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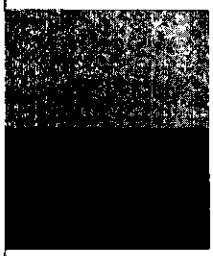
EPRI

Preliminary Draft

FIELD CHEMICAL EMISSIONS MONITORING PROJECT

SITE 111 EMISSIONS REPORT

May 14, 1993



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EPRI
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January 21, 1994

Mr. William H. Maxwell, P.E. (MD13)
Office of Air Quality Planning and Standards
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Research Triangle Park, NC 27711

Dear Mr. Maxwell:

In response to the Clean Air Act Amendments of 1990, the Electric Power Research Institute (EPRI) initiated the PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) program to better characterize the source, distribution, and fate of trace elements from utility fossil-fuel-fired power plants. As part of the PISCES program, the Field Chemical Emissions Monitoring (FCEM) program has sampled extensively at a number of utility sites, encompassing a range of fuels, boiler configurations, and particulate, SO_2, and NO_x control technologies. EPRI is actively pursuing additional FCEM sampling programs, with 29 sites either completed or planned.

This site report presents a preliminary summary of data gathered during a sampling program conducted at one of the FCEM sampling programs - Site 111. Site 111 consists of a pulverized coal-fired boiler burning a sub-bituminous coal, a spray dryer absorber, and a reverse-gas fabric filter. The Site 111 sampling and analysis project was primarily sponsored by a consortium of utilities, with some assistance from EPRI. The project budget was not sufficient to complete the entire PISCES sampling and analytical protocol. The primary interest was a select group of the trace metals, chlorides, benzene, and the polyaromatic hydrocarbons.

The Site 111 sampling and analytical protocol did not necessarily meet all of the PISCES FCEM program objective. In some instances such as mercury, the detection limits were higher than that the detection limits at other PISCES FCEM sites, thus limiting the usefulness of some of the data. Similar to the Group 1 FCEM sites, some sampling or analytical difficulties may have occurred with the volatile organic compounds. The measured VOCs at the stack were significantly higher than at the spray dryer inlet and the baghouse inlet. EPRI is continuing to review the Site 111 data and is considering the need for some follow-up tests. If this is done, the new data will be made available to the Environmental Protection Agency (EPA).

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The primary objective of this report is to transmit the preliminary results from Site 111 to the EPA for use in evaluating select trace chemical emissions from fossil-fuel-fired steam generating plants. **It should be noted that the results presented in this report are considered PRELIMINARY.** In addition to the raw data in the Appendix, the report provides an assessment of the trace metals material balances, discusses the data quality, identifies suspect data, and offers possible explanations for the questionable data. This report does not compare the results from Site 111 with the results from previous utility sites. Generic conclusions and recommendations were not drawn concerning the effectiveness of a spray dryer absorber or a fabric filter as potential control technologies for trace elements; however, removal efficiencies were calculated where possible. Nor does this site report attempt to address the environmental and health risk impacts associated with the trace chemical emissions.

EPRI hopes that this site report is of assistance to the EPA in evaluating utility trace chemical emissions as well as the associated health risk impacts.

Sincerely,

Paul Chu
Manager, Toxic Substances Characterization
Environment Division

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Section 1

INTRODUCTION

This report summarizes data gathered by Clean Air Engineering (CAE) at a power plant, designated Site 111, during a sampling program sponsored by the host utility company, a consortium of utilities, with some assistance from the Electric Power Research Institute (EPRI). The objectives of the *Field Chemical Emissions Monitoring Project* (FCEM) sponsored by EPRI (RP-3177) are to measure selected inorganic and organic substances in the process and discharge streams of power plants, and to examine the fate of selected substances in process operations. The testing performed at Site 111 did not follow the standard FCEM protocol of previous sites. Deviations and their implications are discussed below.

Objectives

The objective of this report is to provide information on fuel and stack emissions and an evaluation of the testing data in a format suitable for the U.S. Environmental Protection Agency (EPA) to use to study emissions from fossil-fuel-fired power plants. In addition to fuel and stack emissions data, intermediate gas stream information is also presented. Site 111, a coal-fired boiler with a spray dryer FGD (flue gas desulfurization) system with fabric filters for controlling emissions, was sampled during December 1991. Table 1-1 is a simplified test matrix. The results for each substance are presented by individual run and as a test average for each sampled process stream. Variability resulting from process, sampling, and analytical bias and precision errors is expressed as 95% confidence intervals for each mean result. The data were evaluated as follows:

- Process operating data were examined to ensure that sampling took place during steady, representative plant operation;
- Sampling and analytical analysis protocols were reviewed to ascertain how the data compared with other FCEM data generated using standard protocols;
- The type and quantity of quality assurance samples were reviewed to qualitatively determine the confidence that can be placed in the results; and
- The QA/QC data results were compared with data quality indicators to qualitatively determine the validity of the data in terms of variability and accuracy.

Each of these evaluation criteria is discussed separately below.

Table 1-1

Summary of Test Matrix for Site 111

Substance	Coal	Flue Gas
Inorganic Species		
Arsenic	X	X
Cadmium	X	X
Chloride		X
Chromium	X	X
Mercury	X	X
Nickel	X	X
Organic Compounds		
Acenapthene		X
Acenapthylene		X
Benz(a)anthracene		X
Benzene		X
Benzo(a)pyrene		X
Benzo(b)fluoranthene		X
Benzo(g,h,i)perylene		X
Benzo(k)fluoranthene		X
Chrysene		X
Dibenz(a,h)anthracene		X
Formaldehyde		X
Indeno(1,2,3-c,d)pyrene		X
Naphthalene		X
Pyrene		X
Other		
Ultimate Analysis	X	
Heating Value	X	

Process Data Evaluation

In addition to traditional sampling and analytical QA/QC checks, the process data were examined to validate the sampling results. An examination of plant operating data collected during the sampling period indicates that the plant was operating at steady state within reasonable control limits. No upsets or unusual conditions were observed. Unit load was greater than 95% of maximum during all testing periods. Further details of this analysis can be found in Section 4.

Sampling and Analysis Protocol Comparison

Tables 1-2 and 1-3 compare the sampling and analysis protocols for Site 111 with the protocols for the FCEM program. Since this test program was not directly managed by EPRI, the FCEM protocols were not followed in all instances.

Sampling methods used by CAE are comparable to those specified in the FCEM protocol. **Analytical techniques used by CAE, while appropriate, differ in many cases from FCEM protocol.** The methods specified by FCEM protocol provide lower detection limits than those used by CAE. For example, the detection limit for mercury in coal using FCEM protocol (CVAAS) is about two orders of magnitude lower than that of the method used in Site 111 (INAA).

Quality Assurance/Quality Control (QA/QC) Data Completeness

The completeness of the quality assurance data was reviewed to judge whether the results could be validated with available information. For gas streams, sufficient QA/QC data were available. No QA/QC data were available for coal analyses. The QA/QC data are presented and discussed in Section 4. An evaluation of accuracy, precision, and bias, even if only qualitative, is considered an important part of the data evaluation; a full discussion of these characteristics can be found in Section 4.

Standard QA/QC checks for this type of sampling program can involve: 1) the use of replicate tests, duplicate field samples and lab analyses, and matrix spike and lab control sample duplicates to determine precision; 2) the use of matrix spikes, surrogate spikes, and laboratory control samples to determine accuracy; and 3) the use of field blanks, trip blanks, method blanks, and reagent blanks to determine the presence of contamination. The QA/QC checks used at Site 111 included replicate tests, sample spikes [isotopic for polynuclear aromatic hydrocarbons (PAHs)], lab control samples, field blanks, and reagent blanks. Section 4 presents a detailed discussion of the QA/QC checks for Site 111.

Data Validity

The available QA/QC results were compared with the data quality objectives discussed in Section 4. QA/QC results outside of the data quality objectives are noted and discussed. Other quality assurance values are also evaluated, as is the potential effect on

Table 1-2

Comparison of Sampling Protocol for the FCEM Project and Site 111

Target Substance	Stream	Sampling Methods: Site 111	Sampling Methods: FCEM Protocol [a]
Metals	Gas Streams	EPA Draft Method 0012	EPA Multi-Metals Method (BIF Regulation) [b]
Chloride	Gas Streams	EPA Method 26	Radian Method [c]
Benzene	Gas Streams	EPA SW 0030 (VOST)	EPA SW 0030 (VOST)
PAHs	Gas Streams	EPA SW 0010 (Modified Method 5)	EPA SW 0010 (Modified Method 5)

[a]Reflects the most recent FCEM sampling and analytical protocol

[b]Combined impinger solutions are not concentrated before analysis. Based on U.S. EPA's "Technical Implementation Document for EPA's Boiler and Industrial Furnace (BIF) Regulations," March 1992.

[c]Modified EPA Method 5 train with hydrogen peroxide solutions buffered with sodium carbonate/bicarbonate

Table 1-3

Comparison of Analytical Protocol for the FCEM Project and Site 111

	Analytical Methods	
Gas Streams	Site 111	FCEM Protocol
Inorganic Species		
Arsenic	EPA SW 7061 (HGAAS)	EPA SW 7060 (GFAAS)
Cadmium	EPA SW 7131 (Flame AAS)	EPA SW 7131 (GFAAS)
Chloride	EPA Draft Method 26 (IC)	EPA 300.0 (IC)
Chromium	EPA SW 7191 (Flame AAS)	EPA SW 7191 (GFAAS)
Mercury	EPA SW 7470 (CVAAS)	EPA SW 7470 (CVAAS)
Nickel	EPA SW 7521 (Flame AAS)	EPA SW 7060 (GFAAS)
Organic Species		
Benzene	EPA SW 8420 (GC/MS)	EPA SW 8240 (GC/MS)
PAH	CARB Method 429 (GC/MS)	EPA SW 8270 (High Resolution GC/MS)
Coal		
Arsenic	INAA	EPA SW 7060 (GFAAS)
Cadmium	INAA	EPA SW 7131 (GFAAS)
Chromium	INAA	EPA SW 7191 (GFAAS)
Mercury	INAA	EPA SW 7470 (CVAAS)
Nickel	INAA	EPA SW 6010 (ICP-AES)

AAS = Atomic Absorption Spectrophotometry

CVAAS = Cold Vapor Atomic Absorption Spectrophotometry

GC/MS = Gas Chromatography/Mass Spectroscopy

GFAAS = Graphite Furnace Atomic Absorption Spectrophotometry

HGAAS = Hydride Generation Atomic Absorption Spectrophotometry

IC = Ion Chromatography

ICP-AES = Inductively Coupled Argon Plasma Emission Spectrometry

INAA = Instrumental Neutron Activation Analysis

the validity of the data. A comparison of Site 111 data with data quality objectives led to one point of caution. **Several polynuclear aromatic hydrocarbons (PAHs) were detected at low levels in field and reagent blanks, indicating the possible contamination of samples; therefore, these results should be used with caution.**

Wide confidence intervals about many mean concentrations are other points of concern. The broad confidence intervals are largely the result of the low number of samples taken for each analyte group during this testing. However, apart from these points of concern, the measurement results are acceptable. The reported QC indicators are generally good. Standard methods were used for sampling and analysis, and stack gas sample collection records are complete.

Report Organization

Section 2 of this report briefly describes the plant and sample locations. Section 3 discusses the results of the chemical analyses of the fuel and flue gas streams sampled at the plant. Section 4 presents QA/QC and engineering evaluations of the data. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and QA/QC results.

Section 2

SITE DESCRIPTION

Descriptions of test Site 111 and the sampling locations appear in this section.

Facility Information

Site 111 consists of a two-flow, single-reheat, coal-fired turbine generator with a net generating capacity of 267 MW. The boiler is a balanced draft, drum type rated at 2 million lbs of main steam at 2,600 psig and 1006° F. The unit burns bituminous and sub-bituminous Western coals and is equipped with low NO_x burners. The unit was operated at >95% load during all testing periods. Table 2-1 provides additional information about the facility.

Flue Gas Treatment Facilities

Particulate matter and sulfur dioxide emissions are controlled by a dry FGD/fabric filter system. Three parallel spray dryers are used to contact reagent slurry (lime and recycled solids) with the flue gas. The spray dryer was designed for 70-76% SO_2 removal depending on the coal source at an inlet gas temperature of 270° F and a 57° F approach temperature. The reagent ratio is 1.25 and the recycle rate is 6 lb recycled spray dryer solids to 1 lb fresh lime. Flue gas bypassing the spray dryer is used to reheat the gas stream before the baghouse. Particulate matter is removed by a 10-compartment reverse-gas baghouse using Teflon-coated fiberglass bags (32' x 11.5" diameter). The baghouse was designed to reduce particulate emissions to a maximum of 14 mg/Nm^3. Design air/cloth ratio is 1.7 at 1,130,000 Nm^3/hr gas flow and a 160° F inlet temperature.

Sampling Locations

Samples were collected at the following locations, which are shown in Figure 2-1: coal feed, spray dryer inlet gas, baghouse inlet gas, stack gas, bottom ash, spray dryer solids, and spray dryer slurry. Ash, coal, and spray dryer stream samples were collected by the "grab" method, and gas samples were collected by traversing the duct with gas sampling probes. Descriptions of the sampling locations are as follows:

- Spray dryer inlet gas samples were collected at the spray dryer inlet duct feeding the three modules. The duct was traversed through eight ports. Four equidistant points were sampled at each port, for a total of 32 sample points per run.

Table 2-1

Unit 2 Summary

Maximum Gross Electrical Output (MW):	290
Particulate Emission Limits (lb/10^6 Btu):	0.03
SO_2 Emission Limits (lb/10^6 Btu):	<0.6
NO_x Emission Limits (lb/10^6 Btu):	0.5
Air Pollution Controls:	Lime Spray Dryer with Fabric Filters
Design SO_2 Removal (%)	70-76[a]
Design Ca:S Ratio (mols)	1.25
Design Air/Cloth Ratio (acf/ft^2)	1.7
Design Particulate Concentration	14 mg/Nm^3 (0.005 gr/scf)
Boiler Type:	Opposed Wall Fired
Boiler Additives:	None
NO_x Control:	Low-NO_x Burners
Design Fuel Feed Rate (ton/hr, dry):	120
Fuel Type:	Subbituminous Coal
Fuel Sulfur Content (% wet):	0.56[b]
Fuel Ash Content (% wet):	14[b]
Fuel Heating Value (Btu/lb, wet):	10,020[b]
FGD/Fly Ash Disposal:	Landfill
Bottom Ash Disposal:	Landfill
Cooling Water System:	Zero Discharge
Cooling Water Source:	Wells

[a]Design removal varies depending on coal sulfur content.

[b]Mean values measured during sampling.

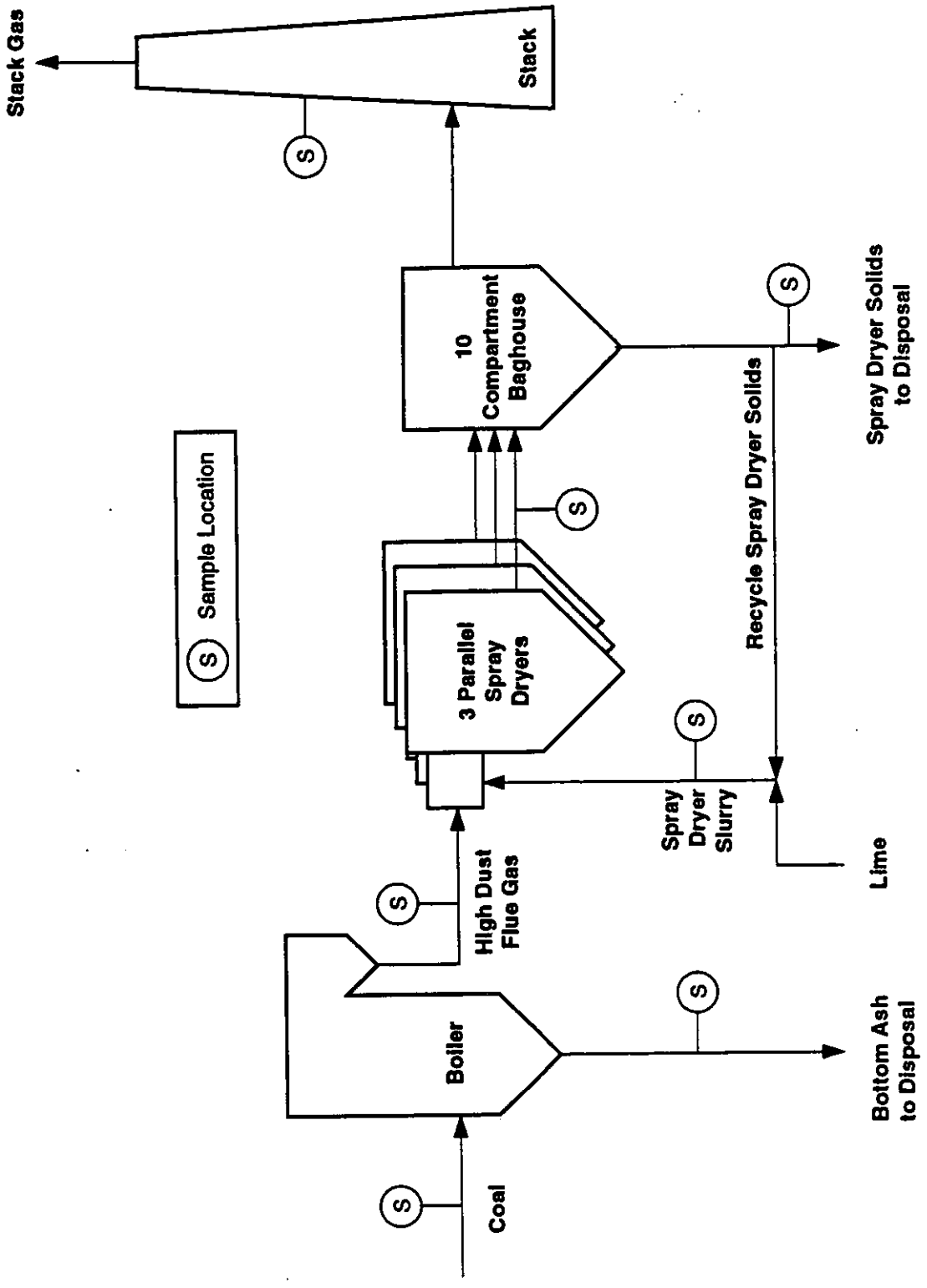


Figure 2-1. Simplified Process Flow Diagram for Site 111

- Baghouse inlet gas samples were collected from the east spray dryer module outlet duct. The duct was traversed through four ports. Four equidistant points were sampled at each port, for a total of 16 sample points per run.

- Stack gas samples were collected from four ports spaced equally around the stack. Three equidistant points between the center of the stack and each port were sampled, for a total of 12 sample points per run.

- Coal was sampled from the feed stream to the boiler.

- Bottom ash was sampled from the bottom ash stream exiting the boiler.

- Spray dryer solids were sampled from the waste solids stream exiting the baghouse.

- Spray dryer feed slurry was sampled after the lime is combined with recycled spray dryer solids.

Section 3

RESULTS

This section presents the results of the sampling of FCEM Site 111. Appendix A contains analytical data generated by CAE (and contracted analytical laboratories). Stream concentrations, calculated by Radian Corporation from the data in the CAE report, can be found in Appendix B. Appendix C presents the details of the analytical and sampling methods used at this site. Example calculations of the results discussed in this section appear in Section 5.

Sampling Schedule

CAE personnel performed sampling on December 17 and 18, 1991. Figure 3-1 presents a timeline of the different sampling events, which have been grouped by time period into "runs." The run numbers shown in Figure 3-1 correspond to those presented in the results tables later in this section and in the appendices.

Data Treatment

As discussed below, several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

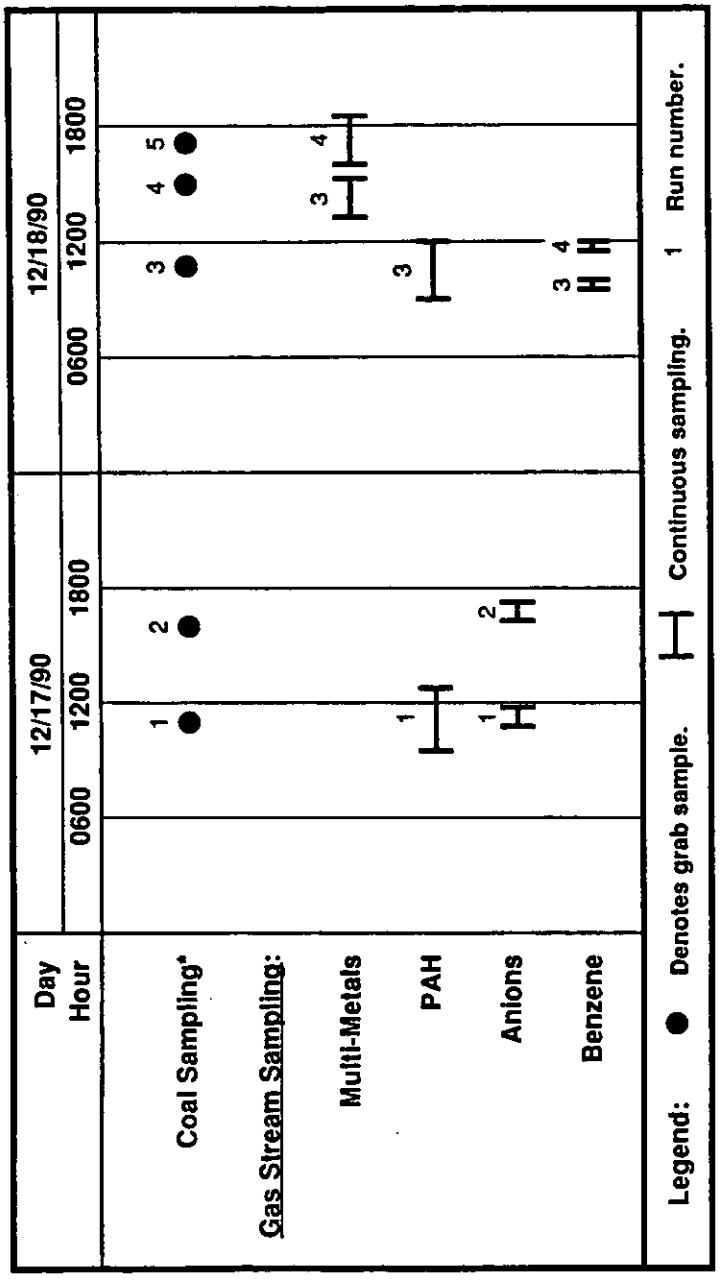
Blank Corrections

When it was available, the reagent blank analytical result was used to correct the individual run measurements for both phases. If the reagent blank was not analyzed, the field blank analysis was used to correct the measurement. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration was flagged with a "B".

When the blank correction resulted in a value less than the detection limit, the concentration is presented as ND(DL). ND(DL) means that the concentration is below the detection limit, which is presented in parentheses. In this report, the detection limit refers to the method detection limit for a particular analytical technique.

Total Concentrations

The solid and vapor phase concentrations are both considered when determining the total gas stream concentration. The absence of detectable concentrations greater than the DL in either (or both) phase(s) requires that conventions be established for



* Ash and reagent samples were taken along with coal samples and combined into daily composite samples.

Figure 3-1. Sampling Timeline for Site 111

calculating total values. For each substance, there are three possible combinations of solid- and vapor-phase concentrations in the emitted gas stream:

Case 1: The concentrations in both phases are above the detection limits.

Case 2: The concentrations in both phases are below the detection limits.

Case 3: The concentration in one phase is above the detection limit, and the concentration in the other phase is below the detection limit.

For inorganic substances (other than mercury) measured in this program, stack gas stream data from other testing indicates that most of the substance is present in the solid phase of the gas stream and that only a small fraction is generally found in the vapor phase. Thus, the following conventions were selected for defining total gas stream concentrations:

Case 1: The total concentration is the sum of the concentrations in the solid and vapor phases.

For example, the total cadmium (Cd) concentration in the spray dryer inlet gas is calculated as follows for Run 3.

Cd in the solid phase = 13.7 $\mu g/Nm^3$

Cd in the vapor phase = 4.1 $\mu g/Nm^3$

Total Cd in the stack gas = 17.8 $\mu g/Nm^3$

Case 2: The total concentration is considered to be the solid-phase detection limit except for mercury. Mercury is present primarily in the vapor phase, and the total concentration is considered to be the gas-phase detection limit.

For example, the total arsenic (As) concentration in the stack gas is calculated as follows for Run 3.

As in the solid phase = ND(0.19) $\mu g/Nm^3$

As in the vapor phase = ND(0.10) $\mu g/Nm^3$

Total As in the stack gas = ND(0.19) $\mu g/Nm^3$

Case 3: The total concentration is considered to be the value measured above the detection limit, regardless of which phase this represents.

For example, the total nickel (Ni) concentration in the stack gas is calculated as follows for Run 4.

Ni in the solid phase = 6.3 $\mu g/Nm^3$

Ni in the vapor phase = ND(5.4) $\mu g/Nm^3$

Total Ni in the stack gas = 6.3 $\mu g/Nm^3$

The above conventions generally agree with guidance provided by EPA (Technical Implementation Document for EPA's Boiler and Furnace Regulations, U. S. Environmental Protection Agency, Office of Solid Waste, Washington, D. C., March 1992).

Average Concentrations

The following conventions were used to average data from individual runs:

- When all values for a given variable were above the detection limit, the arithmetic mean concentration was calculated.

- For results that include values both above and below the detection limit, one half of the detection limit was used to calculate the mean. For example:

Analytical Values	Calculation	Mean Value
10, 12, <8	(10+12+[8/2])/3	8.7

By convention, the calculated mean was not allowed to be smaller than the largest detection limit value. In the following example, using one half the detection limit value would yield a calculated value of 2.8. This is less than the highest detection limit; therefore, the reported mean is <4.

Analytical Values	Calculation	Mean Value
5, ND(4), ND(3)	(5+(4/2)+(3/2))/3 = 2.8 <4	ND(4)

- When all analytical results for a given variable are less than the detection limit, the reported mean is ND (X), where X is the largest detection limit.

Coal Results

Table 3-1 presents coal sample analyses. Concentrations of arsenic, cadmium, chromium, mercury and nickel are presented for each sample. A mean concentration and 95% confidence interval are reported for each element. The 95% confidence interval is the range about the sample mean that has a 95% probability of containing the true mean. Section 5 contains an example confidence interval calculation. INAA (Instrumental Neutron Activation Analysis) was used to determine element concentrations in the coal. Sample proximate analyses, sulfur contents, and coal flow rates are also presented in Table 3-1.

Table 3-1

Coal Composition Data for Site 111

Substance	Run 1	Run 2	Run 3	Run 4	Run 5	Average	95% CI
Load (MW)	283	280	280	278	269	278	6.6
Coal Flow (klb/hr, wet)	246	245	240	241	236	242	13
Ash (wt%, wet)	12.9	14.4	15.2	14.8	13.0	14.0	1.3
HHV (Btu/lb, wet)	10,030	9,870	10,060	10,090	10,080	10,020	114
Moisture (wt%)	10.3	10.4	8.3	9.8	10.2	9.8	1.1
Sulfur (wt%, wet)	0.49	0.58	0.55	0.60	0.57	0.56	0.052
Elements (mg/kg)							
Arsenic	0.68	0.73	0.61	0.47	0.53	0.60	0.11
Cadmium	ND(4)	ND(4)	ND(4)	ND(4)	ND(4)	ND(4)	–
Chromium	8.1	8.5	10.0	6.7	6.7	8.0	1.4
Mercury	ND(0.48)	ND(0.48)	ND(0.48)	ND(0.48)	ND(0.48)	ND(0.48)	–
Nickel	ND(120)	ND(120)	ND(120)	ND(120)	ND(120)	ND(120)	–

CI = Confidence interval.

Only two of the five elements analyzed were detected in the coal stream: arsenic and chromium. Concentrations of these elements were fairly steady over the testing period; 95% confidence intervals for both elements were 18% of their respective means. Results of proximate analyses were also consistent during the testing period (95% CIs of measurements were 1%-11% of their respective means).

Gas Phase Streams

Gas sampling was conducted at three locations (shown in Figure 2-1); at the spray dryer inlet, baghouse inlet, and stack. Sampling of a particular analyte group was conducted concurrently at each location. Concentration data for metals (sampled using EPA Method 0012) are presented for the solid phase, the vapor phase, and the combination of vapor and solid phases. Benzene (sampled using EPA SW 0030) was analyzed only in the vapor phase. Chlorides were only analyzed in the vapor phase. PAH compounds (sampled using EPA SW 0010) and chloride (sampled using EPA Draft Method 26) were analyzed after filter and nozzle rinses were combined with impinger solutions. Only combined phase results are reported for these analyte groups. For each substance, the mass detected in the reagent blank was subtracted from the total mass of the substance before its concentration was calculated (refer to Appendix A for analyte masses detected in samples and blanks). No particulate loading data were taken for any gas stream.

Only two runs of data were sampled for each analyte group, except for benzene. As a result, many mean analyte concentrations have very broad confidence intervals, in many cases exceeding the mean concentrations. For benzene, six runs were conducted at each location. The runs were performed in two groups of three on the second day of sampling (12/18/91). Results from analysis of the largest gas sample volume (slow VOST option--gas sampled at 0.5 liters per minute for 40 minutes) from each run group are presented here. Results from other benzene runs can be found in Appendix B.

The initial multi-metals sampling run conducted by CAE was not analyzed as the impinger trains did not pass the final leak check at all three sampling locations. The first PAH sampling run at the spray dryer inlet was cut short by four minutes (to 156 minutes) because of metal fatigue in the probe.

Spray Dryer Inlet Gas

Table 3-2 summarizes the concentration measurements, concentration means, and 95% confidence intervals for each substance in the gas entering the spray dryer. Data are presented by phase: the solid-phase data include the filter and probe and nozzle rinse, and the vapor-phase data include the impinger solutions.

All analyzed elements except for mercury were detected in the spray dryer inlet gas. Benzene was detected in one run only. Eleven of the sixteen PAH compounds analyzed were detected. Confidence intervals for nearly all analyzed substances are very large, due to the low number of samples and high degree of variability in the analyses.

Table 3-2

Spray Dryer Inlet Composition Data at Site 111 ($\mu g/Nm^3$)

Substance	Particulate				Vapor			
	Run 3	Run 4	Mean	95% CI [a]	Run 3	Run 4	Mean	95% CI
Inlet Gas Flow Rate (Nm^3/hr)	1,013,000	946,000	980,000	429,000				
Elements								
Arsenic	4.4	4.5	4.4	0.8	1.3	2.8	2.1	9.7
Cadmium	13.7	13.8	13.7	0.6	4.1	5.8	5.0	10.8
Chromium	212[b]	41.4[b]	126	1,080	40	29	35	72
Mercury	ND(2.7)[c]	ND(2.9)	ND(2.9)	–	ND(70)	ND(82)	ND(82)	–
Nickel	168	121	145	300	40	36	38	31
Volatile Organic Compounds	Run 3	Run 4	Mean	95% CI	Run 3	Run 4	Mean	95% CI
Benzene	–	–	–	–	ND(0.60)	1.3	0.80	7
Anions[d]	Run 1	Run 2	Mean	95% CI	Run 1	Run 2	Mean	95% CI
Chloride[e]	–	–	–	–	4,200	4,160	4,180	240
Polynuclear Aromatic Hydrocarbons[e]	Run 1	Run 3	Mean	95% CI	Run 1	Run 3	Mean	95% CI
Inlet Gas Flow Rate (Nm^3/hr)	961,000	806,000	884,000	988,000	–	–	–	–
Acenaphthene	0.10	0.053	0.08	0.32	–	–	–	–
Acenaphthylene	0.029	0.021	0.025	0.053	–	–	–	–
Anthracene	0.020	0.055	0.037	0.22	–	–	–	–
Benz(a)anthracene	0.042	0.080	0.061	0.24	–	–	–	–
Benzo(a)pyrene	ND(0.0044)	ND(0.0066)	ND(0.0066)	–	–	–	–	–

Table 3-2 (Continued)

Substance	Particulate				Vapor			
	Run 1	Run 3	Mean	95% CI [a]	Run 3	Run 4	Mean	95% CI
Benzo(b)fluoranthene	0.019	0.023	0.021	0.028	--	--	--	--
Benzo(g,h,i)perylene	ND(0.0044)	ND(0.0066)	ND(0.0066)	--	--	--	--	--
Benzo(k)fluoranthene	ND(0.0044)	ND(0.0066)	ND(0.0066)	--	--	--	--	--
Chrysene	0.0070	0.012	0.0095	0.031	--	--	--	--
Dibenz(a,h)anthracene	ND(0.0044)	ND(0.0066)	ND(0.0066)	--	--	--	--	--
Fluoranthene	0.049	0.074	0.061	0.16	--	--	--	--
Fluorene	0.14	0.088	0.11	0.31	--	--	--	--
Indeno(1,2,3-cd)pyrene	ND(0.0044)	ND(0.0066)	ND(0.0066)	--	--	--	--	--
Naphthalene	16.6	7.9	12.2	55	--	--	--	--
Phenanthrene	0.23	0.21	0.22	0.13	--	--	--	--
Pyrene	0.034	0.046	0.040	0.078	--	--	--	--

[a] CI = Confidence interval.

[b] The variability in these results is probably due to analytical problems associated with the analysis. This cannot be positively ascertained due to the lack of QA/QC data. The variability may not be representative of actual operation.

[c] ND = Indicates the concentrations are below the detection limit, which are shown in parentheses.

[d] Gas flow rate was unavailable.

[e] Concentrations of this substance were calculated using combined solid- and vapor-phase analyses.

Baghouse Inlet Gas

Table 3-3 summarizes the analyte concentration measurements, concentration means, and 95% confidence intervals in the gas entering the baghouse system. The inlet to a single baghouse was sampled (three baghouses are fed by a header). The data are presented separately for the solid-phase and vapor-phase data.

The same set of elements detected in the spray dryer inlet gas stream were also detected in the baghouse inlet. Benzo(g,h,i)perylene, benzo(k)fluoranthene, and indeno(1,2,3-cd)pyrene were detected during one run at the baghouse inlet but not at the spray dryer inlet. Conversely, chrysene, which was detected at the spray dryer inlet, was below the detection limit at the baghouse inlet. Similar to the spray dryer inlet, a high degree of variability exists in the data, quantified by broad confidence intervals.

Stack Gas

Table 3-4 summarizes the solid- and vapor-phase analyte concentrations measured in the stack emissions. Concentration means and 95% confidence intervals are also presented.

The only element detected in the stack gas was nickel (detected in one run only). All calculated mean concentrations of the elements fall below detection limits. Benzo(g,h,i)-perylene, benzo(k)fluoranthene, and indeno(1,2,3-cd)perylene were detected during one stack sampling run but these substances were not detected in the spray dryer inlet. The mean benzene concentration, 19.6 $\mu g/Nm^3$, is much higher than that measured at the spray dryer inlet (0.083 $\mu g/Nm^3$) or the baghouse inlet (ND). In addition, confidence intervals are very wide.

Emission factors were calculated using the mean combined-phase concentrations shown in Table 3-5. Stack gas emissions are reported on a unit-energy basis (emission factor) in Table 3-6. Confidence intervals are also presented. An example emission factor calculation is reported in Section 5.

Control Device Performance

The dry FGD/fabric filter system removal efficiency for each substance is shown in Table 3-7. Removal efficiencies were calculated from the average combined phase concentrations reported in Table 3-5.

The system effectively removed arsenic, cadmium, chromium, and nickel; none of these compounds were detected at the stack. Since mercury was not detected at the inlet, a removal efficiency could not be calculated. Chloride removal was calculated to be 72$\pm$30 percent. Organic compound removals vary widely. Higher benzene concentrations were measured at the stack than at the spray dryer inlet; however, all mean concentrations have wide confidence intervals. The removal is, therefore, reported as zero rather than a negative number. Similarly, PAH removals vary from 0 to 94% and are also characterized by broad confidence intervals.

Table 3-3

Baghouse Inlet Composition Data at Site 111 ($\mu g/Nm^3$)

Substance	Particulate				Vapor			
	Run 3	Run 4	Mean	95% CI [a]	Run 3	Run 4	Mean	95% CI
Inlet Gas Flow Rate (Nm^3/hr)[b]	411,000	387,000	399,000	151,000				
Elements								
Arsenic	2.6	4.2	3.4	10.0	0.19	2.3	1.2	0.8
Cadmium	16.1	19.5	17.8	21.5	3.7	4.6	4.1	0.6
Chromium	26[c]	239[c]	133	1,360	ND(5.0)	16.3	9.4	88.0
Mercury	ND(2.5)[d]	ND(2.6)	ND(2.6)	--	ND(69)	ND(73)	ND(73)	--
Nickel	128	167	148	250	7.5	19.5	13.5	77.0
Volatile Organic Compounds[e]	Run 3	Run 4	Mean	95% CI	Run 3	Run 4	Mean	95% CI
Benzene	--	--	--	--	0.76	ND(0.64)	ND(0.64)	--
Anions[e]	Run 1	Run 2	Mean	95% CI	Run 1	Run 2	Mean	95% CI
Chloride[f]	--	--	--	--	2,310	1,590	1,950	4,540
Polynuclear Aromatic Hydrocarbons[f]	Run 1	Run 3	Mean	95% CI	Run 1	Run 3	Mean	95% CI
Inlet Gas Flow Rate (Nm^3/hr)[b]	412,000	404,000	408,000	51,000	--	--	--	--
Acenaphthene	0.13	0.018	0.080	0.72	--	--	--	--
Acenaphthylene	0.038	0.017	0.028	0.13	--	--	--	--
Anthracene	0.022	0.012	0.017	0.064	--	--	--	--
Benz(a)anthracene	0.022	0.0067	0.014	0.097	--	--	--	--
Benzo(a)pyrene	ND(0.0052)	ND(0.0052)	ND(0.0052)	--	--	--	--	--

Table 3-3 (Continued)

Substance	Particulate				Vapor			
	Run 1	Run 3	Mean	95% CI	Run 3	Run 4	Mean	95% CI
Benzo(b)fluoranthene	0.025	ND(0.0052)	0.014	0.14	--	--	--	--
Benzo(g,h,i)perylene	0.010	ND(0.0052)	0.0065	0.050	--	--	--	--
Benzo(k)fluoranthene	0.0084	ND(0.0052)	0.0055	0.037	--	--	--	--
Chrysene	ND(0.0052)	ND(0.0052)	ND(0.0052)	--	--	--	--	--
Dibenz(a,h)anthracene	ND(0.0052)	ND(0.0052)	ND(0.0052)	--	--	--	--	--
Fluoranthene	0.0063 B[g]	0.0036 B	0.0050	0.017	--	--	--	--
Fluorene	0.25	0.078	0.16	1.1	--	--	--	--
Indeno(1,2,3-cd)pyrene	0.012	ND(0.0052)	0.0073	0.060	--	--	--	--
Naphthalene	0.89	0.88	0.89	0.081	--	--	--	--
Phenanthrene	0.092	0.049	0.070	0.27	--	--	--	--
Pyrene	0.0094	0.0021 B	0.0058	0.047	--	--	--	--

[a] CI = Confidence interval.

[b] Inlet duct is one of three.

[c] The variability in these results is probably due to analytical problems associated with the analysis. This cannot be positively ascertained due to the lack of QA/QC data. The variability may not be representative of actual operation.

[d] ND = Indicates the concentrations are below the detection limit, which are shown in parentheses.

[e] Gas flow rate was unavailable.

[f] Concentrations of this substance were calculated using combined solid- and vapor-phase analyses.

[g] "B" flag indicates that blank value is greater than 50% of uncorrected value.

Table 3-4

Stack Gas Composition Data at Site 111 (μg/Nm³)

Substance	Particulate				Vapor			
	Run 3	Run 4	Mean	95% CI [a]	Run 3	Run 4	Mean	95% CI
Inlet Gas Flow Rate (Nm³/hr)	1,196,000	1,167,000	1,182,000	± 183,000				
Elements								
Arsenic	ND(0.19)[b]	ND(0.20)	ND(0.20)	--	ND(0.10)	ND(0.10)	ND(0.10)	--
Cadmium	ND(2.0)	ND(2.0)	ND(2.0)	--	ND(2.0)	ND(2.0)	ND(2.0)	--
Chromium	ND(3.9)	ND(4.0)	ND(4.0)	--	ND(3.9)	ND(4.0)	ND(4.0)	--
Mercury	ND(2.0)	ND(2.0)	ND(2.0)	--	ND(62)	ND(63)	ND(63)	--
Nickel	6.3	ND(4.9)	ND(4.9)	--	ND(5.4)	ND(5.4)	ND(5.4)	--
Volatile Organic Compounds	Run 3	Run 4	Mean	95% CI	Run 3	Run 4	Mean	95% CI
Benzene	--	--	--	--	21.6	17.7	19.6	24.6
Anions [c]	Run 1	Run 2	Mean	95% CI	Run 1	Run 2	Mean	95% CI
Chloride [d]	--	--	--	--	1,260	1,070	1,160	1,240
Polynuclear Aromatic Hydrocarbons [d]	Run 1	Run 3	Mean	95% CI	Run 1	Run 3	Mean	95% CI
Inlet Gas Flow Rate (Nm³/hr)	1,185,000	1,185,000	1,185,000	1,000	--	--	--	--
Acenaphthene	0.095	0.049	0.072	0.29	--	--	--	--
Acenaphthylene	0.030	0.021	0.026	0.062	--	--	--	--
Anthracene	0.0062	0.033	0.020	0.17	--	--	--	--
Benz(a)anthracene	ND(0.0033)	0.015	0.0082	0.084	--	--	--	--
Benzo(a)pyrene	ND(0.0033)	ND(0.0033)	ND(0.0033)	--	--	--	--	--

Table 3–4 (Continued)

Substance	Particulate				Vapor			
	Run 1	Run 3	Mean	95% CI [a]	Run 3	Run 4	Mean	95% CI
Benzo(b)fluoranthene	0.010	0.0049	0.0077	0.035	--	--	--	--
Benzo(g,h,i)perylene	0.0062	ND(0.0033)	0.0039	0.029	--	--	--	--
Benzo(k)fluoranthene	0.0039	ND(0.0033)	ND(0.0033)	--	--	--	--	--
Chrysene	ND(0.0033)	ND(0.0033)	ND(0.0033)	--	--	--	--	--
Dibenz(a,h)anthracene	ND(0.0033)	ND(0.0033)	ND(0.0033)	--	--	--	--	--
Fluoranthene	0.033	0.021	0.027	0.074	--	--	--	--
Fluorene	0.24	0.089	0.16	0.93	--	--	--	--
Indeno(1,2,3-cd)pyrene	0.0062	ND(0.0033)	0.0039	0.029	--	--	--	--
Naphthalene	0.82	0.59	0.71	1.4	--	--	--	--
Phenanthrene	0.097	0.14	0.12	0.27	--	--	--	--
Pyrene	0.0085	0.016	0.012	0.046	--	--	--	--

[a] CI = Confidence interval.

[b] ND = Indicates the concentrations are below the detection limit, which are shown in parentheses.

[c] Gas flow rate was unavailable.

[d] Concentrations of this substance were calculated using combined solid- and vapor-phase analyses.

Table 3-5

Total Stream Concentration Data for Site 111 ($\mu g/Nm^3$)

Substance	Spray Dryer Inlet Mean	Spray Dryer Inlet 95% CI [a]	Baghouse Inlet Mean	Baghouse Inlet 95% CI	Stack Mean	Stack 95% CI
Elements						
Arsenic	6.4	10.5	4.7	24.0	ND(0.20)[b]	–
Cadmium	18.7	11.4	22.0	27.0	ND(2.0)	–
Chromium	161	1150	141	1,460	ND(4.0)	–
Mercury	ND(82)	–	ND(73)	–	ND(63)	–
Nickel	183	330	161	330	ND(4.9)	–
Volatile Organic Compounds						
Benzene	0.8	7	ND(0.64)	–	19.6	24.6
Anions						
Chloride	4,180	243	1,950	4,540	1,160	1,240
Polynuclear Aromatic Hydrocarbons						
Acenaphthene	0.08	0.32	0.080	0.72	0.072	0.29
Acenaphthylene	0.025	0.053	0.028	0.13	0.026	0.062
Anthracene	0.037	0.22	0.017	0.064	0.020	0.17
Benz(a)anthracene	0.061	0.24	0.014	0.097	0.0082	0.084
Benzo(a)pyrene	ND(0.0066)	–	ND(0.0052)	–	ND(0.0033)	–
Benzo(b)fluoranthene	0.021	0.028	0.014	0.14	0.0077	0.035
Benzo(g,h,i)perylene	ND(0.0066)	–	0.0065	0.050	0.0039	0.029
Benzo(k)fluoranthene	*ND(0.0066)*	–	*0.0055*	*0.037*	ND(0.0033)	–
Chrysene	0.0095	0.031	ND(0.0052)	–	ND(0.0033)	–
Dibenzo(a,h)anthracene	ND(0.0066)	–	ND(0.0052)	–	ND(0.0033)	–
Fluoranthene	0.061	0.16	0.0050	0.017	0.027	0.074
Fluorene	0.11	0.31	0.16	1.1	0.16	0.93
Indeno(1,2,3-cd)pyrene	ND(0.0066)	–	0.0073	0.060	0.0039	0.029
Naphthalene	12.2	55	0.89	0.081	0.71	1.4
Phenanthrene	*0.22*	*0.13*	*0.070*	*0.27*	*0.12*	*0.27*
Pyrene	0.040	0.078	0.0058	0.047	0.012	0.046

[a] CI = Confidence Interval.

[b] ND = Indicates the concentrations are below the detection limit, which are shown in parentheses.

Table 3-6

Stack Gas Emission Factors for Site 111
(lb/10 ^{12} Btu)

Elements	Emission Factor	95% CI
Arsenic	ND(0.21)	--
Cadmium	ND(2.1)	--
Chromium	ND(4.3)	--
Mercury	ND(67)	--
Nickel	ND(5.3)	--
Anions		
Chloride	1,250	1,300
Volatile Organic Compounds [a]		
Benzene	21.1	26.0
Polynuclear Aromatic Hydrocarbons		
Naphthalene	0.76	1.50
Acenaphthylene	0.03	0.07
Acenaphthene	0.08	0.3
Fluorene	0.18	1.0
Phenanthrene	0.13	0.30
Anthracene	0.02	0.18
Fluoranthene	0.03	0.08
Pyrene	0.01	0.05
Chrysene	ND(0.004)	--
Benz(a)anthracene	0.009	0.09
Benzo(b)fluoranthene	0.008	0.04
Benzo(k)fluoranthene	ND(0.004)	--
Benzo(a)pyrene	ND(0.004)	--
Indeno(1,2,3-cd)pyrene	0.004	0.03
Dibenz(a,h)anthracene	ND(0.004)	--
Benzo(g,h,i)perylene	0.004	0.03

[a]Emission factor calculated using gas flow rates from PAH Run 3.

CI = Confidence interval.

Table 3-7

Device Removal Efficiencies

	Dry FGD/Fabric Filter System Removal (%)	95% CI	Estimated Removal Efficiency[a]
Metals			
Arsenic	>97	--	>99.7
Cadmium	>89	--	NC
Chromium	>98	--	>99.4
Mercury	NC[b]	--	NC
Nickel	>97	--	NC
Anions			
Chloride	72	30	NC
Volatile Organic Compounds			
Benzene	0[c]	--	NC
Polynuclear Aromatic Hydrocarbons			
Acenaphthene	9	180	NC
Acenaphthylene	0	120	NC
Anthracene	48	230	NC
Benz(a)anthracene	86	100	NC
Benzo(a)pyrene	>50	--	NC
Benzo(b)fluoranthene	63	140	NC
Benzo(g,h,i)perylene	41	440	NC
Benzo(k)fluoranthene	>50	--	NC
Chrysene	>65	--	NC
Dibenz(a,h)anthracene	>50	--	NC
Fluoranthene	55	58	NC
Fluorene	0	550	NC
Indeno(1,2,3-c,d)pyrene	41	440	NC
Naphthalene	94	18	NC
Phenanthrene	46	110	NC
Pyrene	70	73	NC

[a]Using coal composition and stack gas concentrations, these removals are estimated assuming 100% of arsenic to the gas phase and 20% of the chromium reporting to the bottom ash.

[b]Mercury was not detected in an inlet stream, so a removal efficiency could not be calculated.

[c]Calculated control efficiencies were negative but are shown as zero.

CI = Confidence interval.

The particulate removal efficiency could not be calculated because particulate loadings in the gas streams were not obtained by CAE during the testing.

The concentrations of arsenic and chromium measured at the spray dryer inlet are significantly lower than expected, based on the coal analysis. Assuming 100% of the arsenic and 80% of the chromium (20% of coal chromium was estimated in the bottom ash) are carried over in the flue gas, the estimated removal efficiencies are shown in Table 3-7. They are significantly higher than the calculated removal efficiencies. Values for cadmium, mercury, and nickel could not be estimated since these substances were not detected in the coal.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 111, three methods were used to evaluate data quality. First, process data were examined to determine if unit operating conditions were stable and representative during the sampling periods. Second, traditional QA/QC protocol for sampling and analytical procedures were evaluated; i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. were done. In addition, Site 111 QA/QC data were compared to FCEM project data quality objectives for similar QA/QC procedures. The third data assessment tool used was the calculation of material balance closures for various substances around the entire plant. Material balances involve the summation of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute a significant amount to the overall inlet or outlet mass rate (e.g., coal, bottom ash, collected fly ash, etc.).

Process Data Evaluation

Plant operating data were examined to ensure that process operation was stable and representative during the sampling periods. Excessive scatter or significant trends in relevant process variables can indicate periods of nonrepresentative unit operation. Data scatter is useful for identifying periods of operational difficulty; data trends indicate periods when steady-state operation has not been achieved.

To evaluate data scatter, the coefficient of variation (CV) was calculated for the following variables: coal flow rate, unit load, gas flow rates, gas O_2 and SO_2 contents, and gas temperatures. Table 4-1 shows the results. For Site 111, a CV of 0.20 was set as the limit of acceptable data scatter. No variable had a CV exceeding 0.13 or showed a trend over the test period, indicating process conditions were stable during the test period. The unit was operated at >95% of design load during testing periods.

Process data were also examined to ensure that process parameters were within the ranges observed for normal coal-fired power plant operation. The unit heat rate was calculated to be 8,700 Btu/kWh, a reasonable value for a coal-fired utility boiler operating at near full load. Flue gas flow rates, compositions, and temperatures were also consistent with typical coal-fired boiler operation.

Table 4-1

Process Operations Summary

12/17/91 to 12/18/91

Parameter	Units	Number of Samples	Mean	95% CI [a]	Coefficient of Variation
Coal Flow Rate	klbs/hr	5	242	5	0.02
Unit Load	MW	5	278	7	0.02
Spray Dryer Inlet Gas Flow Rate [b]	Nm^3/hr	4	932,000	141,000	0.09
Baghouse Inlet Gas Flow Rate [b]	Nm^3/hr	4	404,000	18,000	0.03
Stack Gas Flow Rate [b]	Nm^3/hr	4	1,183,000	19,000	0.01
Inlet O_2 [c]	vol %	4	5.9	0.8	0.09
Baghouse O_2 [c]	vol %	4	6.3	0.4	0.04
Stack O_2 [c]	vol %	4	6.4	0.6	0.05
Inlet SO_2 [d]	$lb/10^6$ Btu	4	0.94	0.2	0.13
Stack SO_2 [d]	$lb/10^6$ Btu	4	0.22	0.03	0.08
Inlet Gas Temperature [d]	°F	4	304	5	0.01
Baghouse Gas Temperature [d]	°F	4	161	7	0.03
Stack Gas Temperature [d]	°F	4	181	9	0.03

[a]No bias component in confidence intervals.

[b]Measured by CAE.

[c]Measured by CAE Orsat.

[d]Recorded by Site 111 personnel.

CI = Confidence interval.

Stack Sampling Quality Control Evaluation

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition in the stack. These parameters had acceptable variances at each sample location.

Sampling accuracy is usually inferred from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to determine any biases that may be caused by contamination or operator errors. Blanks were included for all tests.

Sampling representativeness also depends on the characteristics of the sampling locations. The sampling location on the stack was ideal in terms of undisturbed flow distances upstream and downstream of the ports so that the minimum required number of traverse points (12) could be used. The locations at the spray dryer inlet and the baghouse inlet were not as ideal as the stack, but a larger number of traverse points (32 and 16, respectively) were used to ensure representativeness. The isokinetic sampling rate is a measure of the operational performance of sampling for particulate matter, and can be used as an indicator of precision, with consequences for representativeness. All of the applicable sampling runs met the acceptance criteria for isokinetic variation, ± 10 percent.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The SW 846 Method 0010 MM5 for semi-volatile organic compounds is well established, both for sampling and analysis. The EPA multi-metals procedure is still in the evaluation process but is becoming widely accepted; it is well enough documented to be considered a standard method. The volatile organic sampling train (VOST) used for benzene measurements is appropriate for this compound, as well as for several other volatile components of the flue gas. EPA Method 26 for chlorine/chloride, although somewhat more recent than others, has been used extensively and is also published as Method 0050 in the EPA Methods Manual for Boilers and Industrial Furnaces (BIF).

Sampling completeness is mainly a function of providing the requisite number of samples to the analytical laboratories. In the FCEM program, three runs is considered the minimum to obtain reasonable confidence intervals for mean analyte concentrations. The broad confidence intervals present in the Site 111 data are primarily the result of using less than three sampling runs. CAE conducted three EPA Method 0012 (metals) sampling runs. The first run failed the final leak check at all three locations, and these samples were not analyzed. All other sampling runs were analyzed (two runs per analyte group).

Evaluation of Measurement Data Quality

An evaluation of the measurement data quality is based on quality control data obtained during sampling and analysis. Generally, the type of quality control information obtained

pertains to measurement precision, accuracy, and blank effects, determined by collecting various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure the sources of variability. Table 4-2 summarizes the QA/QC measures commonly used as part of the FCEM data evaluation protocol, and the characteristic information obtained. The absence of any of these types of quality control checks in this testing does not necessarily reflect poorly on the quality of the data but does limit the ability to determine the various components of measurement error.

As shown in the table, different QC checks provide different types of information, particularly pertaining to the sources of inaccuracy, imprecision, and blank effects. As part of the FCEM project, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Precision and accuracy estimates are based primarily on the actual sample matrix. Table 4-3 presents the types of quality control data reported by CAE for Site 111. Appendix F contains the results of these analyses. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with the data quality objectives (DQOs) established for the FCEM project, as shown in Table 4-4.

These DQOs are not intended to be used as validation criteria but as empirical estimates of the precision and accuracy that would be expected from existing reference measurement methods and that would be considered acceptable. The precision and accuracy estimates are not necessarily derived from analyses of the same types of samples being investigated. Although analytical precision and accuracy are relatively easy to control and quantify, sampling precision and accuracy are unique to each site and each sample matrix. Data that do not meet these objectives are by no means necessarily unacceptable. Rather, the intent is to document the precision and accuracy actually obtained, and the objectives serve as benchmarks for comparison. The effects of not meeting the objectives should be considered in light of the intended use of the data.

Quality Control Results

The quality control data evaluated for metals, VOC, and PAH measurements show that most of the results met FCEM project objectives. The only limitations are the relatively high blank levels of PAHs (particularly naphthalene and phenanthrene, but also fluorene and fluoranthene) and the wide confidence intervals about the mean gas stream concentrations of some analytes, resulting largely from the small number of samples analyzed and the low levels being measured. No accuracy or precision data were measured for the coal samples; therefore, the quality of these data could not be evaluated.

A discussion of the overall measurement precision, accuracy, and blank effects is presented below for each measurement type, followed by the stack gas sampling quality

Table 4-2

Types of Quality Control Samples

QC Activity	Characteristic Measured
Precision	
Replicate samples collected over time under the same conditions	Total variability, including process or temporal, sampling, and analytical but not bias.
Duplicate field samples collected simultaneously	Sampling plus analytical variability at the actual sample concentrations.
Duplicate analyses of a single sample	Analytical variability at the actual sample concentrations.
Matrix- or media-spiked duplicates	Sampling plus analytical variability at an established concentration.
Laboratory control sample duplicates	Analytical variability in the absence of sample matrix effects.
Surrogate-spiked sample sets	Analytical variability in the sample matrix but at an established concentration.
Accuracy (Including Precision and Bias)	
Matrix-spiked samples	Analyte recovery in the sample matrix, indicating possible matrix interferences and other effects. In a single sample, includes both random error (imprecision) and systematic error (bias).
Media-spiked samples	Same as matrix-spiked samples. *Used where a matrix-spiked sample is not feasible, such as certain stack sampling methods.*
Surrogate-spiked samples	Analyte recovery in the sample matrix, to the extent that the surrogate compounds are chemically similar to the compounds of interest. Primarily used as indicator of analytical efficacy.
Laboratory control samples (LCS)	Analyte recovery in the absence of actual sample matrix effects. Used as an indicator of analytical control.
Blank Effects	
Field Blank	Total sampling plus analytical blank effect, including sampling equipment and reagents, sample transport and storage, and analytical reagents and equipment.
Trip Blank	Blank effects arising from sample transport and storage. Typically used only for volatile organic compound analyses.
Method Blank	Blank effects inherent in analytical method, including reagents and equipment.
Reagent Blank	Blank effects from reagents used.

Table 4-3

Types of Quality Control Data Reported for FCEM Site 111

Analysis	Precision					Accuracy			Blank			
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
Solids[a]												
Metals	✓							✓				
Ultimate/Proximate	✓											
Gas Samples[b]												
Metals	✓			✓		✓			✓			✓
Benzene	✓			✓		✓				✓		✓
PAHs	✓						✓	✓	✓			✓
Acid Gas	✓		✓			✓						✓

[a]Includes coal, fly ash, and bottom ash.

[b]Includes spray dryer inlet, baghouse inlet, and stack gas.

Table 4-4

Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured [a]	FCEM Objectives		Measured	
		Precision [b] (RPD)	Accuracy [c] (Recovery)	Precision (RPD)	Accuracy (Recovery)
Metals in Gas Samples [d]	Precision and Accuracy - Matrix Spikes				
Arsenic		20	75-125	1.2	112-114
Cadmium		20	75-125	2.1	99-101
Chromium		20	75-125	4.9	99-104
Mercury		20	75-125	4.2	105-112
Nickel		20	75-125	2.4	99-102
Metals in Solid Samples [e]	Precision - Data Not Produced Accuracy - Lab Control Sample				
Arsenic		20	75-125	NA	89
Chromium		20	75-125	NA	95
PAHs in Gas Samples	Precision and Accuracy - Laboratory Control Samples				
Acenaphthylene		40	50-150	0.0	97-97
Acenphthene		40	50-150	9.5	80-88
Anthracene		40	50-150	2.6	77-79
Benz(a)anthracene		40	50-150	2.8	70-72
Benzo(b)fluoranthene		40	50-150	12	86-97
Benzo(a)pyrene		40	50-150	2.1	93-95
Benzo(k)fluoranthene		40	50-150	8.1	95-103
Benzo(g,h,i)perylene		40	50-150	16	99-116
Chrysene		40	50-150	12	105-118
Dibenz(a,h)anthracene		40	50-150	3.0	66-68
Fluorene		40	50-150	0.9	111-112
Fluoranthene		40	50-150	2.0	100-102
Indeno(1,2,3 cd)pyrene		40	50-150	1.0	103-104
Naphthalene		40	50-150	NA	NA
Phenanthrene		40	50-150	1.2	86-87
Pyrene		40	50-150	2.6	112-115
		40	50-150	2.3	87-89

Table 4-4 (Continued)

Measurement Parameter	How Measured [a]	FCEM Objectives		Measured	
		Precision [b] (RPD)	Accuracy [c] (Recovery)	Precision (RPD)	Accuracy (Recovery)
Chloride in Stack Gas	Precision - Duplicate Analysis Accuracy - Matrix Spike	20	80-120	1.4	105
Benzene in Stack Gas	Precision and Accuracy - Duplicate Method Spikes	40	50-150	5.6	121-128
PAHs in Spray Dryer Inlet	Precision and Accuracy - Surrogate Spikes				
d12-Benzo(e)pyrene		35	50-150	25	92-118
d14-Terphenyl		35	50-150	9.1	84-92
PAHs in Baghouse Inlet					
d12-Benzo(e)pyrene		35	50-150	43	83-128
d14-Terphenyl		35	50-150	38	109-160
PAHs in Stack Gas					
d12-Benzo(e)pyrene		35	50-150	16	106-124
d14-Terphenyl		35	50-150	23	79-100

[a]Experimental conditions refer to the specific techniques used to estimate precision and accuracy under conditions that reasonably represent the actual field samples. Primary and secondary techniques are given for some analyses. In lieu of data collected under the prescribed conditions, other performance estimate measures may be used.

[b]Precision is expressed as the RPD, relative percent difference, between two samples.

[c]Accuracy is expressed as the range of recoveries expected for individual analysis results.

[d]Includes spray dryer inlet, baghouse inlet, and stack gas.

[e]Sample analyzed is NBS 1632a bituminous coal.

control data review, which includes a discussion of representativeness, comparability, and completeness.

Precision is a measure of the reproducibility of measurements under a given set of conditions. It is expressed in terms of the distribution, or scatter, of the data, calculated as the standard deviation and coefficient of variation (standard deviation divided by mean). For duplicates, precision is expressed as the relative percent difference (RPD).

Accuracy is a measure of the degree of conformity of a value generated by a specific procedure to the assumed or accepted true value and includes both precision and bias. Bias is the persistent positive or negative deviation of the method average value from the assumed or accepted true value.

The efficiency of the analytical procedure for a given sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes or other quality assurance measures, as necessary. However, all spikes, unless made to the flowing stream ahead of sampling, produce only estimates of recovery of the analyte through all of the measurement steps occurring after the addition of the spike. A good spike recovery tells little about the true value of the sample before spiking.

Representativeness expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition. The representativeness criterion is based on making certain that sampling locations were properly selected and that a sufficient number of samples were collected.

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. Sampling data should be comparable with other measurement data for similar samples collected under similar conditions. This goal is achieved by using standard techniques to collect and analyze representative samples and by reporting analytical results in appropriate units. Data sets can be compared with confidence when the precision and accuracy are known.

Completeness is an expression of the number of valid measurements obtained compared with the number planned for a given study. The goal is to generate a sufficient amount of valid data.

Metals

Precision. Table 4-4 presents precision estimates for the analysis of metals in gas samples. The precision estimates are based on replicate spiked sample analyses in the stack gas samples. The laboratory did not specify how the spiked samples were prepared, but the repeatability of the recoveries was very good, less than 5% relative percent deviation for the five metals reported. No QC data were developed for metals in ash or lime samples, but the repeatability of results for the samples from different

runs was acceptable except for mercury in fly ash, which was almost thirty times higher in one of the two ash samples.

Accuracy. Accuracy estimates for metals analyses, as shown in Table 4-4, are based on matrix spike recoveries for gas samples and a bituminous coal reference standard for solids. These data show recoveries for metals well within the 75-125% objective. Cadmium and nickel were detected in the spray dryer inlet gas but not in the coal, most likely because of the relatively high detection limits of the INAA method used for the coal analyses.

Blanks. None of the metals analyzed for in any flue gas stream were detected in the reagent or field blank. A single reagent blank was analyzed for the bottom ash, fly ash, and reagent mixed feed streams; no metals were detected.

PAHs

Precision. Table 4-4 shows the precision estimates for PAH analyses in flue gas samples. Shown are the recoveries for target PAHs in duplicate laboratory control samples and the recoveries for surrogate standard spikes in each sample. The laboratory control sample results show excellent repeatability. The variability of surrogate spike recoveries in the spray dryer inlet and stack gas samples are within the RPD objectives of 35. At 38 and 45 RPD, the variabilities in surrogate standard recoveries in the baghouse inlet samples are slightly outside the objective, which might indicate the presence of some interferences, but which should not be a major concern. The results for PAHs in samples from replicate test runs agree reasonably well, considering the low levels measured.

Accuracy. Table 4-4 summarizes the accuracy estimates for PAHs in the stack gas, which are based on the laboratory control samples and surrogate spike recoveries in spray dryer, baghouse, and stack gas samples. Recoveries of all the target analytes in the laboratory control samples are within the 50-150% objective. Recoveries of the two surrogate standards were also within the recovery objective except for one high recovery of d14-terphenyl (160%) in a baghouse inlet sample.

Blanks. Fourteen of the PAHs analyzed in the blank samples were detected in at least one gas stream. Naphthalene (93-970 ng), acenaphthylene (12 ng), fluorene (14-18 ng), phenanthrene (39-85 ng), and fluoranthene (12-19 ng) were detected in the field and reagent blanks. Pyrene (12 ng) was detected only in the reagent blank. The blank analyses indicate a potential sample contamination problem. The results should be used with caution.

Benzene

Precision. The precision of the benzene analyses, expressed in terms of the relative percent difference for duplicate method-spiked sample analyses, is 5.6 RPD, which is

well within the objective of 40 RPD. Levels of benzene in the replicate test samples, although extremely low, also showed reasonable agreement.

Accuracy. Accuracy estimates for benzene in gas samples (121-128% recovery) are within the 50-150% objective.

Blanks. Benzene was not detected in concentrations above 10 ng in any blank samples, including trip blanks, tube blanks, or lab blanks.

Acid Gases

Precision. Precision estimates for the analysis of chloride in flue gas are based on duplicate analyses. For one duplicate analysis pair, the relative percent difference was 1.4%, compared with the stated objective of 20% (which is intended to include sample variability). Although duplicate analyses address only analytical precision, and not sample or process variability, the precision is very good. The agreement of chloride measurements in the replicate test runs, which includes process, sample, and analytical variability, is also reasonably good. The measured chloride concentrations in the spray dryer inlet and stack gas samples (< 1 RPD and 16 RPD, respectively) agree quite well. Chloride measurements in the baghouse inlet gas samples differ by 37%, but there is no indication that this difference is due to excessive sample or analytical imprecision. This is not a concern since only two samples were analyzed; consequently, the uncertainty in the average emission value is large.

Accuracy. The accuracy of chloride measurements was estimated from one matrix-spiked sample, which showed a recovery of 105%, well within the 80-120% objective.

Blanks. One reagent blank was analyzed for chloride. No chloride was detected in the blank.

Material Balance Results

At Site 111, the overall plant mass balance was simplified to two inlet (coal and spray dryer slurry) and three outlet (stack gas, bottom ash, and spray dryer solids) streams. The ash balance was forced to close, assuming an 80/20 split between fly ash and bottom ash streams, which is typical for this type of unit. (No particulate loading data or ash flow rates were available to calculate the split.) Stream flow and concentration distributions (average and standard deviation) were entered into a statistical error propagation model to estimate the confidence intervals for the material balance closures. A detailed discussion of the statistical error propagation analysis appears in Appendix E.

Closure is defined as the ratio of outlet to inlet mass flow rates. A 100% closure indicates agreement between the outlet and inlet mass flow rates. When trace substances are analyzed, a closure of between 70% and 130% has been set as a goal for the FCEM project. This range reflects the typical level of analytical uncertainty and, therefore, allows the investigator to interpret the inlet and outlet stream component mass

flow rates as being statistically equivalent. Poor closures or high uncertainties may indicate measurement problems in one or more sample matrices.

Table 4-5 presents the results of the material balance closure and error propagation analysis. Mass balances were performed only for those elements detected in the coal and stack gas; in this case, arsenic and chromium.

The arsenic closure, at 131 $\pm$ 19%, is slightly above the desired range. The material balance closure for chromium, 63 $\pm$ 10%, is slightly below the desirable range. The relatively narrow confidence interval indicates that data variability was not the primary reason the closure is outside the target range. Analytical QA/QC data revealed no problems with ash analyses; QA/QC data were unavailable for the coal stream. Process variability was minimal. Two possible causes for the low closure are unrepresentative sampling or analytical bias associated with the coal analyses.

Table 4-5

Material Balance Closure Results

Substance[a]	Closure (%)	95% CI
Arsenic	131	19
Chromium	63	10

[a]Arsenic and chromium were the only two elements detected in the coal.

CI = Confidence interval.

Section 5

EXAMPLE CALCULATIONS

This section describes the methodology and sample calculations used to develop the results discussed in Sections 3 and 4. Specifically, the calculations of reported concentrations, unit-energy-based results, and confidence intervals are described.

Concentration Calculations

The concentrations presented in this report were calculated from raw data presented in the Clean Air Engineering report. The gas concentration is calculated as follows:

$$C = \frac{(M - B)}{SV} * 35.3 * \frac{528}{492} \qquad (5\text{-}1)$$

where:

C = Concentration, $\mu g/Nm^3$

M = Mass measured in the sample, μg

B = Mass measured in the blank (reagent or field), μg

SV = Sample volume (at 60° F), dscf

35.3 = Conversion of ft^3 to m^3

$\frac{528}{492}$ = Temperature correction from standard to normal conditions, (68° F to 32° F)

All concentrations are presented at normal conditions (32° F, 1 atm).

Unit Energy Calculations

The unit-energy-based emission factors (Table 3-3) were determined by dividing the mass flow rate of a substance being emitted by the heat input to the boiler during testing.

The unit-energy-based emission factor during oil firing is calculated from the following equation:

$$E = \frac{g * c}{HHV * coal} * 2202.6 \qquad (5\text{-}2)$$

where:

E = Mean stack emission factor, lb/10^{12} Btu

g = Mean flue gas flow rate, Nm^3/hr (all runs)

c = Mean total flue gas concentration, $\mu g/Nm^3$

HHV = Mean coal higher heating value, Btu/lb (all runs)

coal = Mean coal feed rate, lb/hr (all runs)

2202.6 = Unit conversion coefficient from μg/Btu to lb/10^{12} Btu

Chloride will be used for this example. The following mean values were taken from Tables 3-1 and 3-2c:

g = 1,183,000 Nm^3/hr

c = 1,160 $\mu g/Nm^3$

HHV = 10,020 Btu/lb

coal = 242,000 lb/hr

The emission factor for chloride is calculated from Equation 5-2:

$$E = \frac{1{,}183{,}000 * 1{,}160 * 2202.6}{10{,}020 * 242{,}000} = 1{,}250 \text{ lb}/10^{12} \text{ Btu}$$

Confidence Interval Calculations

Confidence intervals (CIs) were calculated for the total mean concentrations in the gas and oil streams. In addition, CIs were determined for the stack gas emission factors presented in Table 3-4, as well as for the material balance closures. Additional details of the CI calculations for emission factor, removal efficiencies, and material balance closures can be found in Appendix E.

CIs for Stream Concentrations

The 95% CI about the total mean for simple linear addition can be found by:

$$U_{rTOT} = \sqrt{\beta_r^2 + \left(t * \frac{S_r}{\sqrt{N}}\right)^2} \qquad (5\text{-}4)$$

where:

U_{rTOT} = 95% CI for the total mean

β_r = Bias component

t = Student's "t" factor for 97.5 percentile (one-tail) and N-1 degrees of freedom

S_r = Standard deviation of the individual run measurements

N = Number of measurements

The bias component for the mean is found by root-sum-squaring the bias error from each run and the sensitivity of that run to the mean:

$$\beta_r = \sum_{i=1}^{N_i} \sqrt{\sum \left(\beta_p * \theta_p\right)^2} \qquad (5\text{-}5)$$

where:

β_{pi} = Bias for each run i

θ_{pi} = Sensitivity to run i = 1/N

The individual bias is equal to one-half the detection limit for concentrations below the detection limit. Zero bias is assumed for reported quantities.

The following concentrations ($\mu g/Nm^3$), taken from Table 3-3 will be used to demonstrate the method for calculating the 95% CI:

Substance	Fraction	Run 3	Run 4
Chromium	Solid Phase (Baghouse Inlet)	26	239
Chromium	Vapor Phase (Baghouse Inlet)	ND(5.0)	16.3

The calculation of the total chromium concentration for each run is based on the method described in Section 3 (addition of solid and vapor phases). The results are presented below:

Substance	Run 1	Run 2	Mean	Standard Deviation
Chromium	26	256	141	163

The 95% confidence interval is calculated using these values inserted into Equation 5-4:

β_r = 0 (no values below the detection limit)

t = 12.7

S_r = 163

N = 2

$$U_{rTOT} = \sqrt{(0)^2 + \left(\frac{12.7 * 163}{\sqrt{2}}\right)^2} = 1{,}460 \quad \mu g/Nm^3$$

The 95% CI (U_{rTOT}) for the total chromium concentration is $\pm 1{,}460\ \mu g/Nm^3$, as shown in Table 3-5.

Section 6

GLOSSARY

AAS	Atomic Absorption Spectrophotometry
Btu	British Thermal Unit
CARB	California Air Regulatory Board
CI	Confidence Interval
CVAAS	Cold Vapor Atomic Absorption Spectrophotometry
DL	Detection Limit
dscfm	Dry Standard Cubic Feet per Minute (1 atm., 60° F)
FCEM	Field Chemical Emissions Monitoring
FGD	Flue Gas Desulfurization
GC/MS	Gas Chromatography/Mass Spectroscopy
GFAAS	Graphite Furnace Atomic Absorption Spectrophotometry
HHV	Higher Heating Value
IC	Ion Chromatography
ICP-AES	Inductively Coupled Argon Plasma Emissions Spectrometry
INAA	Instrumental Neutron Activation Analysis
MS/MSD	Matrix Spike/Matrix Spike Duplicate
ND	Not Detected
Nm^3	Normal Cubic Meter (1 atm, 0° C)
PAH	Polynuclear Aromatic Hydrocarbons
POM	Polycyclic Organic Matter
QA/QC	Quality Assurance/Quality Control
RPD	Relative Percent Difference
VOC	Volatile Organic Compound
VOST	Volatile Organic Sampling Train

Appendix A

Sampling and Analytical Data from Clean Air Engineering Report

Tables A-1 through A-6 present the test results for each run as well as blank analyses. Reagent and field blanks were analyzed for the multi-metals trains (both solid- and vapor-phase), volatile organics, and PAHs. Only a reagent blank was provided for chloride.

Table A-1

Spray Dryer Inlet Composition Data at Site 111

Substance	Particulate Run 3 12/18/91	Particulate Run 4 12/18/91	Particulate Reagent Blank	Particulate Field Blank
Elements (mg)				
Sample Volume, Nm^3	1.46	1.38		
Arsenic	0.0064	0.0062	ND(0.0004)	ND(0.0004)
Cadmium	0.020	0.019	ND(0.04)	ND(0.04)
Chromium	0.309	0.057	ND(0.008)	ND(0.008)
Mercury	ND(0.004)	ND(0.004)	ND(0.004)	ND(0.004)
Nickel	0.246	0.167	ND(0.010)	ND(0.010)

Substance	Vapor Run 3 12/18/91	Vapor Run 4 12/18/91	Vapor Reagent Blank	Vapor Field Blank
Elements (mg)				
Sample Volume, Nm^3	1.46	1.38		
Arsenic	0.0019	0.0039	ND(0.0002)	ND(0.0002)
Cadmium	0.006	0.008	ND(0.004)	ND(0.004)
Chromium	0.059	0.040	ND(0.008)	ND(0.008)
Mercury (Nitric Impingers)	ND(0.1028)	ND(0.1126)		ND(0.0862)
Mercury ($KMnO_4$ Impingers)	ND(0.0165)	ND(0.0164)		ND(0.0148)
Nickel	0.059	0.049	ND(0.011)	ND(0.010)

	Run 3 12/17/91	Run 4 12/18/91	Reagent Blank	Field Blank
VOCs (μg)				
Sample Volume, Nm^3	0.0166	0.0164		
Benzene	0.010	0.022	ND(0.010)	ND(0.010)

Table A-2

Spray Dryer Inlet Combined Phase Data at Site 111

Substance	Mass Measured in Sample: Run 1 12/17/91	Run 2 12/17/91	Reagent Blank	Field Blank
Anions (mg)				
Sample Volume, Nm^3	0.87	0.91		
Chloride	3.64	3.80	ND(0.1)	
	Run 1 12/17/91	**Run 3 12/18/91**	**Reagent Blank**	**Field Blank**
PAH (ng)				
Sample Volume, Nm^3	2.29	1.51		
Naphthalene	38,000	12,000	93	970
Acenaphthylene	66	31	ND(10)	12
Acenaphthene	240	82	ND(10)	ND(10)
Fluorene	350	150	18	14
Phenanthrene	610	400	85	39
Anthracene	45	83	ND(10)	ND(10)
Fluoranthene	130	130	19	12
Pyrene	90	82	12	ND(10)
Chrysene	16	18	ND(10)	ND(10)
Benz(a)anthracene	95	120	ND(10)	ND(10)
Benzo(b)fluoranthene	43	35	ND(10)	ND(10)
Benzo(k)fluoranthene	ND(10)	ND(10)	ND(10)	ND(10)
Benzo(a)pyrene	ND(10)	ND(10)	ND(10)	ND(10)
Indeno(1,2,3-cd)pyrene	ND(10)	ND(10)	ND(10)	ND(10)
Dibenz(a,h)anthracene	ND(10)	ND(10)	ND(10)	ND(10)
Benzo(g,h,i)perylene	ND(10)	ND(10)	ND(10)	ND(10)

Table A-3

Baghouse Inlet Composition at FCEM Site 111

Substance	Particulate			
	Run 3 12/18/91	Run 4 12/18/91	Reagent Blank	Field Blank
Elements (mg)				
Sample Volume, Nm^3	1.61	1.54		
Arsenic	0.0042	0.0065	ND(0.0004)	ND(0.0004)
Cadmium	0.026	0.030	ND(0.04)	ND(0.04)
Chromium	0.042	0.368	ND(0.008)	ND(0.008)
Mercury	ND(0.004)	ND(0.004)	ND(0.004)	ND(0.004)
Nickel	0.206	0.257	ND(0.010)	ND(0.010)

Substance	Vapor			
	Run 3 12/18/91	Run 4 12/18/91	Reagent Blank	Field Blank
Elements (mg)				
Sample Volume, Nm^3	1.61	1.54		
Arsenic	0.0003	0.0035	ND(0.0002)	ND(0.0002)
Cadmium	0.006	0.007	ND(0.004)	ND(0.004)
Chromium	ND(0.008)	0.025	ND(0.008)	ND(0.008)
Mercury (Nitric Impingers)	ND(0.1118)	ND(0.1118)		ND(0.0862)
Mercury ($KMnO_4$ Impingers)	ND(0.0168)	ND(0.0172)		ND(0.0148)
Nickel	0.012	0.030	ND(0.011)	ND(0.010)

	Run 3 12/17/91	Run 4 12/17/91	Reagent Blank	Field Blank
VOCs (μg)				
Sample Volume, Nm^3	0.0158	0.0156		
Benzene	0.012	0.010	ND(0.010)	ND(0.010)

Table A-4

Baghouse Inlet Combined Phase Data at Site 111

Substance	Mass Measured in Sample			
	Run 1 12/17/91	Run 2 12/17/91	Reagent Blank	Field Blank
Anions (mg)				
Sample Volume, Nm^3	0.867	0.879		
Chloride	2.0	1.4	ND(0.1)	
	Run 1 12/17/91	Run 3 12/18/91	Reagent Blank	Field Blank
PAH (ng)				
Sample Volume, Nm^3	1.91	1.94		
Naphthalene	1,800	1,800	93	970
Acenaphthylene	73	33	ND(10)	12
Acenaphthene	250	34	ND(10)	ND(10)
Fluorene	490	170	18	14
Phenanthrene	260	180	85	39
Anthracene	42	23	ND(10)	ND(10)
Fluoranthene	31	26	19	12
Pyrene	30	16	12	ND(10)
Chrysene	ND(10)	ND(10)	ND(10)	ND(10)
Benz(a)anthracene	42	13	ND(10)	ND(10)
Benzo(b)fluoranthene	48	ND(10)	ND(10)	ND(10)
Benzo(k)fluoranthene	16	ND(10)	ND(10)	ND(10)
Benzo(a)pyrene	ND(10)	ND(10)	ND(10)	ND(10)
Indeno(1,2,3-cd)pyrene	23	ND(10)	ND(10)	ND(10)
Dibenz(a,h)anthracene	ND(10)	ND(10)	ND(10)	ND(10)
Benzo(g,h,i)perylene	20	ND(10)	ND(10)	ND(10)

Table A-5

Stack Gas Composition at Site 111

Substance	Particulate Run 3 12/18/91	Particulate Run 4 12/18/91	Particulate Reagent Blank	Particulate Field Blank
Elements (mg)				
Sample Volume, Nm^3	2.05	2.02		
Arsenic	ND(0.0004)	ND(0.0004)	ND(0.0004)	ND(0.0004)
Cadmium	ND(0.004)	ND(0.004)	ND(0.04)	ND(0.04)
Chromium	ND(0.008)	ND(0.008)	ND(0.008)	ND(0.008)
Mercury	ND(0.004)	ND(0.004)	ND(0.004)	ND(0.004)
Nickel	0.013	ND(0.010)	ND(0.010)	ND(0.010)

Substance	Vapor Run 3 12/18/91	Vapor Run 4 12/18/91	Vapor Reagent Blank	Vapor Field Blank
Elements (mg)				
Sample Volume, Nm^3	2.05	2.02		
Arsenic	ND(0.0002)	ND(0.0002)	ND(0.0002)	ND(0.0002)
Cadmium	ND(0.004)	ND(0.004)	ND(0.004)	ND(0.004)
Chromium	ND(0.008)	ND(0.008)	ND(0.008)	ND(0.008)
Mercury (Nitric Impingers)	ND(0.1274)	ND(0.1264)		ND(0.0862)
Mercury ($KMnO_4$ Impingers)	ND(0.0172)	ND(0.0165)		ND(0.0148)
Nickel	ND(0.011)	ND(0.011)	ND(0.011)	ND(0.010)

	Run 3 12/17/91	Run 4 12/18/91	Reagent Blank	Field Blank
VOCs (μg)				
Sample Volume, Nm^3	0.0153	0.158		
Benzene	0.330	0.280	ND(0.010)	ND(0.010)

Table A-6

Stack Gas Combined Phase Data at Site 111

Substance	Mass Measured in Sample			
	Run 1 12/17/91	Run 2 12/17/91	Reagent Blank	Field Blank
Anions (mg)				
Sample Volume, Nm^3	0.952	0.939		
Chloride	1.2	1.0	ND(0.1)	
	Run 1 12/17/91	Run 3 12/18/91	Reagent Blank	Field Blank
PAH (ng)				
Sample Volume, Nm^3	3.06	3.04		
Naphthalene	2,600	1,900	93	970
Acenaphthylene	93	63	ND(10)	12
Acenaphthene	290	150	ND(10)	ND(10)
Fluorene	740	290	18	14
Phenanthrene	380	510	85	39
Anthracene	19	100	ND(10)	ND(10)
Fluoranthene	120	84	19	12
Pyrene	38	70	12	ND(10)
Chrysene	ND(10)	ND(10)	ND(10)	ND(10)
Benz(a)anthracene	ND(10)	45	ND(10)	ND(10)
Benzo(b)fluoranthene	32	15	ND(10)	ND(10)
Benzo(k)fluoranthene	12	ND(10)	ND(10)	ND(10)
Benzo(a)pyrene	ND(10)	ND(10)	ND(10)	ND(10)
Indeno(1,2,3-cd)pyrene	23	ND(10)	ND(10)	ND(10)
Dibenz(a,h)anthracene	ND(10)	ND(10)	ND(10)	ND(10)
Benzo(g,h,i)perylene	20	ND(10)	ND(10)	ND(10)

Appendix B

Site 111 Stream Concentrations

Appendix B presents the results from the Site 111 sampling event in December of 1991. Table B-1 presents the concentrations of the substances measured in gas streams, coal, bottom ash, spray dryer solids, and spray dryer reagent streams. The analytical techniques used to determine these results are also given.

Gas stream concentrations were calculated from the analytical data contained in the CAE report and presented in Appendix A. Where possible, the data have been corrected using the reagent blank analysis. The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration presented is the detection limit.

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run1	Run2	Run3	Run4
>>>> Bottom ash <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw	1.06		1.31	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw	< 1.96		< 1.93	
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw	5.43		7.14	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw	< 1.96		< 1.93	
Nickel	Atomic absorption spectrophotometry (AAS), flame	ppmw	55.9		34.6	
>>>> Coal <<<<						
Arsenic	Instrumental neutron activation analysis (INAA)	ppmw	0.68	0.73	0.61	0.47
Ash	Proximate analysis	wt %	14.35	15.22	14.80	12.97
Cadmium	Instrumental neutron activation analysis (INAA)	ppmw	< 4	< 4	< 4	< 4
Chromium	Instrumental neutron activation analysis (INAA)	ppmw	8.1	8.5	10	6.7
Heating value	Proximate analysis	Btu/lb	9865	10059	10008	10078
Mercury	Instrumental neutron activation analysis (INAA)	ppmw	< 0.48	< 0.48	< 0.48	< 0.48
Moisture	Proximate analysis	wt %	10.39	8.33	9.75	10.19
Nickel	Instrumental neutron activation analysis (INAA)	ppmw	< 120	< 120	< 120	< 120
Sulfur	Proximate analysis	wt %	0.58	0.55	0.60	0.57
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.095		0.049	
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.03		0.021	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0062		0.033	
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			< 0.19	< 0.2
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0033		0.015	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			21.6	< 2.8
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0033		< 0.0033	
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.01		0.0048	
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0062		< 0.0033	
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0039		< 0.0033	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 2	< 2
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 3.9	< 4
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0033		< 0.0033	

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run5	Run6	Run7	Run8
>>>> Bottom ash <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ppmw				
>>>> Coal <<<<						
Arsenic	Instrumental neutron activation analysis (INAA)	ppmw	0.53			
Ash	Proximate analysis	wt %	12.88			
Cadmium	Instrumental neutron activation analysis (INAA)	ppmw	< 4			
Chromium	Instrumental neutron activation analysis (INAA)	ppmw	6.7			
Heating value	Proximate analysis	Btu/lb	10032			
Mercury	Instrumental neutron activation analysis (INAA)	ppmw	< 0.48			
Moisture	Proximate analysis	wt %	10.32			
Nickel	Instrumental neutron activation analysis (INAA)	ppmw	< 120			
Sulfur	Proximate analysis	wt %	0.49			
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 33.1	17.7	< 3.03	< 14
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run1	Run2	Run3	Run4
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0033		< 0.0033	
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.033		0.021	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.24		0.089	
HCl	Ion chromatography (IC)	ug/Nm3	1260	1070		
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0062		< 0.0033	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 62.1	< 62.5
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.82		0.59	
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			6.3	< 8.8
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.087		0.14	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0085		0.016	
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			< 0.1	< 0.1
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 2	< 2
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 3.9	< 4
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 62.1	< 62.5
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 5.4	< 5.4
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			< 0.19	< 0.19
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 2	< 2
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 3.9	< 4
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 2	< 2
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			6.3	< 4.9
>>>> High dust gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.1		0.054	
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.029		0.021	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.02		0.055	
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			5.7	7.3
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.042		0.08	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.6	3.02
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0044		< 0.0044	

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run5	Run6	Run7	Run8
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
HCl	Ion chromatography (IC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
>>>> High dust gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	11.8	1.3	< 2.44	13.1
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run1	Run2	Run3	Run4
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.019		0.023	
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0044		< 0.0044	
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0044		< 0.0044	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			17.8	19.6
Chloride	Ion chromatography (IC)	ug/Nm3	4200	4160		
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			252	70.4
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.007		0.012	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0044		< 0.0066	
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.049		0.074	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.14		0.088	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0044		< 0.0066	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 70.4	< 81.7
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	16.6		7.9	
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			209	157
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.23		0.21	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.034		0.049	
>>>> High dust gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			1.3	2.8
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			4.1	5.8
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			40.4	29
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 70.4	< 81.7
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			40.4	35.6
>>>> High dust gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			4.4	4.5
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			13.7	13.8
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			212	41.4
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 2.7	< 2.9
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			168	121
>>>> Spray dryer outlet gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.13		0.018	

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run5	Run6	Run7	Run8
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chloride	Ion chromatography (IC)	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
>>>> High dust gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
>>>> High dust gas, solid phase <<<<						
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
>>>> Spray dryer outlet gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run1	Run2	Run3	Run4
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.038		0.017	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.022		0.012	
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			2.8	6.5
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.022		0.0067	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			0.76	< 1.3
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0052		< 0.0052	
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.025		< 0.0052	
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.01		< 0.0052	
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0084		< 0.0052	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			19.9	24.1
Chloride	Ion chromatography (IC)	ug/Nm3	2310	1590		
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			26.1	256
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0052		< 0.0052	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.0052		< 0.0052	
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B 0.0063		B 0.0036	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.25		0.078	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.012		< 0.0052	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 69.4	< 72.8
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.89		0.88	
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			135	187
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.092		0.049	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0094		B 0.0021	
>>>> Spray dryer outlet gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			0.19	2.3
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			3.7	4.6
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 5	16.3
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 69.4	< 72.8
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			7.5	19.5
>>>> Spray dryer outlet gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3			2.43	4.2
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			16.1	19.5

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run5	Run6	Run7	Run8
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.64		
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chloride	Ion chromatography (IC)	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
>>>> Spray dryer outlet gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
>>>> Spray dryer outlet gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run1	Run2	Run3	Run4
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			26.1	239
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 2.5	< 2
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			128	167
>>>> Spray dryer slurry, liquid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	mg/L	0.004		0.020	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	mg/L	0.060		0.067	
Chloride	Ion chromatography (IC)	mg/L	1130		1230	
Chromium	Atomic absorption spectrophotometry (AAS), flame	mg/L	0.38		0.44	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	mg/L	< 0.0025		< 0.003	
Nickel	Atomic absorption spectrophotometry (AAS), flame	mg/L	< 0.19		< 0.22	
>>>> Spray dryer slurry, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw	4.73		4.22	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw	6.86		6.13	
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw	23.7		23.7	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw	1.97		< 1.91	
Nickel	Atomic absorption spectrophotometry (AAS), flame	ppmw	25.6		25.3	
>>>> Spray dryer solids <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw	6.55		6.21	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw	6.93		6.21	
Chloride	Atomic absorption spectrophotometry (AAS), flame	ppmw	2927		2380	
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw	31.3		31.4	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw	1.93		1.84	

Table B-1 Site 111 Stream Concentrations During Coal-Fired Tests

Substance	Method	Units	Run5	Run6	Run7	Run8
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
>>>> Spray dryer slurry, liquid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	mg/L				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	mg/L				
Chloride	Ion chromatography (IC)	mg/L				
Chromium	Atomic absorption spectrophotometry (AAS), flame	mg/L				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	mg/L				
Nickel	Atomic absorption spectrophotometry (AAS), flame	mg/L				
>>>> Spray dryer slurry, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw				
Nickel	Atomic absorption spectrophotometry (AAS), flame	ppmw				
>>>> Spray dryer solids <<<<						
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ppmw				
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Chloride	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ppmw				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ppmw				

Appendix C

Sample Collection and Analysis Data

Appendix C summarizes the sampling and analytical techniques used at Site 111. The following text, which is paraphrased from the CAE report, describes these procedures. Table C-1 presents the sampling periods for gas streams. Table C-2 summarizes the preparation and analytical techniques by sample stream. Table C-3 includes preparation and analytical techniques for coal. Gas sampling locations are described below.

Gas Sampling Locations

The spray dryer inlet has eight ports. For multi-metals testing, four points were sampled per port. The sampling time per point was four minutes for a total sampling time of 128 minutes. For polycyclic aromatics hydrocarbons testing, four points were sampled per port. The sampling time per point was five minutes for a total sampling time of 160 minutes.

The baghouse inlet has four ports. For multi-metals testing, four points were sampled per port. The sampling time per point was eight minutes for a total sampling time of 128 minutes. For polycyclic aromatics hydrocarbons testing, four points were sampled per port. The sampling time per point was ten minutes for a total sampling time of 160 minutes.

The stack has four ports. For multi-metals testing, three points were sampled per port. The sampling time per point was ten minutes for a total sampling time of 120 minutes. For polycyclic aromatics hydrocarbons testing, three points were sampled per port. The sampling time per point was fifteen minutes for a total sampling time of 180 minutes.

Grab Samples

Five (each) coal, bottom ash, spray dryer solids, and reagent feed grab samples were taken (two on December 17 and three on December 18). For analysis, each coal sample was treated separately, while ash and reagent samples were combined by day before being analyzed.

Table C-1

Sampling Periods for Gas Streams

Sampling Technique and Run Number	Spray Dryer Inlet	Baghouse Inlet	Stack
Multi-Metals			
1 (12/18)	1309-1520	1315-1530	1310-1510
2 (12/18)	1615-1838	1615-1821	1617-1820
Anion			
1 (12/17)	1045-1145	1045-1145	1045-1145
2 (12/17)	1530-1630	1530-1630	1530-1630
VOCs			
1a (12/18)	0930-0950	0932-0952	0930-0950
2a (12/18)	1135-1155	1136-1156	1135-1155
PAHs			
1 (12/17)	0930-1230	0931-1246	0938-1250
2 (12/18)	0850-1155	0850-1130	0852-1200

Table C-2

Summary of Preparation Procedures and Analytical Techniques Used to Measure

Elements and Organic Compound Components in Non-Coal Streams and Flue Gas Streams

Component and Procedure	Method Reference	Non-Coal Streams	Flue Gas Streams
METALS			
Sample Collection			
Impinger Train	EPA Draft Method 0012		X
Grab		X	
Analysis			
Arsenic by HGAAS	EPA SW 7061	X	X
Cadmium, Chromium, and Nickel by Flame AAS	EPA SW 7131, 7191, and 7521	X	X
Mercury by CVAAS	EPA SW 7470	X	X
ANION			
Sample Collection			
Impinger Train	EPA Draft Method 26		X
Grab		X	
Analysis			
Chloride by IC	EPA Draft Method 26	X	X
VOCs			
Sample Collection			
VOST	SW 846 Method 0030		X
Analysis			
Benzene by GC/MS	SW-846 Method 8420		X
PAHs			
Sample Collection			
MM5	SW 846 Method 0010		X
Analysis			
All compounds by GC/MS	CARB Method 429		X

Table C-3

Preparation Methods and Chemical Analysis Methods Applied to Coal at Site 111

Component	Method Reference
Ultimate Analysis of Coal	
Moisture	ASTM D 3173
Ash	ASTM D3174
Sulfur	ASTM D4239
Hydrogen	CHN Analyzer
Carbon	CHN Analyzer
Oxygen	By difference
Nitrogen	CHN Analyzer
Higher Heating Value	Bomb Calorimeter
FCEM Target Elements by INAA	
Preparation	None
Analysis by INAA	
Arsenic	None
Cadmium	None
Chromium	None
Mercury	None
Nickel	None

Appendix D

Process Data

Appendix D summarized process data collected during the sampling of Site 111. Table D-1 presents overall average gas and solid stream flow rates. Variability is expressed in the form of confidence intervals. Table D-2 presents power plant operating data based on each coal flow rate measurement. Table D-3 presents gas stream data on a run basis.

Table D-1

Process Stream Flow Rates

Stream (Solids)	Average Flow (lb/hr)	95% CI	Flow Calculated (C) or Measured (M)
Coal	242,000	± 13,000	M
Coal (Ash)	34,000	3,400	M
Bottom Ash [a]	6,800	2,700	C
Spray Dryer Inlet Ash [a]	27,200	10,900	C
Spray Dryer Solids [b]	3,700	820	C
Emitted Fly Ash [c]	29	--	C
Collected Waste [d]	30,870	--	C

Stream (Gases)	Average Flow (Nm^3/hr)	95% CF	Flow Calculated(C) or Measured (M)
Spray Dryer Inlet	931,500	140,700	M
Baghouse Inlet	403,500	18,400	M
Stack	1,183,250	19,100	M

[a]Fly ash and bottom ash flow rates were calculated using the mean coal ash content and flow rate. An 80/20 bottom ash/fly ash distribution was assumed.

[b]Spray dryer solids calculated using 72% SO_2 removal, 25/75 split between $CaSO_4 \cdot 2H_2O$ and $CaSO_3 \cdot ½H_2O$ products, and a 1.25 reagent ratio (plant operating data).

[c]Estimated using design value of 11 mg/Nm^3.

[d]Calculated by difference.

Table D-2

Solid Stream and Power Plant Operating Data

Parameter	Units	Run 1	Run 2	Run 3	Run 4	Run 5	Average	95% CI	Notes
Date		12/17	12/17	12/18	12/18	12/18			
Time		0930-1200	1430-1730	930-1200	1400-1600	1615-1800			
Inlet									
Coal	klb/hr	246	245	240	241	236	242	±13	Measured
Ash (in coal)	klb/hr	31.7	35.3	36.5	35.7	30.7	34.0	3.4	Measured
Lime	lb/hr						2,400	660	Calculated
Outlet									
Bottom Ash	klb/hr						6.8	2.7	Calculated
Collected Fly Ash	klb/hr						27.2	10.9	Calculated
Spray Dryer Solids	lb/hr						3,700	820	Calculated
Plant Op. Data									
Output	MW	283	280	280	278	269	278	6.6	Plant records
Inlet SO_2	lb/MBtu	1.021	0.949	1.015	0.762		0.937	0.19	Plant Records
Stack SO_2	lb/MBtu	0.231	0.201	0.241	0.223		0.226	0.03	Plant Records

Table D-3

Gas Stream Data

Parameter	Multi-Metals Run 3	Multi-Metals Run 4	VOST (PAH) Run 1	VOST (PAH) Run 3
Date:	12/19/91	12/18/91	12/17/91	12/18/91
Time:	1300-1600	1600-1845	0930-1215	0845-1200
Spray Dryer Inlet				
Volumetric Flow (Nm^3/hr)	1,013,000	946,000	961,000	806,000
Temperature (°F)	300	307	304	306
H_2O (vol. %)	10	12.1	13.7	14.1
O_2 (dry vol. %)	6.7	5.7	5.8	5.5
CO_2 (dry vol. %)	12.8	13.9	13.7	14.1
Particulate Loading	–	–	—	–
% Isokinetics	94.6	95.6	91	87.9
Baghouse Inlet				
Volumetric Flow (Nm^3/hr)	411,000	387,000	412,000	404,000
Temperature (°F)	157	165	157	164
H_2O (vol. %)	13.5	14	13	12.4
O_2 (dry vol. %)	6.4	6.3	5.9	6.3
CO_2 (dry vol. %)	13.1	13.3	13.8	12.9
Particulate Loading	–	–	–	–
% Isokinetics	100.4	101.6	94.9	98.2
Stack				
Volumetric Flow (Nm^3/hr)	1,196,000	1,167,000	1,185,000	1,185,000
Temperature (°F)	184	183	173	185
H_2O (vol%)	12.8	13.3	12.7	12.2
O_2 (dry vol%)	6.2	6.8	6	6.5
CO_2 (dry vol%)	13.2	12.9	13.5	13.2
Particulate Loading	–	–	–	–
% Isokinetics	101	102	101.3	100.8

Appendix E

Error Propagation and Material Balance Results

An error propagation analysis was performed on calculated results to determine the contribution of process, sampling, and analytical variability, and measurement bias, to the overall uncertainty in the result. This uncertainty was determined by propagating the bias and precision error of individual parameters into the calculation of the results. This uncertainty does not represent the total uncertainty in the result since many important bias errors are unknown and have been assigned a value of zero for this analysis. Also, this uncertainty is only the uncertainty in the result for the period of time that the measurements were taken.

The measure described below is based on ANSI/ASME PTC 19.1-1985, "Measurement Uncertainty."

Nomenclature

r	=	Calculated result;
S_{pi}	=	Sample standard deviation of parameter i;
θ_i	=	Sensitivity of the result to parameter i;
β_{pi}	=	Bias error estimate for parameter i;
v_i	=	Degrees of freedom in parameter i;
v_r	=	Degrees of freedom in result;
S_r	=	Precision component of result uncert.;
β_r	=	Bias component of result uncert.;
t	=	Student "t" factor (two-tailed distribution at 95%);
U_r	=	Uncertainty in r; and
N_i	=	Number of measurements of parameter i.

For a result, r, the uncertainty in r is calculated as:

$$U_r = \sqrt{\beta_r^2 + (S_r * t)^2} \quad (1)$$

The components are calculated by combining the errors in the parameters used in the result calculation.

$$\beta_r = \sqrt{\sum_{i=1}^{j} \theta_i * \beta_{\overline{pi}}} \quad (2)$$

$$S_r = \sqrt{\sum_{i=1}^{j} \theta_i \, S_{\overline{pi}}} \quad (3)$$

The sensitivity of the result to each parameter is found from a Taylor series estimation method:

$$\theta_i = \frac{\partial r}{\partial pi} \quad (4)$$

Or using a perturbation method (useful in computer applications):

$$\theta_i = \frac{r(P_i + \Delta P_i) - r(P_i)}{\Delta P_i} \quad (5)$$

The standard deviation of the average for each parameter is calculated as:

$$S_{\overline{pi}} = \frac{S_{pi}}{\sqrt{N}} \quad (6)$$

The degrees of freedom for each parameter is found from

$$v_i = N_i - 1 \tag{7}$$

and the degrees of freedom for the result if found by weighing the sensitivity and precision error in each parameter.

$$v_r = \frac{S_r^4}{\sum_{i=1}^{j} \left[\frac{(S_{\bar{p}i} \times \theta_i)^4}{v_i} \right]} \tag{8}$$

The student "t" in Equation 1 is associated with the degrees of freedom in the result.

The precision error terms are easily generated using collected data. When calculating the $S_{\bar{p}}$, care is taken in assigning degrees of freedom to each parameter. For example, if 15-minute average coal data are used to generate a mean coal feed rate for each of three days, the degrees of freedom in the average coal feed rate for the trip should reflect all of the 15 minute averages and not just the three daily averages. However, as another example, running duplicate analyses does not increase the degrees of freedom in analytical results.

The bias error terms are more difficult to quantify. The following conventions were used for this report:

- 5% bias on coal and ash rates;
- 20% bias in lime and FGD flow rates;
- No bias in gas flow rate; and
- No bias in analytical results unless the result is less than reporting limit. Then one-half the reporting limit is used for both the parameter value and its bias in calculations.

The flow rate bias values are assigned using engineering judgment. No bias is assigned to the analytical results (above the reporting limit) or gas flow rate since a good estimate for magnitude of these terms is unknown. These bias terms may be very large (relative to the mean values of the parameters) and may represent a large amount of unaccounted uncertainty in each result. Analytical bias near the instrument reporting limit may be especially large. Therefore, the uncertainty values calculated for this report should be used with care.

In addition to the assumptions about bias errors referred to above, the calculations also assume that the population distribution of each measurement is normally distributed and that the samples collected reflect the true population.

Also, the uncertainty calculated is only for the average value over the sampling period. The uncertainty does not represent long-term process variations. In other words, the calculated uncertainty does not include a bias term to reflect the fact that the sampled system was probably not operating (and emitting) at conditions equivalent to the average conditions for that system over a longer period. An example of the confidence interval calculation is provided below.

Confidence Interval Calculations

Confidence intervals (CIs) were calculated for the mean particulate phase concentrations, the mean vapor phase concentrations, and the total concentrations in all gas streams. In addition, confidence intervals were determined for the stack gas emission factors presented in Table 3-6.

The following example shows an example calculation for the 95% confidence interval around the emission factor. This procedure utilizes the same method outlined earlier in this appendix and used in the computer program. This is a generic example and values used in the calculation are not from Site 111.

$$E = \frac{(g * s) + (g * v)}{HHV * Coal} * 2204.6 \qquad (5\text{-}3)$$

where:

g = Gas flow rate, Nm^3/hr

s = Solid phase conc., mg/Nm^3

v = Vapor phase conc., mg/Nm^3

HHV = Coal higher heating value, Btu/lb

Coal = Coal feed rate, klb/hr

The values used to calculate the emission factor and the confidence interval are as follows:

	Parameter				
	g Nm^3/hr	s mg/Nm^3	v mg/Nm^3	HHV Btu/lb	Coal Klb/hr
Mean	2,607,500	0.00073	0	11,890	573.75
S_p	34,100	0.00039	0	75.6	8.76
$S_{\bar{p}}$	24,116	0.00027	0	43.6	1.26
N	3	2	2	3	48
β_p	0	0	0	0	28.7
θ	$2.4x10^{-7}$	843	--	$-5.2x10^{-5}$	$-1.0x10^{-3}$
v_p	1	1	1	2	47

The calculation for the solid phase values is included for reference.

Solid phase analytical: 0.000452 mg/Nm^3

0.00100 mg/Nm^3

N=2

$$\text{Mean} = \quad 0.00073$$

$$S_p = \quad 0.00039$$

$$S_{\bar{p}} = \frac{0.00039}{\sqrt{2}} = 0.00027$$

As explained in Appendix E, the β for analytical results is assigned as zero.

$$\beta_p = \quad 0$$

Next, calculate the sensitivity using perturbation method and a 0.0001 mg/Nm^3 perturbation:

$$\theta_i = \frac{r\ (0.00083) - r\ (0.00073)}{0.0001}$$

$$= \frac{0.7 - 0.61}{0.0001}$$

$$= \quad 843$$

Similar calculations can be done for each parameter.

The precision component is then found by root-sum-squaring the product of the parameter $S_{\bar{p}}$s and their sensitivities.

$$S_r = \sqrt{\left(\theta_g\ S_{\bar{g}}\right)^2 + \left(\theta_s\ S_{\bar{s}}\right)^2 + \left(\theta_v\ S_{\bar{v}}\right)^2 + \left(\theta_{HHV}\ S_{HHV}\right)^2 + \left(\theta_{coal}\ S_{coal}\right)^2}$$

$$S_r = \quad 0.236$$

The bias component is found using the same equation substituting β_p for the $S_{\bar{p}}$ term.

$$\beta_r = \sqrt{(\theta_g \beta_g)^2 + (\theta_s \beta_s)^2 + (\theta_v \beta_v)^2 + (\theta_{HHV} \beta_{HHV})^2 + (\theta_{coal} \beta_{coal})^2}$$

$$\beta_r = 0.03$$

The uncertainty in the result is then

$$U_r = \sqrt{\beta_r^2 + (t \times S_r)^2}$$

The degrees of freedom is found to be 1.0 for a "t" of 12.7 (i.e., one degree of freedom for N=2).

$$v_r = \frac{S_r^4}{\sum_{i=1}^{j} \frac{(S_{pi} \theta_i)^4}{v_{pi}}}$$

$$= \frac{6.4 \times 10^4}{6.4 \times 10^4} = 1$$

$$U_r = \sqrt{(0.03)^2 + (12.7 \times 0.236)^2}$$

$$= 3.0$$

The emission rate is calculated as 0.59 lb/10^{12} Btu.

The value is reported as 0.59 $\pm$ 3.0 lb/10^{12} Btu.

Improvements in bias estimates will be made as more data is collected and the QA/QC database is expanded. Spike and standard recoveries can be used to begin to estimate

analytical bias. Also, as the analytical methods improve accuracy will improve, resulting in the true bias of the analytical results being closer to the zero bias now assigned.

Accounting for long-term system variability will require repeated sampling trips to the same location.

The tables which follow this discussion are the computer-generated results from the emission factor and material balance error propagation. Each table provides the results for an individual element (e.g., pp. E-13 provides error propagation results for chromium).

Material Balance Closure Results

UNCERTAINTY CONTRIBUTOR

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
c	Chromium MB Closure	out/in	63.16841	2.64E+00	1.01E+01	1.0E+01	2.57E+00	4.7E+00

	INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGNAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1)	coalcon	coal concentration	ppmw	8	PREC	9.42E+01	-6.03E+00	3.60E+00	5
2)	cfaflow	col.fly ash flowrate	lb/hr	46300	PREC	7.34E+00	1.32E-03	4.11E+03	4
3)	coalfr	coal flowrate	lb/hr	242000	BIAS	6.08E+00	-2.04E-04	1.21E+04	-
4)	coalfr	coal flowrate	lb/hr	242000	PREC	7.11E-01	-2.04E-04	9.26E+03	5
5)	stackc	stack gas concentrat	ug/dscm	2	BIAS	5.70E-01	1.89E-01	4.00E+00	-
6)	baconc	bottom ash concentra	ppmw	6.3	PREC	3.85E-01	2.84E-01	3.09E+00	2
7)	sdflow	spray dryer feed flow	lb/hr	19200	BIAS	3.45E-01	-6.12E-04	9.60E+02	-
8)	baflow	bottom ash flowrate	lb/hr	6780	PREC	2.36E-01	2.64E-04	4.11E+03	5
9)	cfaconc	col.fly ash concentr	ppmw	31.4	PREC	6.11E-02	1.94E+00	1.80E-01	2
10)	sdconc	spray dryer feed conc	ppmw	23.3	PREC	8.55E-03	-5.09E-01	2.57E-01	2
11)	gasflow	stack gas flowrate	dscfm	1202000	PREC	2.39E-05	3.14E-07	3.11E+04	4

* PRECISION COMPONENT = t*Srbar

** (Bp*SIGNAp)^2 FOR BIAS ERRORS; (t*Spbar*SIGNAp)^2 FOR PRECISION ERRORS
-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; Sp FOR PRECISION ERRORS

UNCERTAINTY CONTRIBUTOR

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
c	Arsenic MB Closure	out/in	131.6519	4.69E+00	1.82E+01	1.9E+01	2.37E+00	7.0E+00

	INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1)	coalcon	coal concentration	ppmw	.6	PREC	1.93E+02	-1.31E+02	2.37E-01	5
2)	cfaconc	col.fly ash concentr	ppmw	6.400001	PREC	6.44E+01	2.00E+01	5.68E-01	2
3)	sdconc	spray dryer feed conc	ppmw	4.5	PREC	4.14E+01	-1.07E+01	8.51E-01	2
4)	cfaflow	col.fly ash flowrate	lb/hr	46300	PREC	2.73E+01	2.76E-03	3.78E+03	4
5)	coalfr	coal flowrate	lb/hr	242000	BIAS	1.60E+01	-3.31E-04	1.21E+04	-
6)	sdflow	spray dryer feed flow	lb/hr	19200	BIAS	5.81E+00	-2.51E-03	9.60E+02	-
7)	coalfr	coal flowrate	lb/hr	242000	PREC	1.60E+00	-3.31E-04	8.56E+03	5
8)	baconc	bottom ash concentra	ppmw	1.2	PREC	7.77E-01	2.93E+00	4.26E-01	2
9)	baflow	bottom ash flowrate	lb/hr	6780	PREC	7.69E-01	5.18E-04	3.78E+03	5
10)	stackc	stack gas concentrat	ug/Nm3	.1	BIAS	1.51E-01	1.94E+00	2.00E-01	-
11)	gasflow	stack gas flowrate	Nm3/hr	1202000	PREC	5.33E-06	1.62E-07	2.85E+04	4

* PRECISION COMPONENT = t*Srbar

** (Bp*SIGMAp)^2 FOR BIAS ERRORS; (t*Spbar*SIGMAp)^2 FOR PRECISION ERRORS
-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; Sp FOR PRECISION ERRORS

Emission Factor Results

E- FACTOR UNCERTAINTY

AVERAGE VALUE		As		Cd		Cr		Hg		Ni
Coal (lb/hr)		241600		241600		241600		241600		241600
HHV (BTU/lb)		10024		10024		10024		10024		10024
Gasflow (Nm^3/hr)		1183000		1183000		1183000		1183000		1183000
Conc (ug/Nm^3)	<	1.978E-01	<	1.978E+00	<	3.956E+00	<	6.250E+01	<	4.945E+00
ABSOLUTE PREC COMPONENT										
Coal (StDev*t/n^.5*Sens)^2		1.017E-05		1.017E-03		4.068E-03		1.015E+00		6.356E-03
HHV (StDev*t/n^.5*Sens)^2		3.293E-06		3.293E-04		1.317E-03		3.288E-01		2.058E-03
Gasflw (StDev*t/n^.5*Sens)^2		5.173E-06		5.173E-04		2.069E-03		5.166E-01		3.233E-03
Conc (StDev*t/n^.5*Sens)^2		0.000E+00		0.000E+00		0.000E+00		0.000E+00		0.000E+00
ABSOLUTE BIAS COMPONENT										
Coal (Bias*Sens)^2		1.027E-04		1.027E-02		4.108E-02		1.026E+01		6.419E-02
HHV (Bias*Sens)^2		0.000E+00		0.000E+00		0.000E+00		0.000E+00		0.000E+00
Gasflow (Bias*Sens)^2		0.000E+00		0.000E+00		0.000E+00		0.000E+00		0.000E+00
Conc (Bias*Sens)^2		5.578E-03		5.578E-01		2.231E+00		5.613E+02		1.769E+00
ERROR OF INPUT (STD DEV)										
Coal StDev		4037		4037		4037		4037		4037
HHV StDev		91.6		91.6		91.6		91.6		91.6
Gasflow StDev		12010		12010		12010		12010		12010
Conc StDev		0.000E+00		0.000E+00		0.000E+00		0.000E+00		0.000E+00
ERROR OF INPUT (BIAS)										
Coal Bias		12080		12080		12080		12080		12080
HHV Bias		0		0		0		0		0
Gas flow Bias		0		0		0		0		0
Conc Bias		6.941E-02		6.941E-01		1.388E+00		2.202E+01		1.236E+00
NUMBER OF SAMPLES										
Coal N		5		5		5		5		5
HHV N		5		5		5		5		5
Q N		4		4		4		4		4
Conc N		2		2		2		2		2
RESULTS										
E-Factor (lb/10^12 BTU)	<	2.13E-01	<	2.13E+00	<	4.26E+00	<	6.72E+01	<	5.32E+00
Total Uncertainty		RESULT ND		RESULT ND		RESULT ND		RESULT ND		RESULT ND
Bias Component		RESULT ND		RESULT ND		RESULT ND		RESULT ND		RESULT ND
Precision Component		RESULT ND		RESULT ND		RESULT ND		RESULT ND		RESULT ND
Student t Factor		2.11E+00		2.11E+00		2.11E+00		2.11E+00		2.11E+00
Degrees of Freedom		9.26E+00		9.26E+00		9.26E+00		9.26E+00		9.26E+00

E- FACTOR UNCERTAINTY

AVERAGE VALUE	Cl-	Benzene	Napthalene	Acenaphthylene	Acenaphthene
Coal (lb/hr)	241600	241600	241600	241600	241600
HHV (BTU/lb)	10024	10024	10024	10024	10024
Gasflow (Nm^3/hr)	1183000	1183000	1183000	1183000	1183000
Conc (ug/Nm^3)	1.163E+03	1.962E+01	7.070E-01	2.556E-02	7.208E-02
ABSOLUTE PREC COMPONENT					
Coal (StDev*t/n^.5*Sens)^2	1.199E+04	3.472E+00	4.637E-03	6.093E-06	4.883E-05
HHV (StDev*t/n^.5*Sens)^2	3.882E+03	1.124E+00	1.501E-03	1.973E-06	1.581E-05
Gasflw (StDev*t/n^.5*Sens)^2	6.100E+03	1.766E+00	2.359E-03	3.100E-06	2.484E-05
Conc (StDev*t/n^.5*Sens)^2	4.899E+04	1.928E+01	2.348E+00	4.353E-03	9.641E-02
ABSOLUTE BIAS COMPONENT					
Coal (Bias*Sens)^2	3.553E+03	1.011E+00	1.312E-03	1.715E-06	1.364E-05
HHV (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Gasflow (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Conc (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ERROR OF INPUT (STD DEV)					
Coal StDev	4037	4037	4037	4037	4037
HHV StDev	91.6	91.6	91.6	91.6	91.6
Gasflow StDev	12010	12010	12010	12010	12010
Conc StDev	1.382E+02	2.741E+00	1.601E-01	6.877E-03	3.224E-02
ERROR OF INPUT (BIAS)					
Coal Bias	12080	12080	12080	12080	12080
HHV Bias	0	0	0	0	0
Gas flow Bias	0	0	0	0	0
Conc Bias	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NUMBER OF SAMPLES					
Coal N	5	5	5	5	5
HHV N	5	5	5	5	5
Q N	4	4	4	4	4
Conc N	2	2	2	2	2
RESULTS					
E-Factor (lb/10^12 BTU)	1.25E+03	2.11E+01	7.61E-01	2.75E-02	7.76E-02
Total Uncertainty	1.30E+03	2.60E+01	1.54E+00	6.61E-02	3.11E-01
Bias Component	5.96E+01	1.01E+00	3.62E-02	1.31E-03	3.69E-03
Precision Component	1.30E+03	2.60E+01	1.54E+00	6.61E-02	3.11E-01
Student t Factor	1.23E+01	1.24E+01	1.26E+01	1.26E+01	1.27E+01
Degrees of Freedom	1.03E+00	1.02E+00	1.01E+00	1.01E+00	1.00E+00

E- FACTOR UNCERTAINTY

AVERAGE VALUE	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene
Coal (lb/hr)	241600	241600	241600	241600	241600
HHV (BTU/lb)	10024	10024	10024	10024	10024
Gasflow (Nm^3/hr)	1183000	1183000	1183000	1183000	1183000
Conc (ug/Nm^3)	1.628E-01	1.181E-01	1.954E-02	2.720E-02	1.214E-02
ABSOLUTE PREC COMPONENT					
Coal (StDev*t/n^.5*Sens)^2	2.496E-04	1.299E-04	3.600E-06	6.917E-06	1.384E-06
HHV (StDev*t/n^.5*Sens)^2	8.083E-05	4.205E-05	1.166E-06	2.240E-06	4.482E-07
Gasflw (StDev*t/n^.5*Sens)^2	1.270E-04	6.607E-05	1.831E-06	3.519E-06	7.041E-07
Conc (StDev*t/n^.5*Sens)^2	1.002E+00	8.554E-02	3.304E-02	6.301E-03	2.447E-03
ABSOLUTE BIAS COMPONENT					
Coal (Bias*Sens)^2	6.956E-05	3.660E-05	1.002E-06	1.942E-06	3.868E-07
HHV (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Gasflow (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Conc (Bias*Sens)^2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ERROR OF INPUT (STD DEV)					
Coal StDev	4037	4037	4037	4037	4037
HHV StDev	91.6	91.6	91.6	91.6	91.6
Gasflow StDev	12010	12010	12010	12010	12010
Conc StDev	1.038E-01	3.050E-02	1.884E-02	8.263E-03	5.138E-03
ERROR OF INPUT (BIAS)					
Coal Bias	12080	12080	12080	12080	12080
HHV Bias	0	0	0	0	0
Gas flow Bias	0	0	0	0	0
Conc Bias	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NUMBER OF SAMPLES					
Coal N	5	5	5	5	5
HHV N	5	5	5	5	5
Q N	4	4	4	4	4
Conc N	2	2	2	2	2
RESULTS					
E-Factor (lb/10^12 BTU)	1.75E-01	1.27E-01	2.10E-02	2.93E-02	1.31E-02
Total Uncertainty	1.00E+00	2.93E-01	1.82E-01	7.95E-02	4.95E-02
Bias Component	8.34E-03	6.05E-03	1.00E-03	1.39E-03	6.22E-04
Precision Component	1.00E+00	2.93E-01	1.82E-01	7.95E-02	4.95E-02
Student t Factor	1.27E+01	1.26E+01	1.27E+01	1.26E+01	1.27E+01
Degrees of Freedom	1.00E+00	1.01E+00	1.00E+00	1.00E+00	1.00E+00

E- FACTOR UNCERTAINTY

AVERAGE VALUE		Chrysene	Benz(a)anthracene	Benzo(b)fluoranthene		Benzo(k)fluoranthene
Coal (lb/hr)		241600	241600	241600		241600
HHV (BTU/lb)		10024	10024	10024		10024
Gasflow (Nm^3/hr)		1183000	1183000	1183000		1183000
Conc (ug/Nm^3)	<	3.286E-03	8.211E-03	7.699E-03	<	3.286E-03
ABSOLUTE PREC COMPONENT						
Coal (StDev*t/n^.5*Sens)^2		2.806E-09	6.360E-07	5.576E-07		2.806E-09
HHV (StDev*t/n^.5*Sens)^2		9.086E-10	2.059E-07	1.806E-07		9.086E-10
Gasflw (StDev*t/n^.5*Sens)^2		1.428E-09	3.236E-07	2.837E-07		1.428E-09
Conc (StDev*t/n^.5*Sens)^2		0.000E+00	8.052E-03	1.425E-03		0.000E+00
ABSOLUTE BIAS COMPONENT						
Coal (Bias*Sens)^2		2.834E-08	1.770E-07	1.556E-07		2.834E-08
HHV (Bias*Sens)^2		0.000E+00	0.000E+00	0.000E+00		0.000E+00
Gasflow (Bias*Sens)^2		0.000E+00	0.000E+00	0.000E+00		0.000E+00
Conc (Bias*Sens)^2		1.556E-06	7.744E-07	0.000E+00		7.811E-07
ERROR OF INPUT (STD DEV)						
Coal StDev		4037	4037	4037		4037
HHV StDev		91.6	91.6	91.6		91.6
Gasflow StDev		12010	12010	12010		12010
Conc StDev		0.000E+00	9.299E-03	3.918E-03		0.000E+00
ERROR OF INPUT (BIAS)						
Coal Bias		12080	12080	12080		12080
HHV Bias		0	0	0		0
Gas flow Bias		0	0	0		0
Conc Bias		1.159E-03	8.179E-04	0.000E+00		8.214E-04
NUMBER OF SAMPLES						
Coal N		5	5	5		5
HHV N		5	5	5		5
Q N		4	4	4		4
Conc N		2	2	2		2
RESULTS						
E-Factor (lb/10^12 BTU)	<	3.54E-03	8.83E-03	8.28E-03	<	3.54E-03
Total Uncertainty		RESULT ND	8.97E-02	3.78E-02		RESULT ND
Bias Component		RESULT ND	9.75E-04	3.94E-04		RESULT ND
Precision Component		RESULT ND	8.97E-02	3.78E-02		RESULT ND
Student t Factor		2.11E+00	1.27E+01	1.27E+01		2.11E+00
Degrees of Freedom		9.26E+00	1.00E+00	1.00E+00		9.26E+00

E- FACTOR UNCERTAINTY

AVERAGE VALUE		Benzo(a)pyrene		Indeno(1,2,3-c,d)pyrene	Dibenz(a,h)anthracene		Benzo(g,h,i)perylene
Coal (lb/hr)		241600		241600	241600		241600
HHV (BTU/lb)		10024		10024	10024		10024
Gasflow (Nm^3/hr)		1183000		1183000	1183000		1183000
Conc (ug/Nm^3)	<	3.286E-03		3.929E-03	< 3.286E-03		3.929E-03
ABSOLUTE PREC COMPONENT							
Coal (StDev*t/n^.5*Sens)^2		2.806E-09		1.456E-07	2.806E-09		1.456E-07
HHV (StDev*t/n^.5*Sens)^2		9.086E-10		4.713E-08	9.086E-10		4.713E-08
Gasflw (StDev*t/n^.5*Sens)^2		1.428E-09		7.406E-08	1.428E-09		7.406E-08
Conc (StDev*t/n^.5*Sens)^2		0.000E+00		9.732E-04	0.000E+00		9.732E-04
ABSOLUTE BIAS COMPONENT							
Coal (Bias*Sens)^2		2.834E-08		4.053E-08	2.834E-08		4.053E-08
HHV (Bias*Sens)^2		0.000E+00		0.000E+00	0.000E+00		0.000E+00
Gasflow (Bias*Sens)^2		0.000E+00		0.000E+00	0.000E+00		0.000E+00
Conc (Bias*Sens)^2		1.556E-06		7.811E-07	1.556E-06		7.811E-07
ERROR OF INPUT (STD DEV)							
Coal StDev		4037		4037	4037		4037
HHV StDev		91.6		91.6	91.6		91.6
Gasflow StDev		12010		12010	12010		12010
Conc StDev		0.000E+00		3.234E-03	0.000E+00		3.234E-03
ERROR OF INPUT (BIAS)							
Coal Bias		12080		12080	12080		12080
HHV Bias		0		0	0		0
Gas flow Bias		0		0	0		0
Conc Bias		1.159E-03		8.214E-04	1.159E-03		8.214E-04
NUMBER OF SAMPLES							
Coal N		5		5	5		5
HHV N		5		5	5		5
Q N		4		4	4		4
Conc N		2		2	2		2
RESULTS							
E-Factor (lb/10^12 BTU)	<	3.54E-03		4.23E-03	< 3.54E-03		4.23E-03
Total Uncertainty		RESULT ND		3.12E-02	RESULT ND		3.12E-02
Bias Component		RESULT ND		9.06E-04	RESULT ND		9.06E-04
Precision Component		RESULT ND		3.12E-02	RESULT ND		3.12E-02
Student t Factor		2.11E+00		1.27E+01	2.11E+00		1.27E+01
Degrees of Freedom		9.26E+00		1.00E+00	9.26E+00		1.00E+00

Appendix F

Quality Assurance/Quality Control Data

Appendix F presents QA/QC results for the Site 111 sampling event. The blank analyses are presented as well as quality control results and detection limits. Table F-1 summarizes blank analyses for PAHs, benzene, chloride, and multi-metals. Table F-2 presents spike recovery data for metals and chloride. Table F-3 contains results for a lab control sample spike for PAHs and Table F-4 contains isotopic recovery results for PAHs. Table F-5 lists pre-spike recovery standards for PAHs. Table F-6 includes duplicate analyses for metals in the flue gas and non-coal solid streams. Finally, Table F-7 gives the quality control results for a coal standard analyzed by INAA.

Table F-1

Summary of Blank Samples Results

Method	Number of Blank Samples Analyzed	Number of Detects	Range of Mass Detected (μg)	Detection Limits (μg)
MM5				
Field Blank				
Naphthalene	1	1	0.97	–
Acenaphthylene	1	1	0.012	–
Acenaphthene	1	0		0.01
Fluorene	1	1	0.014	–
Phenanthrene	1	1	0.039	–
Anthracene	1	0		0.01
Fluoranthene	1	1	0.012	–
Pyrene	1	0		0.01
Benz(a)anthracene	1	0		0.01
Chrysene	1	0		0.01
Benzo(b)fluoranthene	1	0		0.01
Benzo(k)fluoranthene	1	0		0.01
Benzo(a)pyrene	1	0		0.01
Indeno(1;2,3-c,d)pyrene	1	0		0.01
Dibenzo(a,h)anthracene	1	0		0.01
Benzo(g,h,i)perylene	1	0		0.01
Reagent Blank				
Naphthalene	1	1	0.093	
Acenaphthylene	1	0		0.01
Acenaphthene	1	0		0.01
Fluorene	1	1	0.018	
Phenanthrene	1	1	0.085	
Anthracene	1	0		0.01
Fluoranthene	1	1	0.019	
Pyrene	1	1	0.012	
Benz(a)anthracene	1	1		0.01
Chrysene	1	0		0.01
Benzo(b)fluoranthene	1	0		0.01

Table F-1 (Continued)

Method	Number of Blank Samples Analyzed	Number of Detects	Range of Mass Detected (μg)	Detection Limits (μg)
Benzo(k)fluoranthene	1	0		0.01
Benzo(a)pyrene	1	0		0.01
Indeno(1,2,3-c,d)pyrene	1	0		0.01
Dibenz(a,h)anthracene	1	0		0.01
Benzo(g,h,i)perylene	1	0		0.01
VOST				
Field Blank				
Benzene	3	0		0.01
Trip Blank				
Benzene	2	0		0.01
Regeant Blank				
Benzene	4	0		0.01
Tube Blank				
Benzene	3	0		0.01
Chloride				
Reagent Blank				
Chloride	1	0		23.5
Multi-Metals (FAA)				
Field Blank (solid phase)				
Cadmium	1	0		4
Chromium	1	0		8
Nickel	1	0		10
Field Blank (vapor phase)				
Cadmium	1	0		5
Chromium	1	0		8
Nickel	1	0		11
Reagent Blank (solid phase)				
Cadmium	2	0		4
Chromium	2	0		8
Nickel	2	0		10

Table F-1 (Continued)

Method	Number of Blank Samples Analyzed	Number of Detects	Range of Mass Detected (μg)	Detection Limits (μg)
Reagent Blank (vapor phase)				
Cadmium	1	0		4
Chromium	1	0		8
Nickel	1	0		10
Multi-Metals (HGAAS)				
Field Blank (solid phase)				
Arsenic	1	0		4
Field Blank (vapor phase)				
Arsenic	1	0		2
Reagent Blank (solid phase)				
Arsenic	2	0		4
Reagent Blank (vapor phase)				
Arsenic	1	0		2
Multi-Metals (CVAAS)				
Field Blank (solid phase)				
Mercury	1	0		4
Field Blank (vapor phase)				
Mercury	1	0		86.2
Field Blank (vapor phase)				
Mercury	1	0		14.8
Reagent Blank (solid phase)				
Mercury	2	0		4

Table F-2

Summary of Spiked Sample Results

Compound	No. of Spikes	Mean Spike Recovery	RPD (%)
Multi-Metals by FAAS			
Cadmium	3	98.1	6.2
Chromium	3	99.0	10.0
Nickel	3	100.9	2.9
Multi-Metals by HGAAS			
Arsenic	3	105.5	23
Multi-Metals by CVAAS			
Arsenic	4	106.0	11.0
VOCs			
Benzene	3	126	5.6
Anion			
Chloride	1	105	–

Table F-3

Summary of Lab Control Sample Spike Results

Compound	No. of Spikes	Mean Spike Recovery	RPD (%)
PAH			
Naphthalene	2	86.5	1.2
Acenaphthylene	2	97	0
Acenaphthene	2	84	9.5
Fluorene	2	101	2
Phenanthrene	2	113.5	2.6
Anthracene	2	78	2.6
Fluoranthene	2	103.5	1
Pyrene	2	88	2.3
Chrysene	2	67	3
Benz(a)anthracene	2	71	2.8
Benzo(b)fluoranthene	2	91.5	12
Benzo(k)fluoranthene	2	99	8.1
Benzo(a)pyrene	2	94	1.2
Indeno(1,2,3-cd)pyrene	2	111.5	0.9
Benzo(g,h,i)perylene	2	111.5	12
Dibenz(a,h)anthracene	2	107.5	16

Table F-4

Summary of Isotopic Recovery Results

Compound	Mean Spike Recovery	RPD (%)	No. of Spikes
PAH			
Method Blank			
d8-Naphthalene	51		1
d8-Acenaphthylene	51		1
d10-Acenaphthene	68		1
d10-Fluorene	73		1
d10-Phenanthrene	82		1
d10-Anthracene	87		1
d10-Fluoranthene	97		1
d10-Pyrene	97		1
d12-Chrysene	67		1
d12-Benz(a)anthracene	95		1
d12-Benzo(b)fluoranthene	69		1
d12-Benzo(k)fluoranthene	81		1
d12-Benzo(a)pyrene	53		1
d12-Indeno(1,2,3-cd)pyrene	51		1
d12-Benzo(g,h,i)perylene	54		1
d14-Dibenz(a,h)anthracene	48		1
Lab Control Samples			
d8-Naphthalene	103.5	1.0	2
d8-Acenaphthylene	58	10.3	2
d10-Acenaphthene	57	14.0	2
d10-Fluorene	56	10.7	2
d10-Phenanthrene	44	22.7	2
d10-Anthracene	19	10.5	2
d10-Fluoranthene	140	5.7	2
d10-Pyrene	105	11.4	2
d12-Chrysene	102.5	2.9	2
d12-Benz(a)anthracene	112.5	2.7	2
d12-Benzo(b)fluoranthene	51	3.9	2
d12-Benzo(k)fluoranthene	91.5	1.1	2
d12-Benzo(a)pyrene	75	8.0	2
d12-Indeno(1,2,3-cd)pyrene	140.5	5.0	2
d12-Benzo(g,h,i)perylene	106.5	12.2	2
d14-Dibenz(a,h)anthracene	91.5	108.2	2

Table F-4 (Continued)

Compound	Mean Spike Recovery	RPD (%)	No. of Spikes
Field Blank			
d8-Naphthalene	71		1
d8-Acenaphthylene	59		1
d10-Acenaphthene	63		1
d10-Fluorene	62		1
d10-Phenanthrene	68		1
d10-Anthracene	72		1
d10-Fluoranthene	61		1
d10-Pyrene	61		1
d12-Chrysene	56		1
d12-Benz(a)anthracene	67		1
d12-Benzo(b)fluoranthene	69		1
d12-Benzo(k)fluoranthene	70		1
d12-Benzo(a)pyrene	62		1
d12-Indeno(1,2,3-cd)pyrene	64		1
d12-Benzo(g,h,i)perylene	59		1
d14-Dibenz(a,h)anthracene	64		1
Spray Dryer Inlet			
d8-Naphthalene	59	37.3	2
d8-Acenaphthylene	45.5	54.9	2
d10-Acenaphthene	62.5	46.4	2
d10-Fluorene	61.5	53.7	2
d10-Phenanthrene	43.5	39.1	2
d10-Anthracene	24.5	102.0	2
d10-Fluoranthene	26.5	11.3	2
d10-Pyrene	24.5	4.1	2
d12-Chrysene	13	15.4	2
d12-Benz(a)anthracene	12	16.7	2
d12-Benzo(b)fluoranthene	15.5	32.3	2
d12-Benzo(k)fluoranthene	8.2	29.3	2
d12-Benzo(a)pyrene	6.55	16.8	2
d12-Indeno(1,2,3-cd)pyrene	4.3	32.6	2
d12-Benzo(g,h,i)perylene	4.3	60.5	2
d14-Dibenz(a,h)anthracene	4.65	36.6	2

Table F-4 (Continued)

Compound	Mean Spike Recovery	RPD (%)	No. of Spikes
Baghouse Inlet			
d8-Naphthalene	50	8.0	2
d8-Acenaphthylene	25	8.0	2
d10-Acenaphthene	59.5	1.7	2
d10-Fluorene	35.5	8.5	2
d10-Phenanthrene	13.5	37.0	2
d10-Anthracene	4.15	89.2	2
d10-Fluoranthene	5.5	54.5	2
d10-Pyrene	7.15	4.2	2
d12-Chrysene	4	100.0	2
d12-Benz(a)anthracene	2.5	120.0	2
d12-Benzo(b)fluoranthene	7.5	66.7	2
d12-Benzo(k)fluoranthene	3	133.3	2
d12-Benzo(a)pyrene	3.2	56.3	2
d12-Indeno(1,2,3-cd)pyrene	5		1
d12-Benzo(g,h,i)perylene	4.3		1
d14-Dibenz(a,h)anthracene	5.2		1
Stack			
d8-Naphthalene	79	10.1	2
d8-Acenaphthylene	85.5	12.9	2
d10-Acenaphthene	84.5	27.2	2
d10-Fluorene	69	81.2	2
d10-Phenanthrene	59	149.2	2
d10-Anthracene	51	121.6	2
d10-Fluoranthene	56.5	23.0	2
d10-Pyrene	62.5	40.0	2
d12-Chrysene	21	57.1	2
d12-Benz(a)anthracene	11.65	74.7	2
d12-Benzo(b)fluoranthene	118.5	34.6	2
d12-Benzo(k)fluoranthene	78.5	19.1	2
d12-Benzo(a)pyrene	81	2.5	2
d12-Indeno(1,2,3-cd)pyrene	81	81.5	2
d12-Benzo(g,h,i)perylene	88	115.9	2
d14-Dibenz(a,h)anthracene	94	93.6	2

Table F-5

Summary of Pre-Spike Recovery Standards for Semivolatile Organic Analyses

Component	No. of Analyses	Mean % Recovery	Mean RPD
Field Blank			
Benzo(e)pyrene-d12	1	121	--
Terphenyl-314	1	122	--
Reagent Blank			
Benzo(e)pyrene-d12	0	NA	--
Terphenyl-d14	0	NA	--
Scrubber Inlet			
Benzo(e)pyrene-d12	2	105	24.8
Terphenyl-d14	2	88	9.1
Baghouse Inlet			
Benzo(e)pyrene-d12	2	105.5	42.7
Terphenyl-d14	2	134.5	37.9
Stack Gas			
Benzo(e)pyrene-12	2	115	15.7
Terphenyl-d14	2	89.5	23.5

Table F-6

Summary of Duplicate Sample and Duplicate Analysis Results

Component	No. of Pairs	Amount Detected	% Deviation
DUPLICATE SAMPLES			
None			
DUPLICATE ANALYSES			
Multi-Metals by FAAS in Flue Gas (mg)			
Solid Phase			
Cadmium	1	0.020	0.98
Chromium	1	0.309	1.43
Nickel	1	0.246	1.15
Vapor Phase			
Cadmium	1	0.006	1.92
Chromium	1	ND(0.008)	–
Nickel	1	ND(0.011)	–
Multi-Metals by HGAAS in Flue Gas (mg)			
Solid Phase			
Arsenic	1	0.0064	0.47
Vapor Phase			
Arsenic	1	0.0019	3.41
Multi-Metals by CVAAS in Flue Gas (mg)			
Solid Phase			
Mercury	1	ND(0.004)	–
Vapor Phase			
Mercury (front half)	1	ND(0.1118)	–
Mercury (back half)	1	ND(0.0172)	–
Anions by IC in Flue Gas (mg)			
Chloride	1	3.8	1.4
Multi-Metals by FAAS in Solid Streams (mg/kg)			
Cadmium	1	ND(1.96)	–
Chromium	1	7.14	2.78
Nickel	1	34.6	3.98
Multi-Metals by HGAAS in Solid Streams (mg/kg)			
Arsenic	1	1.31	5.45
Multi-Metals by CVAAS in Solid Streams (mg/kg)			
Mercury	1	ND(1.93)	–

Table F-7

Summary of Quality Control Sample Results for Coal

Substance (ppm)	INAA Measurement of NBS 1632a	"True" Values	Recovery %
Arsenic	8.25	9.3 ±1.0	89
Cadmium	ND (46.1)	0.17 ±0.02	--
Chromium	32.7	34.4 ±1.5	95
Mercury	ND (0.30)	0.13 ±0.03	--
Nickel	ND (3050)	19.4 ±1.0	--