10	6.58	10	10	10.0	0.03	9.95
HCl	-0.05	614947	614947	0	612839	10	6.58	10	10	10	6.58	10	10	354.8	-6194	15392
Hf	-0.05	87507	87507	0	86535	10	8.20	10	10	10	8.20	10	10	381.9	-6194	15393

- (1) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (2) Estimated bias in the reinjected flyash flowrate measurement.
- (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence $t=4.3$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-9c. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (BASELINE - GSA + FF PARALLEL)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	Outlet Flue Gas Mass Flowrate Bias	GSA Inlet Concentration Bias	Reinjected Fly Ash Flowrate Bias	Reinjected Fly Ash Concentration Bias	Outlet Flue Gas Flowrate Bias	Outlet Flue Gas Concentration Bias	Total Bias (%)	Total Precision (%)	Total Uncertainty (%)
ANTIMONY	97.68	83	75	15	2,744	10	10	11.10	10	1	10	11.10	13.5	1.74	14.17
ARSENIC	99.83	15886	6516	9370	26	10	10	7.63	10	4	10	7.63	8.1	0.05	8.10
BARIUM	99.54	32376	9616	22760	150	10	10	6.50	10	2	10	6.50	7.9	0.02	7.92
CADMIUM	71.40	283	205	78	81	10	10	7.16	10	16	10	7.16	10.7	3.02	13.11
CHROMIUM	99.46	16164	11270	4894	87	10	10	7.63	10	3	10	7.63	9.2	0.02	9.23
COBALT	98.68	2954	1715	1239	38,738	10	10	6.80	10	12	10	6.80	9.5	0.09	9.51
LEAD	99.51	6955	3543	3412	34	10	10	9.55	10	7	10	9.55	9.2	0.07	9.16
MANGANESE	99.57	27958	13747	14212	118	10	10	6.80	10	10	10	6.80	9.2	0.13	9.24
MERCURY	31.97	60	51	19	40,687	10	10	6.50	10	9	10	6.50	13.2	212.26	527.49
SELENIUM	99.93	3037	2260	777	2	10	10	6.50	10	10	10	6.50	9.5	0.00	9.49
VANADIUM	99.07	31244	22754	8490	193	10	10	13.65	10	12	10	13.65	12.9	0.02	12.90
PARTICULATE	99.86	286	101	0	0.598	10	10	6.58	10	10	10	6.58	4.2	0.01	4.16
HCl	7.71	614947	614647	186	556,627	10	10	6.58	10	11	10	6.58	10.4	192.69	478.82
HF	22.08	87507	87507	0	556,635	10	10	8.20	10	10	10	8.20	14.6	196.35	488.02

- (1) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (2) Estimated bias in the reinjected flyash flowrate measurement.
 - (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26 Two tailed 95% Confidence: $t=4.3$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-9d. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (BASELINE - GSA + ESP + FF SERIES)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias	Reinjected Fly Ash Flowrate Bias	Reinjected Fly Ash Concentration Bias	Outlet Flue Gas Flowrate Bias	Outlet Flue Gas Concentration Bias	Total Bias (%)	Total Precision (%)	Total Uncertainty (%)
ANTIMONY	89.67	23	16	15	2.5	10	11.10	10	1	10	11.10	12.3	4.80	17.10
ARSENIC	99.98	14639	5844	8795	2	10	7.63	10	4	10	7.63	8.1	0.02	8.11
BARIUM	99.69	44028	22000	22028	137	10	6.50	10	2	10	6.50	7.8	0.02	7.77
CADMIUM	94.03	272	216	56	17	10	7.16	10	16	10	7.16	10.4	1.21	10.85
CHROMIUM	99.63	22996	13514	9482	79.33	10	7.63	10	3	10	7.63	8.5	0.05	8.47
COBALT	98.66	2680	1770	911	35.26	10	6.80	10	12	10	6.80	9.5	0.22	9.51
LEAD	99.69	7118	4018	3100	21.61	10	9.55	10	7	10	9.55	9.4	0.06	9.35
MANGANESE	99.77	40305	21954	18350	79	10	6.80	10	10	10	6.80	9.1	0.20	9.13
MERCURY	94.45	65	56	18	4.05	10	6.50	10	9	10	6.50	10.8	3.73	14.26
SELENIUM	99.11	4560	3953	627	41.49	10	6.50	10	10	10	6.50	10.4	0.38	10.41
VANADIUM	99.17	33279	26550	6729	264	10	13.65	10	12	10	13.65	13.7	0.23	13.74
PARTICULATE	99.90	298	115	199	0.32	10	6.58	10	10	10	6.58	10.4	0.03	10.41
HCl	-12.38	532375	532375	0	593845	10	6.58	10	11	10	6.58	19.4	-149.03	370.75
Hf	-73.24	85387	85387	0	136534	10	8.20	10	10	10	8.20	24.7	-99.71	248.95

- (1) Determined from average achieved quality assurance objectives shown in Table 7-3.
- (2) Estimated bias in the reinjected flyash flowrate measurement.
- (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
- (4) Determined from test runs
- (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence $t=4.3$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-10a. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (DEMONSTRATION - GSA + ESP SERIES)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias (1)	Reinjected Fly Ash Flowrate Bias (2)	Reinjected Fly Concentration Bias (1)	Outlet Flue Gas Flowrate Bias (2)	Outlet Flue Gas Concentration Bias (1)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)
ANTIMONY	84.72	37	28	16	6,302	10	11.10	10	1	10	11.10	12.2	14.48	37.99
ARSENIC	99.96	18315	5408	12907	6	10	7.63	10	4	10	7.63	8.4	0.03	8.37
BARIUM	99.63	34248	4999	29249	122	10	6.50	10	2	10	6.50	8.8	0.10	8.80
CADMIUM	98.68	266	206	60	3	10	7.16	10	16	10	7.16	10.3	1.23	10.77
CHROMIUM	99.48	13651	10064	3587	71	10	7.63	10	3	10	7.63	9.6	0.04	9.58
COBALT	98.66	2350	1407	943	31,497	10	6.80	10	12	10	6.80	9.5	0.09	9.48
LEAD	99.88	6714	2817	3897	7	10	9.55	10	7	10	9.55	9.1	0.18	9.08
MANGANESE	92.44	27970	11179	16791	2724	10	6.80	10	10	10	6.80	9.7	12.88	33.45
MERCURY	88.27	46	36	20	4,765	10	6.50	10	9	10	6.50	11.0	8.92	24.72
SELENIUM	76.87	2994	2519	475	768	10	6.50	10	10	10	6.50	10.6	35.51	88.86
VANADIUM	99.18	28670	23186	5484	236	10	13.65	10	12	10	13.65	13.9	0.06	13.87
PARTICULATE	99.86	291	89	199	0.42	10	6.58	10	10	10	6.58	10.2	0.04	10.24
HCl	99.96	668988	668988	0	335	10	6.58	10	10	10	6.58	11.8	0.01	11.85
HF	99.27	79869	79869	0	888	10	8.20	10	10	10	8.20	12.8	0.08	12.80

(1) Determined from average achieved quality assurance objectives shown in Table 7-3.
 (2) Estimated bias in the reinjected flyash flowrate measurement.
 (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
 (4) Determined from test runs
 (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3^*$
 * American Society of Mechanical Engineers Performance Test Code 19.1-1985; Reaffirmed 1990

TABLE 8-10b. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (DEMONSTRATION - GSA + ESP PARALLEL)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Fly Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias (1)	Reinjected Fly Ash Flowrate Bias (2)	Reinjected Fly Ash Concentration Bias (1)	Outlet Fly Gas Flowrate Bias (2)	Outlet Fly Gas Concentration Bias (1)	Total Bias (3)	Total Precision (4)	Total Uncertainty (5)
ANTIMONY	98.78	189	181	16	2.5	10	11.10	10	1	10	11.10	14.2	0.14	14.24
ARSENIC	96.36	16122	8297	7825	560	10	7.63	10	4	10	7.63	8.2	5.24	47.79
BARIUM	92.72	27090	1849	25241	1923	10	6.50	10	2	10	6.50	9.5	9.98	90.19
CADMIUM	93.27	259	193	66	17	10	7.16	10	16	10	7.16	10.3	7.11	64.71
CHROMIUM	95.11	15782	10232	5550	795	10	7.63	10	3	10	7.63	8.9	6.48	58.92
COBALT	94.27	3260	1968	1291	180	10	6.80	10	12	10	6.80	9.5	7.09	64.39
LEAD	92.08	6396	3795	2601	516	10	9.55	10	7	10	9.55	9.5	11.87	107.09
MANGANESE	95.58	24071	8106	15965	1041	10	6.80	10	10	10	6.80	10.1	5.87	53.68
MERCURY	38.89	70	60	20	90.95	10	6.50	10	9	10	6.50	14.3	-213.58	1918.94
SELENIUM	99.81	985	307	678	1.912	10	6.50	10	10	10	6.50	10.3	0.07	10.34
VANADIUM	93.37	26906	18526	8380	1704	10	13.65	10	12	10	13.65	12.5	8.30	75.62
PARTICULATE	96.63	296	100	197	10	10	6.58	10	10	10	6.58	10.1	4.77	44.05
HCl	97.72	641539	641539	0	10	10	6.58	10	10	10	6.58	11.8	0.56719957	12.90
HF	96.47	58644	58644	0	10	10	8.20	10	10	10	8.20	12.8	3.20404102	31.50

(1) Determined from average achieved quality assurance objectives shown in Table 7-3.
 (2) Estimated bias in the reinjected flyash flowrate measurement.
 (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
 (4) Determined from test runs
 (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=12.7$ *
 * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-10c. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (DEMONSTRATION - GSA + FF PARALLEL)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Flue Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias (1)	Reinjected Fly Ash Flowrate Bias (2)	Reinjected Fly Ash Concentration Bias (1)	Outlet Flue Gas Flowrate Bias (2)	Outlet Flue Gas Concentration Bias (1)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)
ANTIMONY	98.65	189	181	16	2,504	10	11.10	10	1	10	11.10	14.2	0.20	14.20
ARSENIC	99.98	16122	8297	7825	4	10	7.63	10	4	10	7.63	8.2	0.02	8.24
BARIUM	99.49	27090	1849	25241	137	10	6.50	10	2	10	6.50	9.4	0.05	9.44
CADMIUM	78.63	259	193	66	54	10	7.16	10	16	10	7.16	10.5	6.99	20.31
CHROMIUM	99.50	15782	10232	5550	79.54	10	7.63	10	3	10	7.63	8.9	0.03	8.85
CORBALT	98.91	3260	1968	1291	35.35	10	6.80	10	12	10	6.80	9.5	0.06	9.47
LEAD	99.61	6396	3795	2601	23.6	10	9.55	10	7	10	9.55	9.5	0.21	9.51
MANGANESE	99.13	24071	8106	15965	206	10	6.80	10	10	10	6.80	10.1	0.45	10.18
MERCURY	49.23	70	60	20	29.62	10	6.50	10	9	10	6.50	11.8	54.61	136.17
SELENIUM	99.80	985	307	678	1.91	10	6.50	10	10	10	6.50	10.3	0.06	10.32
VANADIUM	99.00	26906	18526	8380	265.12	10	13.65	10	12	10	13.65	12.5	0.17	12.50
PARTICULATE	99.94	296	100	197	0.19	10	6.58	10	10	10	6.58	10.1	0.02	10.14
HCl	99.96	641539	641539	0	244.03	10	6.58	10	11	10	6.58	11.8	0.01	11.85
HF	96.82	58644	58644	0	748.31	10	8.20	10	10	10	8.20	12.8	2.89	14.67

- (1) Determined from average achieved quality assurance objectives shown in Table 7-3.
 - (2) Estimated bias in the reinjected flyash flowrate measurement.
 - (3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *
 - (4) Determined from test runs
 - (5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *
- * American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990

TABLE 8-10d. REMOVAL EFFICIENCY UNCERTAINTY CALCULATIONS (DEMONSTRATION - GSA + ESP + FF SERIES)

PARAMETER	Reported Removal Efficiency (%)	Total Input Mass Flowrate	GSA Inlet Mass Flowrate	Reinjected Fly Ash Mass Flowrate	Outlet Fly Gas Mass Flowrate	GSA Inlet Flowrate Bias	GSA Inlet Concentration Bias (1)	Reinjected Fly Ash Flowrate Bias (2)	Reinjected Fly Ash Concentration Bias (1)	Outlet Fly Gas Flowrate Bias (2)	Outlet Fly Gas Concentration Bias (1)	Total Bias (3) (%)	Total Precision (4) (%)	Total Uncertainty (5) (%)
ANTHONY	93.01	37	28	16	1.46	10	11.10	10	1	10	11.10	12.0	5.72	18.59
ARSENIC	99.99	18315	5408	12907	1	10	7.63	10	4	10	7.63	8.4	0.01	8.37
BARIUM	99.74	34248	4999	29249	80	10	6.50	10	2	10	6.50	8.8	0.21	8.81
CADMIUM	97.37	266	206	60	7	10	7.16	10	16	10	7.16	10.3	2.24	11.73
CHROMIUM	99.66	13651	10064	3587	46.49	10	7.63	10	3	10	7.63	9.6	0.26	9.60
COBALT	99.13	2350	1407	943	20.66	10	6.80	10	12	10	6.80	9.5	0.66	9.62
LEAD	99.88	6714	2817	3897	7.56	10	9.55	10	7	10	9.55	9.1	0.10	9.07
MANGANESE	99.87	27970	11179	16791	35	10	6.80	10	10	10	6.80	9.7	0.10	9.67
MERCURY	90.16	46	36	20	4.12	10	6.50	10	9	10	6.50	10.9	10.09	27.34
SELENIUM	99.96	2994	2519	475	1.12	10	6.50	10	10	10	6.50	10.2	0.03	10.18
VANADIUM	99.46	28670	23186	5484	154.96	10	13.65	10	12	10	13.65	13.9	0.41	13.90
PARTICULATE	98.71	291	89	199	0.13	10	6.58	10	10	10	6.58	10.2	0.04	10.24
HCl	98.99	668988	668988	0	7641	10	6.58	10	11	10	6.58	11.8	2.18	13.03
HF	98.99	79869	79869	0	798	10	8.20	10	10	10	8.20	12.8	0.13	12.81

(1) Determined from average achieved quality assurance objectives shown in Table 7-3.

(2) Estimated bias in the reinjected flyash flowrate measurement.

(3) Calculated using listed biases and flowrates, removal efficiency equation, partial derivatives, and Taylor Series *

(4) Determined from test runs

(5) From ASME PTC 19.1 Eq 2.26. Two tailed 95% Confidence. $t=4.3$ *

* American Society of Mechanical Engineers Performance Test Code 19.1-1985 Reaffirmed 1990