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FIELD CHEMICAL EMISSIONS MONITORING PROJECT: SITE 114 REPORT

PRELIMINARY DRAFT REPORT

Prepared for:

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13 May 1994

EPRI
Electric Power
Research Institute *Leadership in Science and Technology*

May 13, 1994

Mr. William H. Maxwell, P.E. (MD13)
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
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 114. Site 114 sampling program was sponsored by EPRI, DOE, and the host utility. Site 114 consists of a 100 MW cyclone boiler burning a bituminous coal, with an electrostatic precipitator (ESP) for particulate control. Overfire air and reburn burners in the upper furnace were used for NO_x control. Tests were conducted both with and without coal reburn. **It should be noted that the results presented in this report are considered PRELIMINARY**. The results are believed to be essentially correct except as noted. As additional data from other sites are collected and evaluated, however, EPRI may conduct verification tests at this site. If this is done, the new data will be made available to the Environmental Protection Agency (EPA).

The primary objective of this report is to transmit the preliminary results from Site 114 to the EPA for use in evaluating select trace chemical emissions from fossil-fuel-fired steam generating plants. 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. Because the discussion only focuses upon the suspect or invalidated data, please keep in mind that most of the data meet the standards of quality established for this study. This report does not compare the results from Site 114 with the results from previous utility sites.

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Generic conclusions and recommendations were not drawn concerning the effectiveness of an ESP as potential control technology 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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1

INTRODUCTION

This report summarizes data gathered by Acurex Environmental Corporation at a power plant, designated Site 114, during a sampling program sponsored by Electric Power Research Institute (EPRI), the Department of Energy (DOE), and the host utility. 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 within the power plant.

Objectives

The objective of this report is to provide information about fuel characteristics and stack emissions and data quality 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 114, a bituminous coal-fired boiler equipped with electrostatic precipitators (ESPs) for controlling emissions, was sampled during November 1992. The sampling was conducted under two boiler operating conditions, baseline and reburn. Reburn operating conditions use wall-fired burners located at a higher elevation in the boiler and overfire air to reduce NO_x emissions. Table 1-1 lists the substances tested at this site. The results for each substance are presented by individual run and as averages of replicate runs 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 protocols were reviewed, and the data from this test were compared with other FCEM data generated using standard protocols;
- The type and number of quality assurance samples were reviewed to qualitatively estimate the level of confidence that can be placed in the results; and
- The QA/QC data results were compared with data quality objectives to evaluate the data in terms of precision and accuracy.

Table 1-1
Summary of Measured Substances and Characteristics at Site 114

Elements [a,b]	Organic Compounds [b]
Arsenic	Benzene
Beryllium	Toluene
Cadmium	Formaldehyde
Chloride	Acetaldehyde
Chromium	Acenaphthene
Fluoride	Acenaphthylene
Lead	Anthracene
Manganese	Benzo(a)anthracene
Mercury	Benzo(a)pyrene
Nickel	Benzo(b)fluoranthene
Selenium	Benzo(g,h,i)perylene
Other [a]	Benzo(k)fluoranthene
Proximate Analysis (moisture, ash)	Chrysene
Ultimate Analysis (C,H,N,O_2,S)	Dibenzo(a,h)anthracene
HHV	Fluoranthene
	Fluorene
	Indeno(1,2,3-cd)pyrene
	Naphthalene

[a]Measured in coal.

[b]Measured in emitted gas stream.

Each of these evaluation criteria is discussed separately below.

Process Data Evaluation

An examination of plant operating and CEM data collected during the sampling periods indicate that the plant was operating at steady state with respect to key monitoring parameters. A limited bituminous coal supply, due to the plant's conversion to a subbituminous western coal, required the unit to run at low loads between tests, but unit load was kept constant at full load (100 MW) during all test periods. The reduced test schedule, which included baseline testing on the first two days and alternated between reburn and baseline testing on the last three days, contributed to large confidence intervals for the mean coal and gas concentrations and limited the ability to discern differences in the emission levels under these two conditions. Further discussion of the process data evaluation is included in Section 4.

Sampling and Analysis Protocol Comparison

Tables 1-2 and 1-3 compare the sampling and analysis protocols for Site 114 with the protocols for the FCEM program. Most sampling methods used by Acurex are comparable to those specified in the FCEM protocol. The carbon molecular sieve (CMS) sorbent used in the VOST train is not an approved substitute for the Tenax traps specified in Method 0030. The resulting volatile organic data are thus difficult to compare with VOST. Analytical techniques used by Acurex, while appropriate, differ in several cases or are less sensitive than analytical methods specified by FCEM protocol.

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

The completeness of the quality assurance data was reviewed to judge whether a statement of data quality could be made about these results. Minimal QA/QC data are available for Site 114, making it difficult to ascertain the quality of the measurement data. The QA/QC information is presented and discussed in Section 4. A determination of accuracy, precision, and bias, even if only qualitative, is considered an important part of the data evaluation.

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 114 included replicate tests, matrix spikes, lab control samples, field blanks, and trip blanks for limited combinations of streams and analytes.

Table 1-2
Comparison of Sampling Protocol for the FCEM Project and Site 114

Sampling Methods		
Target Substance	**Site 114**	**FCEM Protocol[a]**
Gas Streams		
Metals	EPA Multiple Metals Method 0012	EPA Multi-Metals Method 29[b]
Chloride, Fluoride	CARB 421, Carbonate Impingers	Modified Method 5[c]
Benzene, Toluene	VOST Train with CMS Sorbent	EPA SW 0030 (VOST)
Formaldehyde, Acetaldehyde	CARB 430, DNPH Midget Impingers	BIF 0011
POM Matter	EPA SW 0010 (Modified Method 5)	Modified Method 5
Coal		
Metals	Grab/Composite	Grab/Composite
Chloride, Fluoride	Grab/Composite	Grab/Composite

[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 114

Analytical Methods		
Target Substance	**Site 114**	**FCEM Protocol**
Gas Streams		
Arsenic	EPA SW 7060 (GFAAS)	Same
Beryllium	EPA SW 6010 (ICP-AES)	Same
Cadmium	EPA SW 6010 (ICP-AES)	EPA SW 7131 (GFAAS)
Chloride	EPA 300.0 (IC)	Same
Chromium	EPA SW 6010 (ICP-AES)	Same
Fluoride	CARB 421 (IC)	EPA 340.2 (SIE)
Lead	EPA SW 6010 (ICP-AES)	EPA SW 7421 (GFAAS)
Manganese	EPA SW 6010 (ICP-AES)	Same
Mercury	ASTM D 3684-78 (CVAAS)	EPA SW 7470 (CVAAS)
Nickel	EPA SW 6010 (ICP-AES)	EPA SW 7520 (GFAAS)
Selenium	EPA SW 7740 (GFAAS)	Same
Benzene	EPA SW 5041 (GC/MS)	EPA SW 8240 (GC/MS)
Toluene	EPA SW 5041 (GC/MS)	EPA SW 8240 (GC/MS)
Formaldehyde	CARB 430 (HPLC)	BIF 0011 (HPLC)
PAHs	EPA SW 8270	EPA SW 8270 (High Resolution GC/MS)
Coal		
Arsenic	EPA SW 7060 (GFAAS)	ASTM D3684 (GFAAS)
Beryllium	EPA SW 6010 (ICP-AES)	Same
Cadmium	EPA SW 6010 (ICP-AES)	ASTM D3684 (GFAAS)
Chloride	Not specified	SM 4500 Potentiometric Titration
Chromium	EPA SW 6010 (ICP-AES)	Same
Fluoride	Not specified	ASTM 3761-84 (SIE)
Lead	EPA SW 7421 (GFAAS)	ASTM D3684 (GFAAS)
Manganese	EPA SW 6010 (ICP-AES)	Karr, Ch. 12 and 46 (INAA)
Mercury	ASTM D 3684-78 (CVAAS)	Karr, Ch. 14 (DGA/CVAAS)
Nickel	EPA SW 6010 (ICP-AES)	Same
Selenium	EPA SW 7740 (GFAAS)	ASTM D3684 (GFAAS)

Data Validity

Insufficient QA/QC data are currently available to evaluate the quality of the data from Site 114. The shortage of QA/QC results indicates the data cannot be used with the same confidence as data from other FCEM sites.

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

Specific points highlighted below are QA/QC issues of concern:

- Minimal QA/QC data were available to draw conclusions about the samples collected.
- The testing schedule alternated between baseline and reburn conditions; the samples retrieved during the two configurations are significantly different. The coal concentrations for the first two days of testing did not concur with coal concentrations for the last three days of testing.
- Because of the variability seen in most results, it is not possible to determine if the two modes of operation produce significantly different levels of emissions, except for NO_x levels.

The large confidence intervals about many of the mean concentrations found in these tests are a point of concern. Standard methods were used for most sampling and analyses, and stack gas sample collection records are complete.

Report Organization

Section 2 of this report briefly describes the plant and identifies the 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.

2

SITE DESCRIPTION

This section describes the test site (Site 114) and its sampling locations.

Facility Information

Site 114 is rated at 100 MW. The unit has a Babcock & Wilcox, cyclone-fired reheat boiler. Sampling activities were conducted during November of 1992. The characteristics of the unit during both series of tests are summarized in Table 2-1.

Table 2-1
Site 114 Process Summary

Maximum Electrical Output (MW)	100
Boiler Type	Cyclone fired
Boiler Additive	None
Fuel Type	Indiana Lamar bituminous coal
Fuel Sulfur Content (avg. % S, dry)	1.6%
Fuel Ash Content (avg. % ash, dry)	8.8%
Fuel Heating Value (avg. Btu/lb, dry)	13,400
Coal Feed Rate (avg. klb/hr, dry)	98
Particulate Matter Controls	ESP
SO_2 Controls	None
NO_x Controls	Overfire air and reburn burners in upper furnace (reburn configuration only)

Figure 2-1 presents a process flow diagram of Site 114. Bottom ash is removed from the boiler via sluice tanks at the slag quench tap. Dry fly ash collected in the dual Research Cottrell ESP is pneumatically conveyed to a landfill. No conditioning occurs upstream of the particulate matter control devices. Low-sulfur coals are used at this site to comply with emission limits; no other SO_2 controls are present.

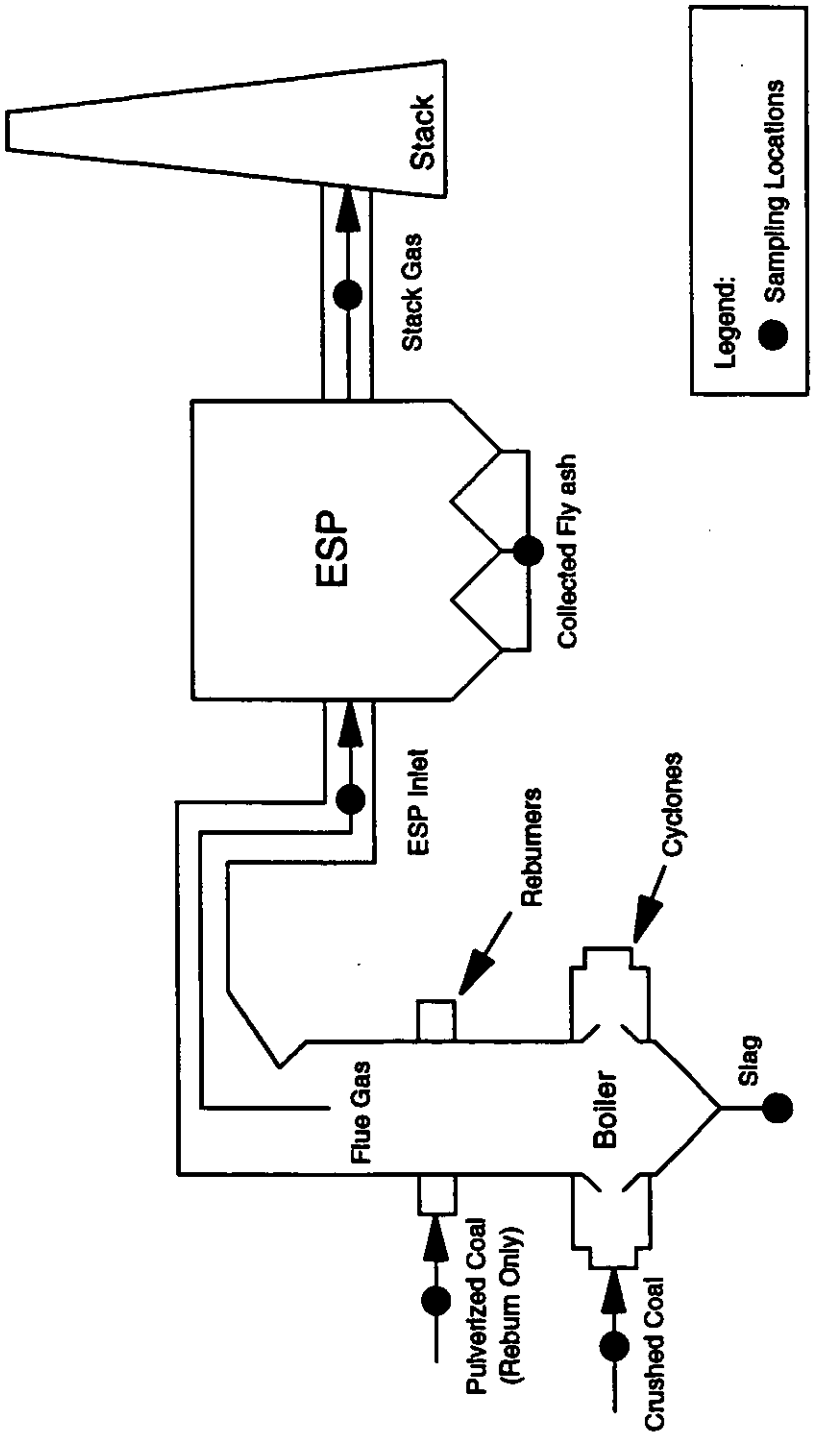

Figure 2-1
Process Flow Diagram for Site 114

During 1991, the boiler at Site 114 was modified with a low-NO_x reburn retrofit that consisted of the installation of a pulverizer, reburn burners in the furnace, overfire air ports, and modifications to the control system. The unit can operate in baseline mode without the reburn burners or in the reburn mode with the reburners providing approximately 20% of the heat input.

Sampling Locations

Samples were collected at five locations in the plant. Coal was the only feed stream sampled. One internal stream, the inlet gas to the ESP, was sampled. Three discharge streams were sampled: the stack gas, the boiler slag, and the collected fly ash from the ESP. These sampling points are shown in Figure 2-1. A brief description of each sampling location appears below:

- Crushed coal was sampled at the gravimetric feeder before its entry into the cyclone burner. During reburn testing, coal samples were also collected at the pulverizer outlet entering the reburners and composited with the crushed coal.

- Boiler slag samples were collected from the sluice tanks at the slag quench tap.

- Collected fly ash was sampled from the ESP hoppers. Different hoppers from each of the three ESP banks were included in each of the grab samples to represent the collection across the entire ESP unit.

- Flue gas entering the ESP was sampled through eight 4-inch test ports on the two ESP inlet ducts.

- Flue gas leaving the ESP was sampled at six of the eight 4-inch test ports on the outlet ducts from the ESP. The remaining two ports (one on each duct) were dedicated to the plant's continuous emissions monitor (CEM).

Table 2-2 lists the types of analyses performed on each sample collected.

Appendix B contains additional information on the sampling and analytical methods used at Site 114.

Table 2-2
Process Stream Analyses Performed

Stream	Metals	Anions	Semivolatile Organic Compounds	Volatile Organic Compounds	Aldehydes
Coal	X,O	X,O			
Bottom Ash	X,O				
ESP Ash	X,O				
ESP Inlet Gas	X,O				
Stack Gas	X,O	X,O	X,O	X,O	X,O

X = Baseline test

O = Reburn Test

3

RESULTS

This section discusses the results of the sampling conducted at FCEM Site 114 during baseline and reburn conditions. Because the focus of this report is on gaseous emissions, only coal characterization data and gas stream data are presented here in detail. These results were derived from field and laboratory data reported by Acurex Environmental Corporation and the host utility.

Appendix A shows the raw analytical data used to calculate ESP inlet and stack gas concentrations. Appendix B contains information on the sampling and analytical methods used at Site 114. Appendix C contains concentration data for each run for the baseline and reburn conditions. Appendix D contains process stream flow rates and characterization data for the unit obtained during the sampling events. Example calculations of the results discussed in this section appear in Section 5.

Sampling Schedule

On November 2 through November 6, 1992, sampling was conducted at Site 114 during both baseline and reburn conditions Figure 3-1 shows the sampling events at Site 114 during the baseline and reburn conditions. The run numbers shown in Figure 3-1 correspond to those presented in the results tables in this section and in the appendices. Baseline testing was performed on November 2, 3, and 5, and reburn testing occurred on November 4 and 6.

Data Treatment

As discussed below, several conventions were developed for treating the test data and developing average (or mean) concentrations of substances in the coal and gas streams.

Blank Corrections

When it was available, the reagent blank analytical result was used to correct the individual run measurements. Because reagent blank results were not available at this site, 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 corrected concentration was flagged with a "B".

When the blank correction resulted in a value less than the reporting limit, the concentration is presented as NR(RL), meaning that the concentration is below the reporting limit, which is presented in parentheses.

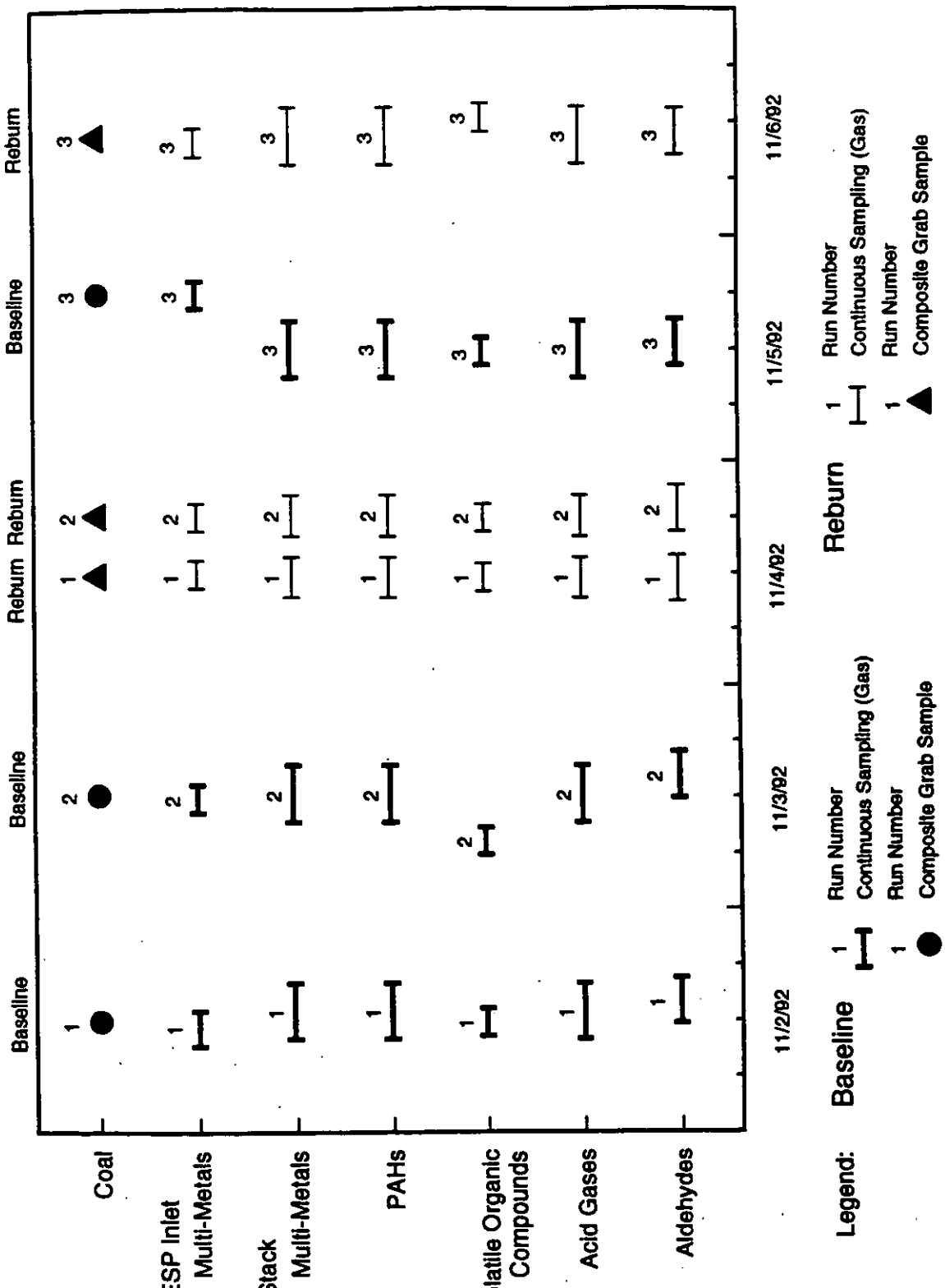

Figure 3-1
Sampling Timeline for Site 114 - Baseline and Reburn

Average Concentrations

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

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

- For results that include values both above and below the reporting limit, one half of the reporting 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 reporting limit value. In the following example, using one half the reporting limit value would yield a calculated value of 2.8. This is less than the highest reporting limit; therefore, the reported mean is <4.

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

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

Coal Results

Tables 3-1 and 3-2 present coal sample analytical results for baseline and reburn conditions, respectively. Appendix B contains a list of the analytical methods used to determine elemental concentrations in coal. 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. Sample proximate analyses, sulfur contents, and coal flow rates are also shown in Tables 3-1 and 3-2. Most of the results have large confidence intervals associated with both testing configurations. A trend in the coal concentrations appears when comparing the first two days of testing with the last three days of testing. The concentrations in the third run for the baseline tests are in agreement with the concentrations for the reburn tests (e.g., lead, nickel, cadmium, and chloride). This may be an indication that the coal was not uniform as the coal supply was exhausted. Extremely high levels of cadmium were detected in the coal during Run 3 in the baseline test and Runs 1 and 2 during the reburn test. The lack of supporting QA/QC information makes it impossible to judge the validity of these cadmium levels. The corresponding ESP inlet ash compositions do not correspond to the high cadmium levels reported in the coal.

Table 3-1
Site 114 Coal Composition Data - Baseline

Parameter	Run 1	Run 2	Run 3	Mean	95% CI[a]
Coal Flow Rate (lb/hr, dry)	108,600	96,900	94,600	100,000	18,700
HHV (Btu/lb, dry)	13,160	13,550	13,770	13,490	770
Sulfur (%, dry)	1.3	2.3	1.6	1.7	1.3
Moisture (%)	15.7	13.8	17.3	15.6	4.3
Ash (%, dry)	7.6	10.0	8.4	8.7	3.1
Elements (mg/kg, dry)					
Arsenic	7	23	6	12	23
Beryllium	3.49	3.65	3.78	3.64	0.36
Cadmium	NR(1.2)[b]	1.29	114	39	161
Chloride	69	27	110	69	103
Chromium	6	14	14	11	12
Fluoride	NR(5.6)	NR(4.0)	NR(4.1)	NR(5.6)	--
Lead	46	46	18	37	40
Manganese	24.3	25.8	29.4	26.5	6.5
Mercury	NR(0.12)	NR(0.12)	NR(0.12)	NR(0.12)	--
Nickel	15	16	51	28	51
Selenium	NR(1.2)	NR(1.2)	NR(1.2)	NR(1.2)	--

[a]CI = Confidence interval.

[b]NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

Table 3-2
Site 114 Coal Composition Data - Reburn

Parameter	Run 1	Run 2	Run 3	Mean	95% CI [a]
Coal Flow Rate (lb/hr, dry)	94,800	97,700	96,500	96,300	3,600
HHV (Btu/lb, dry)	13,580	13,160	13,090	13,280	670
Sulfur (%, dry)	1.72	1.37	1.43	1.51	0.46
Moisture (%)	12.0	12.9	12.5	12.5	1.2
Ash (%, dry)	8.21	9.2	9.4	8.9	1.6
Elements (mg/kg, dry)					
Arsenic	3.1	10.6	10.7	8.1	9.4
Beryllium	3.45	3.30	3.07	3.26	0.44
Cadmium	80	60	NR(1.1) [b]	47	89
Chloride	74	75	95	82	26
Chromium	9.8	8.4	10.1	9.4	2.0
Fluoride	NR(3.9)	NR(5.6)	NR(3.9)	NR(5.6)	--
Lead	12	21	14	16	10
Manganese	33	27	21	27	13
Mercury	NR(0.11)	NR(0.11)	NR(0.11)	NR(0.11)	--
Nickel	56	43	40	46	19
Selenium	NR(1.1)	NR(1.1)	NR(1.1)	NR(1.1)	--

[a] CI = Confidence interval.

[b] NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

Gas Stream Results

Two gas streams, ESP inlet gas and stack gas, were sampled at Site 114. The solid- and vapor-phase fraction of the multi-metals trains were combined before analysis. Concentration data for metals were corrected for background levels associated with the field blank. Data are presented for each run with a mean and 95% confidence interval. Acetaldehyde, benzene, formaldehyde, and toluene are vapor-phase results only. Particulate loading, chloride, and fluoride were collected together in accordance with CARB Method 421. The filter was used for particulate loading and the impinger solutions were analyzed for acid gases.

ESP Inlet Gas Results

Table 3-3 summarizes the results of the ESP inlet gas inorganic sampling for baseline and reburn conditions. Field blank-corrected concentrations are presented by run with the mean and 95% confidence interval for the total quantity detected. All substances were detected during all runs. The level of cadmium measured in Run 3 of the reburn test was equivalent to the field blank level. A reporting limit range of 0.03 $\mu g/Nm^3$ to 6.2 $\mu g/Nm^3$ was presented by Acurex for metals analyzed by ICP-AES. Specific limits were not available for each analyte. The lower limit is consistent with Radian's previous experience with cadmium reporting limits, thus NR(0.03) $\mu g/Nm^3$ was considered to be the level found in Run 3. This value appears in this table and in Table 3-5.

The particulate loading into the ESP during reburn testing increased, compared to the baseline testing results. The increase in particulate loading was caused by the operating characteristics of the coal reburners. Although the particulate loading doubled (1600 to 3000 mg/Nm^3), most metal concentrations did not change significantly. Ashes collected at this location were not subjected to loss-on-ignition (LOI) tests to determine if the increased particulate loading during reburn was due to unburned carbon. This is an unusual result and may indicate some difficulty in sampling at this location.

Stack Gas Results

Tables 3-4 and 3-5 summarize the results of the stack gas sampling for baseline and reburn conditions, respectively. The total concentrations, corrected for the field blank, are presented by run with the mean and 95% confidence interval. In most circumstances, the 95% confidence interval approaches or exceeds the average concentration. The Acurex report discounts the high levels of fluoride reported in the samples from Runs 2 and 3 of the reburn test because an unidentified compound was eluting in high quantities at nearly the same time, masking the true fluoride concentrations. Therefore, only the first run was used to estimate the mean for fluoride.

Table 3-6 presents the stack gas emission factors for the baseline and reburn conditions on a unit-energy basis. These emission factors are based on the average numbers for the

Table 3-3
ESP Inlet Gas Composition Data

	Run 1	Run 2	Run 3	Mean	95% CI[a]
Baseline					
Stream Flow Rate (Nm^3/hr)	416,500	396,000	388,000	400,200	36,500
Particulate Loading (mg/Nm^3)	1,130	2,060	1,530	1,580	1,160
Elements ($\mu g/Nm^3$)					
Arsenic	57	96	473	210	570
Beryllium	61	57	65	61	10
Cadmium	23.4	30.3	26.0	26.6	8.6
Chromium	360	290	460	370	210
Lead	1,960	1,910	2,410	2,090	680
Manganese	440	520	830	600	500
Mercury	9.8	12.5	7.4	9.9	6.3
Nickel	2,000	1,900	2,700	2,200	1,100
Selenium	8	14	86	36	109
Reburn					
Stream Flow Rate (Nm^3/hr)	380,100	389,600	377,000	382,200	16,300
Particulate Loading (mg/Nm^3)	2,850	3,240	3,060	3,050	470
Elements ($\mu g/Nm^3$)					
Arsenic	520	150	20	230	650
Beryllium	145	15	6	55	193
Cadmium	89	6B[b]	NR(0.03)B[c]	32	124
Chromium	640	65	40	250	840
Lead	3,900	330	340	1,530	5,110
Manganese	1,330	170	200	570	1,630
Mercury	9.2	5.6	5.6	6.8	5.2
Nickel	4,200	420	260	1,630	5,530
Selenium	220	200	50	160	230

[a] CI = Confidence interval.
[b] "B" flag indicates that the blank level is greater than 50% of the uncorrected sample value.
[c] NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

Table 3-4
Stack Gas Composition for Site 114 - Baseline

	Run 1	Run 2	Run 3	Mean	95% CI[a]
Stream Flow Rate (Nm^3/hr)	392,400	370,200	396,300	386,300	35,000
Particulate Loading (mg/Nm^3)	46.9	31.2	43.0	40.3	20.3
Elements ($\mu g/Nm^3$)					
Arsenic	9	4	21	11	21
Beryllium	4.4	2.1	4.7	3.8	3.5
Cadmium	0.9B[b]	0.9B	6.8	2.8	8.4
Chloride	6,590	6,500	7,420	6,840	1,250
Chromium	28	13	23	21	19
Fluoride	95	113	96	101	24
Lead	80	180	150	140	130
Manganese	30	18	49	32	38
Mercury	2.8	11.0	7.8	7.2	10.3
Nickel	160	82	130	124	97
Selenium	140	470	540	390	540
Benzene	4.9	4.4	1.8	3.7	4.1
Toluene	1.4	1.9	1.6	1.6	0.6
PAHs[d]	NR(14.0)[c]	NR(14.0)	NR(15.0)	NR(15.0)	--
Formaldehyde	5.1	NR(4.1)	NR(4.0)	NR(4.1)	--
Acetaldehyde	10.2	NR(4.1)	NR(4.0)	NR(4.1)	--

[a]CI = Confidence interval.

[b]"B" flag indicates that the blank level is greater than 50% of the uncorrected sample value.

[c]NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

[d]Reporting limits apply to each of the 16 individual PAHs measured. See Table 1-1 for a list of these compounds.

Table 3-5
Stack Gas Composition for Site 114 - Reburn

	Run 1	Run 2	Run 3	Mean	95% CI[a]
Stream Flow Rate (Nm^3/hr)	369,400	391,800	366,000	375,700	34,800
Particulate Loading (mg/Nm^3)	9.3	20.9	45.2	25.1	45.4
Elements ($\mu g/Nm^3$)					
Arsenic	9.1	13.8	14.2	12.4	7.0
Beryllium	0.4	1.3	2.0	1.2	2.0
Cadmium	NR(0.03)B[b,c]	1.5B	0.2B	0.6	2.1
Chloride	8,100	10,200	9,500	9,300	2,600
Chromium	4.3	6.2	10.9	7.1	8.5
Fluoride	139	3,307[d]	3,135[d]	139	--
Lead	65	96	102	88	49
Manganese	12	26	33	23	27
Mercury	9.3	4.1	4.0	5.8	7.4
Nickel	24	45	87	52	80
Selenium	470	50	180	230	530
Benzene	1.9	1.9	1.1	1.6	1.1
Toluene	1.1	1.2	0.9	1.1	0.3
PAHs[e]	NR(24.7)	NR(19.3)	NR(14.0)	NR(24.7)	--
Formaldehyde	NR(4.0)	NR(4.0)	NR(4.0)	NR(4.0)	--
Acetaldehyde	NR(4.0)	NR(4.0)	NR(4.0)	NR(4.0)	--

[a]CI = Confidence interval.

[b]NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

[c]"B" flag indicates that the blank level is greater than 50% of the uncorrected sample value.

[d]An unknown compound eluted with the fluoride at the same time, masking the true fluoride concentration. Data are considered suspect.

[e]Reporting limits apply to each of the 16 individual PAHs measured. See Table 1-1 for a list of these compounds.

Table 3-6
Stack Gas Emission Factors (lb/trillion Btu unless noted)

	Baseline		Reburn	
Substance	Emission Factor	95% CI [a]	Emission Factor	95% CI
Particulate (lb/million Btu)	0.025	0.010	0.016	0.029
Arsenic	7	13	8.0	4.6
Beryllium	2.4	2.3	0.8	1.3
Cadmium	1.8	5.3	0.4	1.3
Chromium	14	12	4.6	5.5
Manganese	20	25	15	17
Nickel	78	63	34	52
Lead	86	82	57	32
Selenium	240	340	150	340
Mercury	4.5	6.6	3.8	4.8
Chloride	4,310	740	6,000	1,390
Fluoride	64	12	89.9	--
Benzene	2.3	2.6	1.04	0.73
Toluene	1.02	0.34	0.70	0.17
PAHs [b]	NR(9.5) [c]	--	NR(16)	--
Formaldehyde	NR(2.6)	--	NR(2.6)	--
Acetaldehyde	NR(2.6)	--	NR(2.6)	--

[a]CI = Confidence interval.

[b]Reporting limits apply to each of the 16 individual PAHs measured. See Table 1-1 for a list of these compounds.

[c]NR indicates that the concentration is below the reporting limits, which are shown in parentheses.

substances listed in Tables 3-4 and 3-5. An example emission factor calculation is presented in Section 5.

Control Device Performance

The ESP system removal efficiency for each inorganic substance is shown in Table 3-7 for the baseline and reburn conditions. Removal efficiencies were calculated from the mean concentrations in the ESP inlet and the stack. The baseline result for overall particulate matter removal (97.4%) is lower than the removal for the reburn testing (99.2%). However, the stack particulate levels are statistically equivalent (40 ± 20 mg/Nm^3 versus 25 ± 45 mg/Nm^3 for baseline and reburn, respectively). Selenium measurements indicated negative removal efficiencies, which are presented as zero in Table 3-7 for both tests. The removal efficiencies for all other substances, except mercury, were at or above 90 percent.

Table 3-7
Site 114 Removal Efficiencies

	Baseline		Reburn	
Substance	Removal Efficiency	95% CI[a]	Removal Efficiency	95% CI
Particulate Matter	97.4	1.3	99.2	1.5
Arsenic	94.5	8.7	94.6	9.6
Beryllium	93.8	5.8	97.8	3.7
Cadmium	89	32	98.2	5.6
Chromium	94.2	4.4	97.1	4.8
Lead	93.5	6.4	94	11
Manganese	94.6	5.5	95.9	6.3
Mercury	27	83	15	91
Nickel	94.3	3.8	96.8	5.1
Selenium	0	--	0	--

[a]CI = Confidence interval.

4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 114, 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. The third data evaluation 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, and CEM data. Table 4-1 shows the results for baseline and reburn operations. Except for carbon monoxide, no variable had a CV exceeding 20% or showed a trend over the test period, indicating that process conditions were reasonably stable during the test period. NO_x levels dropped by a half from baseline to reburn, but CO levels rose during reburn by an order of magnitude. The unit was operated at 100% of design load during both baseline and reburn 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 12,200 Btu/kW-hr, a relatively high value for a coal-fired utility boiler operating at near full load.

Table 4-1
Summary of Process Monitoring Data - Site 114

	Run 1 11/2/92		Run 2 11/3/92		Run 3 11/5/92	
Baseline	**Mean**	**CV (%)**	**Mean**	**CV (%)**	**Mean**	**CV (%)**
Load (MWe)	110	--	111	--	111	--
Coal Flow Rate (1,000 lb/hr)	104	--	97	--	95	--
Stack Gas Flow Rate (Nm^3/hr)	392,400	--	370,200	--	396,300	--
Stack CO (ppmv)	3	124	10	36	6.8	68.5
Stack CO_2 (%)	13.6	0.8	13.8	1.6	13.7	0.8
Stack NO_x (ppmv)	571	2	574	2	582	2
Stack SO_2 (ppmv)	1,150	13	1,428	19	1,069	4
Stack O_2 (%)	2.9	10.5	3.4	5.1	3.3	2.5
	Run 1 11/4/92		**Run 2 11/4/92**		**Run 3 11/6/92**	
Reburn	**Mean**	**CV (%)**	**Mean**	**CV (%)**	**Mean**	**CV (%)**
Load (MWe)	112	--	111	--	111	--
Coal Flow Rate (1,000 lb/hr, dry)	95	--	98	--	97	--
Stack Gas Flow Rate (Nm^3/hr)	369,400	--	391,800	--	366,000	--
Stack CO (ppmv)	91	234	94	121	31	64
Stack CO_2 (%)	14.4	1.9	14.3	1.2	14.2	1.5
Stack NO_x (ppmv)	267	7	275	4	282	3
Stack SO_2 (ppmv)	1,252	6	1,107	1	1,044	4
Stack O_2 (%)	2.7	15.8	3.0	6.0	2.6	2.9

CV = Coefficient of Variation (standard deviation divided by the mean).

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 biases that may be caused by contamination or operator errors. Field and method blanks were included for some of the tests.

Sampling representativeness also depends on the characteristics of the sampling locations. Limited information on the sampling locations make it difficult to draw conclusions on the quality of the flow through the ducts. It is not known if Acurex experienced any problems with sample collection. Twenty-four (8 ports, 3 points per port) traverse points were used upstream of the ESP and 18 points (6 ports, 3 points per port) downstream of the ESP, which may indicate the sampling locations were not ideal in terms of undisturbed flow. 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, i.e., 100 $\pm$ 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 semivolatile organic compounds is well established for both sampling and analysis. The EPA Multi-Metals Method 0012 is still in the evaluation process but is becoming widely accepted; it is documented well enough to be considered a standard method. The CARB 430 Method for aldehydes is a single-point, nonisokinetic procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011, using the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 421 Method for acid gases and particulate loadings varies from Method 5 in several steps, but the main criteria for collecting the acid gases, carbonate, and bicarbonate impingers, are satisfied. The VOST train modified with CMS sorbent is not an approved replacement for a VOST train with Tenax traps. The Acurex report cites use of CMS as routine with Method TO-02, but Method 0030 makes no provision for using CMS as a substitute for Tenax. Reproducibility (e.g., precision) has been the foremost problem with CMS sorbent cartridges. Because of the use of the CMS sorbent and the lack of QA/QC data, the results of this test for benzene and toluene are questionable.

Sampling completeness is mainly fulfilled by providing the requisite number of samples to the analytical laboratories. In the FCEM program, three runs are considered the minimum number to obtain reasonable confidence intervals for mean analyte concentrations. Three runs were made for all substances during baseline and reburn sampling. Eighteen runs were made for VOST samples.

Evaluation of Measurement Data Quality

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

Analytical Quality Control Results

Generally, the type of quality control information obtained pertains to measurement precision, accuracy (which includes precision and bias), and blank effects, determined using various types of replicate, spiked, and blank samples. Appendix F contains detailed QA/QC data available for Site 114. 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. The QA/QC measures commonly used as part of the FCEM data evaluation protocol, and the characteristic information obtained, are summarized in Table 4-2. The absence of any of these types of quality control checks from the data does not necessarily reflect poorly on the quality of the data but does limit the ability to estimate the magnitude of the measurement error and hence, prevents placing an estimate of confidence in the results.

As shown in Table 4-2, 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 measurements are based primarily on the actual sample matrix. The precision and accuracy estimates obtained experimentally during the test program are compared with the data quality objectives (DQOs) established for the FCEM project.

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. Although analytical precision and accuracy are relatively easy to quantify and control, sampling precision and accuracy are unique to each site and each sample matrix. Data that do not meet these DQOs are not 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.

Table 4-3 presents the types of quality control data reported for this site. Table 4-4 presents a summary of precision and accuracy estimates. Minimal QC analysis was performed with these samples; however, almost all of the quality control results met the project objectives. For most analytes, no precision estimates were available.

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 concentration.
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 bias and precision)	
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 an 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.
Standard reference material	Analyte recovery in a matrix similar to the actual samples.
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 the analytical method, including reagents and equipment.
Reagent blank	Blank effects from reagents used.

Table 4-3
Types of Quality Control Data Reported

		Precision				Accuracy				Blank			
Analyte Group	Replicate Samples	Duplicate Field Samples	Duplicate Lab Analysis	MSD	LCSD	MS	Surrogate Spike	LCS	Std. Ref. Mat'l	Field Blank	Trip Blank	Method Blank	Reagent Blank
Gas Samples													
Metals	✓									✓			
Anions	✓												
Semivolatile Organic Compounds	✓					✓	✓						
Volatile Organic Compounds	✓					✓	✓	✓					
Aldehydes	✓		✓			✓		✓			✓	✓	
Coal Samples													
Metals	✓												
Anions	✓												
Ultimate/Proximate	✓												
Ash Samples													
Metals	✓								✓				

Table 4-4
Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured	FCEM Objectives		Measured Precision	Measured Accuracy
		RPD	% Recovery	(% CV)	(% Recovery)
Metals in Train/Acid Audit Sample	Accuracy - Analyses of NIST Standard Reference Material Solution				
Arsenic		20	75-125	NR	86
Beryllium		20	75-125	NR	80
Cadmium		20	75-125	NR	96
Chlorine		20	75-125	NR	110
Chromium		20	75-125	NR	95
Lead		20	75-125	NR	67
Manganese		20	75-125	NR	91
Nickel		20	75-125	NR	108
Selenium		20	75-125	NR	114
Metals in Fly Ash Sample	Accuracy - Analyses of Standard Reference Materials				
Arsenic		20	75-125	70	66.2
Beryllium		20	75-125	9	NR
Cadmium		20	75-125	115	BRL
Chloride		20	75-125	9	NR
Chromium		20	75-125	32	77.6
Fluoride		20	75-125	9	NR
Lead		20	75-125	62	58.3
Manganese		20	75-125	12	88.6
Mercury		20	75-125	NC	BRL
Nickel		20	75-125	45	89.0
Selenium		20	75-125	NC	BRL

Table 4-4 (Continued)

Measurement Parameter	How Measured	FCEM Objectives RPD	FCEM Objectives % Recovery	Measured Precision (% CV)	Measured Accuracy (% Recovery)
Metals in Stack Gas	Accuracy - Not Available Precision - Replicate Runs				
Arsenic		20	75-125	47	NR
Beryllium		20	75-125	69	NR
Cadmium		20	75-125	147	NR
Chloride		20	75-125	66	NR
Chromium		20	75-125	19	NR
Fluoride		20	75-125	66	NR
Lead		20	75-125	18	NR
Manganese		20	75-125	39	NR
Mercury		20	75-125	46	NR
Nickel		20	75-125	51	NR
Selenium		20	75-125	58	NR
Volatile Organic Compounds in Adsorbent Tubes	Surrogates				
Benzene-d_6		35[a]	50-150	108	37
Toluene-d_8		35[a]	50-150	10.3	97
Benzene	15L Breakthrough Check				
Semivolatile Organic Compounds in XAD Cartridges	Surrogates				
Nitrobenzene-d_5		35	50-150	13.2	91
2-Fluorobiphenyl		35	50-150	5.3	95
Terphenyl-d_5		35	50-150	5.4	92
Benzo(a)pyrene-d_{12}[a]		35	50-150	3.2	93

Table 4-4 (Continued)

Measurement Parameter	How Measured	FCEM Objectives		Measured Precision	Measured Accuracy
		RPD	% Recovery	(% CV)	(% Recovery)
Aldehydes					
Formaldehyde	Matrix Spike	40[b]	50-150	NR	68
Formaldehyde	Lab Spike	40[b]	50-150	NR	100
Acetaldehyde	Trip Spike	40[b]	50-150	NR	87
Formaldehyde	Analytical Dups	40[b]	50-150	NR	83-109
Acetaldehyde		40[b]	50-150	NR	83-101
Formaldehyde		40[b]	50-150	17[b]	NR
Acetaldehyde		40[b]	50-150	24[b]	NR

[a]Spiked in lab and taken through sampling, extraction, and analysis.

[b]Expressed as relative percent difference (RPD).

BRL = Below reporting limit.

NR = Not reported.

NC = Not calculated.

The following potential problems were identified by the quality control data.

- A standard NIST metals solution was prepared by dilution and submitted for analysis as a performance evaluation (PE) sample. Lead recovery in this sample (67%) was below the 75-125% objective. This may indicate a slightly low bias for lead in field samples.

- A standard NIST metals fly ash sample was also submitted as a PE sample. The recoveries of arsenic and lead (66.2% and 58.3%, respectively) were low when analyzed by GFAA. These results may indicate a slightly low bias for arsenic and lead in fly ash and bottom ash samples.

- Field blank results for metals indicate that cadmium and mercury field sample results may be biased slightly high because of contamination. All gas samples for metals were corrected for field blank measurements.

- Benzene-d_8 surrogate recoveries were low (average recovery 37%) in the adsorbent tube samples and exhibited poor precision (108% CV). These results may indicate a low bias and greater than expected variability for benzene in the adsorbent tube field samples. Compounding these results with the substitution of CMS sorbent for Tenax traps in the VOST method, the volatile organic compound concentrations are questionable.

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 or coefficient of variation (CV, standard deviation divided by the 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 analytical procedures 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. Spikes made at or near the concentration of the native sample can provide valuable information about matrix interferences and recoveries.

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 are properly selected and that a sufficient number of samples are 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 using standard techniques to collect and analyze representative samples and by 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. The only data available to estimate precision for metals in coal and stack gas (ESP inlet gas was not included because of different test conditions) were replicate test runs, which include process variability. No data were available to determine sampling or analytical precision alone. A summary of precision estimates is presented in Table 4-4. Data from the replicate test runs indicated that precision was poor for metals in both matrices. Overall, 2 out of 8 (or 25%) of the metals in the coal and 2 out of 12 (or 17%) of the stack gas metals met the project precision objective. This objective was specified for the matrix spike duplicates and was not intended to incorporate the process variation reflected in the replicate test precision estimates presented.

For coal sample results where a coefficient of variation could be calculated, the concentrations of all the elements except for beryllium and manganese exhibited higher than expected variability.

Precision estimates for 12 elements in the stack gas samples were outside the project objective except for chloride and fluoride. Cadmium variability may be influenced by contamination. The field blank measurement for cadmium was greater than 50% of the uncorrected sample for 5 of 6 measurements; therefore, the precision estimates do not accurately reflect analytical reproducibility.

Accuracy. The accuracy of metals analyses was estimated for coal, ash, and slag samples using PE samples. Two National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) samples were submitted. A fly ash sample and a metals solution were analyzed for metals. The use of a diluted standard for gas samples is an inadequate QA procedure since it does not address digestion of the sample. Lead was recovered (at 67% and 58.3%) outside the accuracy objectives (75-125%) for both PE samples. Arsenic (66.2%) was also recovered below the objectives in the fly ash PE

sample. These recoveries indicate that lead and arsenic concentrations may be biased slightly low in the field sample results.

Blank Effects. A field blank was analyzed for metals, along with the inlet and outlet samples. Cadmium was detected at 12.5 μg and mercury at 2 μg in the field blank, with field sample concentrations ranging from 12.5 to 162 μg (cadmium) and 11.1 to 26.8 μg/dscf (mercury). The blank results indicated that the cadmium and mercury concentrations reported for the field samples may be biased slightly high. Sample results were corrected for the field blanks for all the metals.

Volatile Organic Compounds

Precision. The only precision estimates available from the reported data for volatile organic compounds in adsorbent tubes were the surrogate percent CVs. The laboratory injected a known amount of toluene-d_8 and benzene-d_6 onto each of the 40 sample tubes during analysis. The percent CV for toluene-d_8 was 10%, which met the precision objective (35%). The percent CV for benzene-d_6 was 108%, which did not meet the precision objective. These results indicate that the benzene results from the CMS sorbent tube field samples may have higher than expected variability.

Accuracy. The accuracy of volatile organic compound results was estimated for adsorbent tubes using surrogate recoveries. The average recoveries for toluene-d_8 and benzene-d_6, based on 40 adsorbent tube samples, were 97 and 37%, respectively. Since the benzene-d_6 recoveries were reported to have a standard deviation of 40 and an average recovery of 37%, it is apparent that some of the individual recoveries were below the accuracy objectives (50-150%). The number of recoveries below the objectives cannot be determined from the data reported, but a low bias for benzene in the field samples is indicated by these surrogate results.

A breakthrough test was performed in the laboratory by injecting a known amount of benzene onto a sample tube, then passing 15 liters of air through the tube at 0.5 liter/minute for 30 minutes, which simulated the sampling conditions. Benzene was recovered at 95% in this breakthrough check sample.

Blank Effects. No results were reported for blank samples.

Semivolatile Organic Compounds

Precision. Precision could only be estimated for semivolatile organic analyses using surrogate percent CVs. Each cartridge was spiked with three surrogate compounds, nitrobenzene-d_5, 2-fluorobiphenyl, and terphenyl-d_{12}. The percent CVs for these surrogates ranged from 13.2 to 5.3% and were well within the 40% precision objective. In addition, each cartridge was spiked with benzo(a)pyrene-d_{12} before sampling to determine breakthrough and recovery efficiency. The percent CV for this compound was 3.2%, which indicates low variability and good precision.

Accuracy. Estimates for accuracy were based on surrogate recoveries. The average surrogate recoveries ranged from 91 to 95%, and indicate acceptable accuracy.

Blank Effects. No results were reported for blank samples.

Aldehydes

Precision. Precision estimates for aldehydes were based on an analytical duplicate. The RPDs for formaldehyde (17%) and acetaldehyde (24%) were within the project precision objective (40%) and indicate acceptable precision for aldehydes.

Accuracy. Accuracy estimates were made for aldehydes using a matrix spike sample, a lab spike sample, and a trip spike sample. Formaldehyde was recovered at 68% in the matrix spike sample, which is below Acurex's laboratory objectives (80-120%) but within the project objectives (50-150%). The lab spike recoveries were 100% for formaldehyde and 87% for aldehyde. The trip spike sample recoveries for formaldehyde and acetaldehyde ranged from 84 to 109%, and 83 to 101%, respectively. The lab spike and trip spike results indicate acceptable accuracy for aldehydes.

Blank Effects. A trip blank and a lab blank were analyzed for aldehydes. The lab reported that both blanks showed nondetectable concentrations of aldehydes.

Material Balance Results

At Site 114, the overall plant mass balance included one inlet (coal) and three outlet (bottom ash, collected fly ash, and stack gas) streams. Bottom ash and collected fly ash flow rates were estimated using the coal flow rate, the coal ash content, and the particulate loading into and out of the ESP. 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 measured 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 for baseline and reburn conditions. Mass balances were performed only for those elements detected in the coal and stack gas.

Table 4-5
Material Balance Closure Results for Site 114

	Baseline		Reburn	
Elements	Closure (%)	95% CI	Closure (%)	95% CI
Arsenic	34	34	93	100
Beryllium	26	1	32	4
Cadmium	1.4	3.0	1.3	2.0
Chromium	70	46	77	34
Lead	38	29	112	56
Manganese	139	40	125	53
Mercury	NC	--	NC	--
Nickel	170	220	92	31
Selenium	NC	--	NC	--

NC = Not calculated.

Only chromium has acceptable closure during the baseline tests. For reburn conditions, beryllium and cadmium have closures outside the desired range. The variability in stream compositions is reflected in the large confidence intervals.

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.

Stream Flow Rates

Appendix D presents information about the stream flow rates measured or calculated at Site 114. No bottom ash or captured fly ash flow rate data were collected for Site 114. Thus, the bottom ash flow rate was calculated from the particulate loading into the ESP subtracted from the coal ash flow rate into the boiler. The collected fly ash flow rate was calculated from the particulate loadings into and out of the ESP. The material balances in Section 4 were computed from these calculated flow rates and the measured coal and stack gas flow rates.

Concentration Calculations

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

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

where:

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

M = Mass measured in the sample, μg

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

V = Sample volume (at 68° F), ft^3

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 3-6) 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 coal firing is calculated from the following equation:

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

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

Arsenic (baseline conditions) will be used for this example. The following mean values were taken from Tables 3-1 and 3-4:

g = 386,300 Nm^3/hr

c = 11 $\mu g/Nm^3$

HHV = 13,490 Btu/lb

coal = 100,000 lb/hr

The emission factor for arsenic is calculated from equation 2:

$$E = \frac{386{,}300 * 11 * 2202.6}{13{,}491 * 100{,}000} = 7 \text{ lb}/10^{12} \text{ Btu} \qquad \text{(eq. 3)}$$

Confidence Interval Calculations

Confidence intervals (CIs) were calculated for the total mean concentrations in the gas and coal streams. In addition, CIs were determined for the stack gas emission factors, removal efficiencies, and material balance closures. Additional details of the CI calculations for emission factors, 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:

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

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:

$$\beta_r = \sqrt{\sum_{i=1}^{N_i} (\beta_p * \theta_p)^2} \qquad \text{(eq. 5)}$$

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 reporting limit for concentrations below the reporting limit. Zero bias is assumed for reported quantities.

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

Substance	Run 1	Run 2	Run 3	Mean	Standard Deviation
Cadmium	89	6	NR(0.03)	32	50

The 95% confidence interval is calculated using these values inserted into equation 4:

β_r = 0.015

t = 4.3

S_r = 50

N = 3

$$U_{rTOT} = \sqrt{(0.015)^2 + \left(\frac{4.3 * 50}{\sqrt{3}}\right)^2} = 124 \quad \mu g/Nm^3$$

The 95% CI (U_{rTOT}) for the total cadmium concentration is $\pm$ 124 $\mu g/Nm^3$, as shown in Table 3-3.

6

GLOSSARY

AAS	Atomic Absorption Spectrophotometry
Btu	British Thermal Unit
CI	Confidence Interval
CEM	Continuous Emissions Monitor
CMS	Carbon Molecular Sieve
CVAAS	Cold Vapor Atomic Absorption Spectrophotometry
DGA	Double Gold Amalgamation
dscfm	Dry Standard Cubic Feet per Minute (1 atm., 68° F)
ESP	Electrostatic Precipitator
FCEM	Field Chemical Emissions Monitoring
GC/MS	Gas Chromatography/Mass Spectroscopy
GFAAS	Graphite Furnace Atomic Absorption Spectrophotometry
HHV	Higher Heating Value
IC	Ion Chromatography
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrophotometry
INAA	Instrumental Neutron Activation Analysis
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NC	Not Calculated
NR	Not Reported (below reporting limit)
Nm^3	Dry Normal Cubic Meter (1 atm, 0° C)
NO_x	Nitrogen Oxides
PAH	Polynuclear Aromatic Hydrocarbon
QA/QC	Quality Assurance/Quality Control
RPD	Relative Percent Difference
RL	Reporting Limit
SIE	Selective Ion Electrode
VOC	Volatile Organic Compound
VOST	Volatile Organic Sampling Train

APPENDIX A:
RAW ANALYTICAL DATA FROM ACUREX

Table A-1 presents the multi-metals test results for the ESP inlet gas of the baseline and reburn tests. Tables A-2 and A-3 present raw analytical data for the stack gas of the baseline and reburn tests. Only one field blank was given for all multi-metals tests. Only a reagent blank is presented for the aldehydes.

Table A-1
Results of the Sample and Blank Analyses for the ESP Inlet Gas at Site 114

	Mass Collected in Sample (μg)			
	Run 1	Run 2	Run 3	Field Blank (μg)[a]
Baseline				
Gas Sample Volume (Nm^3)	2.54	1.70	1.70	
Multi-Metals (μg)				
Arsenic	148	167	807	3.6
Beryllium	155	97.4	111	1
Cadmium	72	64	56.7	12.5
Chromium	908	505	787	5
Manganese	1,130	899	1,410	8.6
Nickel	5,110	3,170	4,540	10
Lead	4,970	3,260	4,100	5.1
Selenium	22.3	26.3	150	3.3
Mercury	26.8	23.2	14.5	2
Reburn				
Gas Sample Volume (Nm^3)	1.69	1.68	1.64	
Multi-Metals (μg)				
Arsenic	889	249	41.7	3.6
Beryllium	246	25.3	11.3	1
Cadmium	162	22.4	12.5	12.5
Chromium	1,080	113	74.5	5
Manganese	2,250	297	344	8.6
Nickel	7,090	718	428	10
Lead	6,590	561	569	5.1
Selenium	373	331	86.2	3.3
Mercury	17.5	11.4	11.1	2

[a]Only one field blank was collected for all multi-metals runs in the ESP inlet and stack.

Table A-2
Results of the Sample and Blank Analyses for the Stack Gas at Site 114

	Mass Collected in Sample (μg)			
Baseline	**Run 1**	**Run 2**	**Run 3**	**Field Blank (μg)[a]**
Multi-Metals (μg)				
Gas Sample Volume (Nm^3)	8.77	8.91	8.80	
Arsenic	86	41.2	184	3.6
Beryllium	40	20.1	42.3	1
Cadmium	20	20.9	71.9	12.5
Chromium	252	121	208	5
Manganese	271	173	439	8.6
Nickel	1,410	742	1,150	10
Lead	694	1,590	1,330	5.1
Selenium	1,190	4,200	4,770	3.3
Mercury	26.2	99.9	70.2	2
Anions				
Gas Sample Volume (Nm^3)	8.38	8.00	8.33	
Chloride	55,200	52,000	61,800	ND(100)
Fluoride	800	900	800	
VOST (ng)				
Gas Sample Volume (Nm^3)	0.014	0.015	0.014	
Benzene	70.4	64.6	26.5	
Toluene	19.6	28	23.16667	
				Reagent Blank
Aldehydes (μg)				
Gas Sample Volume (Nm^3)	0.123	0.122	0.124	
Formaldehyde	0.63	ND(0.5)	ND(0.5)	ND(0.5)
Acetaldehyde	1.25	ND(0.5)	ND(0.5)	ND(0.5)

[a]Only one field blank was collected for all multi-metals runs in the ESP inlet and stack.

Table A-3
Results of the Sample and Blank analyses for the Stack Gas at Site 114

	Mass Collected in Sample (μg)			
Reburn	**Run 1**	**Run 2**	**Run 3**	**Field Blank (μg)***
Multi-Metals (μg)				
Gas Sample Volume (Nm^3)	5.61	5.60	8.32	
Arsenic	54.9	81	122	3.6
Beryllium	3.15	8.5	17.7	1
Cadmium	ND(12.5)	21.1	14	12.5
Chromium	29	39.7	96	5
Manganese	74.2	155	280	8.6
Nickel	143	260	736	10
Lead	372	543	856	5.1
Selenium	2,630	307	1,480	3.3
Mercury	53.9	25.2	35.2	2
Anions				
Gas Sample Volume (Nm^3)	5.04	5.23	7.53	
Chloride	41,000	53,600	71,200	ND(100)
Fluoride	700	17,300	23,600	
VOST (ng)				
Gas Sample Volume (Nm^3)	0.014	0.015	0.015	
Benzene	27.0	27.3	16.0	
Toluene	16.0	17.3	13.7	
				Reagent Blank
Aldehydes (μg)				
Gas Sample Volume (Nm^3)	0.125	0.125	0.125	
Formaldehyde	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.5)
Acetaldehyde	ND(0.5)	ND(0.5)	ND(0.5)	ND(0.5)

*Only one field blank was collected for all multi-metals runs in the ESP inlet and stack.

APPENDIX B:
SITE 114 SAMPLING AND ANALYTICAL METHODS

Table B-1 contains a list of sampling methods by stream. Sampling methods are separated into sampling trains for the gas streams, ESP inlet and stack gas. Table B-2 contains a list of analytical methods by stream and target substance. All streams sampled at Site 114 are included, even those not discussed in the text of this report.

Table B-1
Sampling Method Used at Site 114

Target Substance	Sampling Method
Gas Streams - ESP Inlet Gas and Stack Gas	
Metals	EPA Multiple Metals Method 0012
Gas Streams - Stack Gas	
Chloride, Fluoride	CARB Method 421, Carbonate Impingers
Volatiles	VOST Train with CMS Sorbent
Formaldehyde	CARB Method 430, DNPH Midget Impingers
Semivolatiles	EPA SW 0010 Modified Method 5
Solid Streams	
Coal	Grab/Composite
Bottom Ash	Grab/Composite
Collected Fly Ash	Grab/Composite

Table B-2
Analytical Methods Used at Site 114

Target Substance	Analytical Method
Gas Streams	
Multi-Metals[a]	EPA SW 6010 (ICP-AES)
Arsenic	EPA SW 7060 (GFAAS)
Chloride	EPA 300.0 (IC)
Fluoride	CARB 421 (IC)
Mercury	ASTM D 3684-78 (CVAAS)
Selenium	EPA SW 7740 (GFAAS)
Volatile Organics	EPA SW 8240 (GC/MS)
Aldehydes	CARB 430 (HPLC)
Semivolatile Organics	EPA SW 8270 (GC/MS)
Coal	
Multi-Metals[a]	EPA SW 6010 (ICP-AES)
Arsenic	EPA SW 7060 (GFAAS)
Chloride and Fluoride	Not specified
Lead	EPA SW 7421 (GFAAS)
Mercury	ASTM D 3684-78 (CVAAS)
Selenium	EPA SW 7740 (GFAAS)
Moisture, Ash, HHV	Proximate Analysis
Carbon, Hydrogen, Nitrogen, Sulfur, Oxygen	Ultimate Analysis
Bottom Ash, Collected Fly Ash	
Multi-Metals[a]	EPA SW 6010 (ICP-AES)
Arsenic	EPA SW 7060 (GFAAS)
Lead	EPA SW 7421 (GFAAS)
Mercury	ASTM D 3684-78 (CVAAS)
Selenium	EPA SW 7740 (GFAAS)

[a]Multi-metals include beryllium, cadmium, chromium, manganese, and nickel.

APPENDIX C:
SITE 114 DATA USED IN CALCULATIONS

Appendix C presents the results from the sampling done at Site 114 during baseline and reburn conditions. Tables C-1 and C-2 present the concentrations of the substances measured for baseline and reburn conditions, respectively. The analytical techniques used to determine these results are also given. The data presented in Section 3 were obtained from this appendix. The higher heating values for coal are presented on a wet basis; all other values for coal are on a dry basis.

FCEM 114 Table C-1 Stream Concentrations During Baseline Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
>>>> Bottom ash <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1	< 1	2.87	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	6.79	7.8	5.21	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	3.97	4.99	2.39	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	47.9	92	66	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	1.73	12.6	< 1	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	458	432	444	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	< 0.5	< 0.5	< 0.5	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	371	412	410	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1	< 1	10.5	
>>>> Coal <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	7.14	22.97	6.21	
Ash	Proximate analysis	wt %	7.59	10.01	8.41	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	3.49	3.65	3.78	
Sulfur	Ultimate analysis	wt %	1.34	2.32	1.57	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	< 1.2	1.29	113.5	
Chloride	Ion chromatography (IC)	ug/g	68.9	26.9	109.9	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	5.82	13.69	14.02	
Fluoride	Ion chromatography (IC)	ug/g	< 5.62	< 4.04	< 4.11	
HHV	Proximate analysis	Btu/lb	11092	11680	11389	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	45.7	45.8	18	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	24.3	25.8	29.4	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	< 0.12	< 0.12	< 0.12	
Moisture	Proximate analysis	wt %	15.68	13.81	17.28	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	15.4	16.1	51.1	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1.2	< 1.2	< 1.2	
>>>> Collected fly ash <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	292	332	237	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	40	35	18.9	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	< 17	14.1	10.5	

FCEM 114 Table C-1 Stream Concentrations During Baseline Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	214	179	180	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	988	983	803	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	306	276	316	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	< 0.5	< 0.5	< 0.5	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	1162	1252	1085	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 34	< 1	< 1	
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Acetaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	10.2	< 4.1	< 4	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	9.4	4.2	20.5	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	4.9	4.4	1.8	
Benzo(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	4.4	2.1	4.7	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B 0.9	B 0.9	6.8	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	28.2	13	23.1	
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	5.1	< 4.1	< 4	
HCl	Ion chromatography (IC)	ug/Nm3	6588	6502	7415	
HF	Ion chromatography (IC)	ug/Nm3	95	113	96	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	78.6	177.9	150.6	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	29.9	18.4	48.9	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	2.8	11	7.8	

FCEM 114 Table C-1 Stream Concentrations During Baseline Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	159.6	82.1	129.6	
Particulate	Gravimetric	gr/dscf	0.0191	0.0127	0.0175	
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 13	< 13	< 14	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	135.3	470.9	541.8	
Toluene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	1.4	1.9	1.6	
>>>> High dust gas <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	56.9	96.1	473	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	60.7	56.7	64.8	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	23.4	30.3	26	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	355.7	294	460.4	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	1955.6	1914.1	2410.7	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	441.7	523.6	825	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	9.8	12.5	7.4	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	2008.8	1858.3	2666.8	
Particulate	Gravimetric	gr/dscf	0.46075	0.8399	0.6248	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	7.5	13.5	86.4	

FCEM 114R Table C-2 Stream Concentrations During Reburn Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
>>>> Bottom ash <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1	< 1	42	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	< 16.7	4.33	4.62	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	< 179	2.77	1.77	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	80.6	32.1	53	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	10	7.82	7.05	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	386	524	327	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	< 0.1	< 0.5	< 0.5	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	317	301	276	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1	< 1	< 1	
>>>> Coal <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	3.06	10.58	10.66	
Ash	Proximate analysis	wt %	8.21	9.2	9.4	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	3.45	3.26	3.07	
Sulfur	Ultimate analysis	wt %	1.72	1.37	1.43	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	80	60	< 1.1	
Chloride	Ion chromatography (IC)	ug/g	74.4	75	95.3	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	9.8	8.4	10.1	
Fluoride	Ion chromatography (IC)	ug/g	< 3.92	< 5.55	< 3.92	
HHV	Proximate analysis	Btu/lb	11954	11453	11453	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	12.2	20.8	13.6	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	33	26.9	21.4	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	< 0.11	< 0.11	< 0.11	
Moisture	Proximate analysis	wt %	12	12.94	12.51	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	56	43	40	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	< 1.1	< 1.1	< 1.1	
>>>> Collected fly ash <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	266	318	253	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	29.6	28	28	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	< 159	10.6	< 18	

FCEM 114R Table C-2 Stream Concentrations During Reburn Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	132	139	158	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	564	602	658	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	195	357	332	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/g	0.1	< 0.5	< 0.5	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/g	851	955	880	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/g	6.7	< 1	3.4	
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Acetaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	< 4	< 4	< 4	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	9.7	13.8	14.2	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	1.9	1.9	1.1	
Benzo(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Benzo(b)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Benzo(k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.4	1.3	2	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B< 0.03	B 1.5	B 0.2	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	4.3	6.2	10.9	
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	< 4	< 4	< 4	
HCl	Ion chromatography (IC)	ug/Nm3	8138	10247	9457	
HF	Ion chromatography (IC)	ug/Nm3	139	3307	3135	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	65.4	96	102.3	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	11.7	26.1	32.6	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	9.3	4.1	4	

FCEM 114R Table C-2 Stream Concentrations During Reburn Tests

Substance	Method	Units	Run1	Run2	Run3	RunNull
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	23.7	44.6	87.3	
Particulate	Gravimetric	gr/dscf	0.0038	0.0085	0.0184	
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/dscm	< 23	< 18	< 13	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	468.3	54.2	177.5	
Toluene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	1.1	1.2	0.9	
>>>> High dust gas <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	524.8	146.5	23.3	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	145.2	14.5	6.3	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	89	B 5.9	B< 0.03	
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	637.2	64.5	42.5	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	3903.2	331.8	344.6	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	1328.6	172.1	204.9	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	9.2	5.6	5.6	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	4196.7	422.6	255.4	
Particulate	Gravimetric	gr/dscf	1.163	1.318	1.246	
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	219.1	195.6	50.7	

APPENDIX D: SITE 114 PROCESS DATA

Appendix D summarizes process data collected during the sampling of Site 114. Table D-1 presents power plant operating data for the baseline sampling, while Table D-2 presents data for reburn sampling.

Table D-1
Process Stream Flow Rates and Characterization Data for Site 114 - Baseline

Stream (dry)	Units of Measure	11/2/92 Run 1	11/3/92 Run 2	11/5/92 Run 3	Average	Measured (M) or Calculated (C)
Coal	lb/hr	108,631	96,890	94,566	100,000	M
Ash	lb/hr	8,245	9,699	7,953	8,630	M
Unit Load	MW	110	111	111	111	M
Bottom Ash	lb/hr	7,207	7,899	6,641	7,250	C
Collected Fly Ash	lb/hr	998	1,775	1,275	1,350	C
ESP Inlet Gas						
Flow Rate	Nm^3/hr	416,500	396,000	388,000	400,200	M
Particulate Loading	mg/Nm^3	1.13	2.06	1.53	1.58	M
Ash	lb/hr	1,039	1,800	1,312	1,380	C
Moisture	%	4.0	5.9	5.9	5.3	M
Oxygen	%	3.23	3.23	3.23	3.23	M
Isokineticity	%	103.7	106.5	106.0	105.4	C
Stack Gas						
Flow Rate	Nm^3/hr	392,400	370,200	396,300	386,300	M
Particulate Loading	mg/Nm^3	46.9	31.2	43.0	40.3	M
Ash	lb/hr	41	25	38	40	C
Moisture	%	9.7	8.8	10.3	9.6	M
Oxygen	%	2.9	3.4	3.3	3.2	M
Isokineticity	%	103.7	103.3	103.5	103.5	C

Table D-2
Process Stream Flow Rates and Characterization Data for FCEM 114 - Reburn

Stream	Units of Measure	11/4/92 Run 1	11/4/92 Run 2	11/6/92 Run 3	Average	Measured (M) or Calculated (C)
Coal	lb/hr	94,816	97,680	96,519	96,300	M
Ash	lb/hr	7,784	8,987	9,073	8,620	M
Unit Load	MW	112	111	111	111	M
Bottom Ash	lb/hr	5,393	6,208	6,531	6,040	C
Collected Fly Ash	lb/hr	2,384	2,761	2,505	2,550	C
ESP Inlet Gas						
Flow Rate	Nm^3/hr	380,100	389,600	377,000	382,200	M
Particulate Loading	g/Nm^3	2.85	3.24	3.06	3.05	M
Ash	lb/hr	2,391	2,779	2,542	2,570	C
Moisture	%	5.9	6.0	6.1	6.0	M
Oxygen	%	3.23	3.23	3.23	3.23	M
Isokineticity	%	109.4	106.6	105.7	107.2	C
Stack Gas						
Flow Rate	Nm^3/hr	369,400	391,800	366,000	375,700	M
Particulate Loading	mg/Nm^3	9.3	20.9	45.2	25.1	M
Ash	lb/hr	8	18	36	20	C
Moisture	%	9.4	9.4	9.0	9.2	M
Oxygen	%	2.7	3.0	2.6	2.8	M
Isokineticity	%	102.8	102.4	102.4	102.5	C

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.;
B_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:

$$U_r = \sqrt{\beta_r^2 + (S_r * t)^2} \qquad \text{(eq. 1)}$$

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

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

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

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

$$\theta_i = \frac{\partial r}{\partial pi} \qquad \text{(eq. 4)}$$

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

$$\theta_i = \frac{r(P_i + \Delta P_i) - r(P_i)}{\Delta P_i} \qquad \text{(eq. 5)}$$

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

$$S_{\bar{pi}} = \frac{S_{pi}}{\sqrt{N}} \qquad \text{(eq. 6)}$$

The degrees of freedom for each parameter is found from

$$v_i = N_i - 1 \qquad \text{(eq. 7)}$$

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

$$v_r = \frac{S_r^4}{\sum_{i=1}^{j} \left[\frac{(S_{\bar{pi}} \times \theta_i)^4}{v_i} \right]} \qquad \text{(eq. 8)}$$

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.
- 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 total concentrations in all gas streams. In addition, confidence intervals were determined for the stack gas emission factors presented in Table 3-6, the ESP removals in Table 3-7, and material balances in Table 4-4.

The following example shows an example calculation for the 95% confidence interval around an 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 114.

$$E = \frac{(g * s) + (g * v)}{HHV * Coal} * 2204.6 \qquad \text{(eq. 9)}$$

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

Mean = 0.00073

S_p = 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.

$$\beta_p = 0$$

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

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

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

$$= 843$$

Similar calculations can be done for each parameter.

The precision component is then found by root-sum-squaring the product of the parameter S_ps and their sensitivities.

$$S_r = \sqrt{(\theta_g\ S_g)^2 + (\theta_s\ S_s)^2 + (\theta_v\ S_v)^2 + (\theta_{HHV}\ S_{HHV})^2 + (\theta_{coal}\ S_{coal})^2}$$

$$S_r = 0.236$$

The bias component is found using the same equation substituting β_p for the S_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

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

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.

Tables E-1, E-2, and E-3, which follow this discussion, are the computer-generated results from the emission factor, removal efficiency, and material balance error propagation, respectively. An "ERR" in the calculation table indicates a concentration used in formula was not detected.

Emission Factor Results

Stack Gas Emission Factors (lb/10E+12Btu)

Baseline Substance		Em Fac Mean	95% CI About Mean	Mean Conc (ug/Nm3)	Std Dev (ug/Nm3)	N	Bias	Perturb	Sensitivity Gas Conc	Sensitivity Gas Flow	Sensitivity Coal Flow	Sensitivity Coal HHV	Sens*Sphar Gas Conc	Sens*Sphar Gas Flow	Sens*Sphar Coal Flow	Sens*Sphar Coal HHV	Sr	Vr	t	Br
Gas Flow (Nm3/hr)		386,300	35,000		14,100	3	0	8,141												
Coal Rate (lb/hr, dry)		100,029	18,718		7,540	3	5,001	5,001												
HHV (Btu/lb, dry)		13,491	772		311	3	0	170												
Particulate (lb/10e6 Btu)		0.025	0.010	4.03E+01	8.18E+00	3	0.00E+00	4.72E+00	6.31E-04	6.58E-08	-2.42E-07	-1.86E-06	2.98E-03	5.36E-04	-1.05E-03	-3.34E-04	3.22E-03	2.695	3.182	1.21E-03
Arsenic		7.17	13.12	1.14E+01	8.32E+00	3	0.00E+00	4.80E+00	6.31E-01	1.86E-05	-6.83E-05	-5.25E-04	3.03E+00	1.51E-01	-2.97E-01	-9.43E-02	3.05E+00	2.052	4.303	3.41E-01
Beryllium		2.37	2.26	3.76E+00	1.41E+00	3	0.00E+00	8.12E-01	6.31E-01	6.14E-06	-2.26E-05	-1.74E-04	5.12E-01	5.00E-02	-9.83E-02	-3.12E-02	5.25E-01	2.202	4.303	1.13E-01
Cadmium		1.80	5.31	2.85E+00	3.38E+00	3	0.00E+00	1.95E+00	6.31E-01	4.65E-06	-1.71E-05	-1.32E-04	1.23E+00	3.79E-02	-7.45E-02	-2.36E-02	1.23E+00	2.020	4.303	8.56E-02
Chromium		13.50	12.41	2.14E+01	7.71E+00	3	0.00E+00	4.45E+00	6.31E-01	3.50E-05	-1.29E-04	-9.89E-04	2.81E+00	2.85E-01	-5.60E-01	-1.78E-01	2.88E+00	2.218	4.303	6.43E-01
Manganese		20.45	24.50	3.24E+01	1.54E+01	3	0.00E+00	8.89E+00	6.31E-01	5.29E-05	-1.95E-04	-1.50E-03	5.60E+00	4.31E-01	-8.47E-01	-2.69E-01	5.69E+00	2.125	4.303	9.74E-01
Nickel		78.05	63.42	1.24E+02	3.91E+01	3	0.00E+00	2.26E+01	6.31E-01	2.02E-04	-7.43E-04	-5.71E-03	1.47E+01	1.64E+00	-3.23E+00	-1.03E+00	1.47E+01	2.285	4.303	3.72E+00
Lead		85.54	82.41	1.36E+02	5.13E+01	3	0.00E+00	2.96E+01	6.31E-01	2.21E-04	-8.14E-04	-6.26E-03	1.87E+01	1.80E+00	-3.53E+00	-1.12E+00	1.91E+01	2.198	4.303	4.07E+00
Selenium		241.29	344.00	3.83E+02	2.17E+02	3	0.00E+00	1.25E+02	6.31E-01	6.25E-04	-2.30E-03	-1.77E-02	7.90E+01	5.08E+00	-1.00E+01	-3.17E+00	7.99E+01	2.087	4.303	1.15E+01
Mercury		4.52	6.56	7.17E+00	4.14E+00	3	0.00E+00	2.39E+00	6.31E-01	1.17E-05	-4.30E-05	-3.31E-04	1.51E+00	9.52E-02	-1.87E-01	-5.94E-02	1.52E+00	2.084	4.303	2.15E-01
Chloride		4309.46	742.45	6.83E+03	5.04E+02	3	0.00E+00	2.91E+02	6.31E-01	1.12E-02	-4.10E-02	-3.15E-01	1.83E+02	9.08E+01	-1.79E+02	-5.67E+01	2.78E+02	5.322	2.571	2.05E+02
Fluoride		63.89	12.44	1.01E+02	9.70E+00	3	0.00E+00	5.60E+00	6.31E-01	1.65E-04	-6.08E-04	-4.68E-03	3.53E+00	1.35E+00	-2.65E+00	-8.40E-01	4.69E+00	4.644	2.571	3.04E+00
Benzene		2.34	2.63	3.71E+00	1.65E+00	3	0.00E+00	9.51E-01	6.31E-01	6.05E-06	-2.23E-05	-1.71E-04	5.99E-01	4.93E-02	-9.69E-02	-3.07E-02	6.10E-01	2.143	4.303	1.11E-01
Toluene		1.02	0.34	1.62E+00	2.57E-01	3	0.00E+00	1.49E-01	6.31E-01	2.65E-06	-9.74E-06	-7.49E-05	9.37E-02	2.15E-02	-4.24E-02	-1.34E-02	1.06E-01	3.126	3.182	4.87E-02
PAHs	<	9.46	-	1.50E+01	6.20E-01	3	7.50E+00	7.50E+00	6.31E-01	2.45E-05	-9.00E-05	-6.92E-04	2.26E-01	1.99E-01	-3.92E-01	-1.24E-01	5.10E-01	4.816	2.571	4.75E+00
Formaldehyde	<	2.59	-	4.10E+00	6.17E-01	3	1.85E+00	1.85E+00	6.31E-01	6.69E-06	-2.46E-05	-1.89E-04	2.25E-01	5.45E-02	-1.07E-01	-3.40E-02	2.57E-01	3.246	3.182	1.17E+00
Acetaldehyde	<	2.59	-	4.10E+00	3.53E+00	3	1.85E+00	1.85E+00	6.31E-01	6.69E-06	-2.46E-05	-1.89E-04	1.29E+00	5.45E-02	-1.07E-01	-3.40E-02	1.29E+00	2.038	4.303	1.17E+00

Stack Gas Emission Factors (lb/10E+12Btu)

Substance	Reburn	Emi Fac Mean	95% CI About Mean	Mean Conc (ug/Nm3)	Std Dev (ug/Nm3)	N	Bias	Perturb	Sensitivity Gas Conc	Sensitivity Gas Flow	Sensitivity Coal Flow	Sensitivity Coal HHV	Sens*Splur Gas Conc	Sens*Splur Gas Flow	Sens*Splur Coal Flow	Sens*Splur Coal HHV	Sr	Vr	t	Br
Gas Flow (Nm3/hr)		375,700	34,800		14,000	3	0	8,985												
Coal Rate (lb/hr, dry)		90,338	3,575		1,440	3	4,817	4,817												
HHV (Btu/lb, dry)		13,277	666		268	3	0	167												
Particulate (lb/10E+6 Btu)		0.016	0.029	2.51E+01	1.83E+01	3	0.00E+00	1.06E+01	6.47E-04	4.33E-08	-1.61E-07	-1.21E-06	6.85E-03	3.90E-04	-1.34E-04	-1.87E-04	6.85E-03	2.015	4.303	7.74E-04
Arsenic		8.02	4.64	1.24E+01	2.82E+00	3	0.00E+00	1.63E+00	6.47E-01	2.13E-05	-7.93E-05	-5.97E-04	1.05E+00	1.73E-01	-6.59E-02	-9.24E-03	1.07E+00	2.155	4.303	3.82E-01
Beryllium		0.80	1.32	1.24E+00	8.16E-01	3	0.00E+00	4.71E-01	6.47E-01	2.14E-06	-7.95E-06	-5.98E-05	3.05E-01	1.73E-02	-6.61E-03	-9.26E-03	3.06E-01	2.018	4.303	3.83E-02
Cadmium		0.37	1.34	5.77E-01	8.34E-01	3	0.00E+00	4.81E-01	6.47E-01	9.93E-07	-3.69E-06	-2.78E-05	3.11E-01	8.03E-03	-3.07E-03	-4.30E-03	3.12E-01	2.004	4.303	1.78E-02
Chromium		4.62	5.54	7.14E+00	3.43E+00	3	0.00E+00	1.98E+00	6.47E-01	1.23E-05	-4.56E-05	-3.43E-04	1.28E+00	9.93E-02	-3.79E-02	-5.32E-02	1.29E+00	2.035	4.303	2.20E-01
Manganese		15.19	17.31	2.35E+01	1.07E+01	3	0.00E+00	6.18E+00	6.47E-01	4.04E-05	-1.50E-04	-1.13E-03	4.00E+00	3.27E-01	-1.25E-01	-1.75E-01	4.07E+00	2.058	4.303	7.23E-01
Nickel		33.55	52.21	5.19E+01	3.24E+01	3	0.00E+00	1.87E+01	6.47E-01	8.93E-05	-3.32E-04	-2.50E-03	1.21E+01	7.22E-01	-2.76E-01	-3.86E-01	1.21E+01	2.020	4.303	1.60E+00
Lead		56.87	32.43	8.79E+01	1.97E+01	3	0.00E+00	1.14E+01	6.47E-01	1.51E-04	-5.62E-04	-4.22E-03	7.37E+00	1.22E+00	-4.67E-01	-6.55E-01	7.51E+00	2.159	4.303	2.71E+00
Selenium		150.96	342.23	2.33E+02	2.13E+02	3	0.00E+00	1.23E+02	6.47E-01	4.07E-04	-1.49E-03	-1.12E-02	7.94E+01	3.25E+00	-1.24E+00	-1.74E+00	7.95E+01	2.010	4.303	7.19E+00
Mercury		3.75	4.84	5.79E+00	3.00E+00	3	0.00E+00	1.73E+00	6.47E-01	9.94E-06	-3.71E-05	-2.79E-04	1.12E+00	8.07E-02	-3.08E-02	-4.32E-02	1.12E+00	2.030	4.303	1.79E-01
Chloride		6004.67	1388.45	9.28E+03	1.07E+03	3	0.00E+00	6.15E+02	6.47E-01	1.60E-02	-5.94E-02	-4.47E-01	3.99E+02	1.29E+02	-4.94E+01	-6.92E+01	4.27E+02	2.617	3.182	2.86E+02
Fluoride		89.50	..	1.39E+02	0.00E+00	1	0.00E+00	0.00E+00	6.47E-01	2.39E-04	-8.89E-04	-6.69E-03	0.00E+00	1.93E+00	-7.39E-01	-1.04E+00	2.31E+00	ERR	ERR	4.28E+00
Benzene		1.04	0.73	1.61E+00	4.47E-01	3	0.00E+00	2.58E-01	6.47E-01	2.78E-04	-1.03E-03	-7.76E-03	1.67E-01	2.24E-02	-8.58E-03	-1.20E-02	1.69E-01	2.104	4.303	4.97E-02
Toluene		0.70	0.17	1.08E+00	1.29E-01	3	0.00E+00	7.45E-02	6.47E-01	1.86E-06	-6.89E-06	-5.18E-05	4.87E-02	1.50E-02	-5.73E-03	-8.03E-03	5.14E-02	2.567	3.182	3.32E-02
PAHs	<	15.98	..	2.47E+01	0.00E+00	3	1.24E+01	0.00E+00	6.47E-01	4.25E-03	-1.58E-02	-1.19E-01	0.00E+00	3.44E-01	-1.31E-01	-1.84E-01	4.12E-01	3.720	2.776	8.00E+00
Formaldehyde	<	2.59	..	4.00E+00	4.88E-03	3	1.83E+00	2.87E-03	6.47E-01	6.89E-06	-2.56E-05	-1.93E-04	1.87E-03	5.57E-02	-2.13E-02	-2.98E-02	6.67E-02	3.725	2.776	1.20E+00
Acetaldehyde	<	2.59	..	4.00E+00	4.88E-03	3	1.83E+00	2.87E-03	6.47E-01	6.89E-06	-2.56E-05	-1.93E-04	1.87E-03	5.57E-02	-2.13E-02	-2.98E-02	6.67E-02	3.725	2.776	1.20E+00

Removal Efficiency

Site 114 Removal Efficiencies

Baseline Substance	Rem Eff Mean	95% CI About Mean	Mean Conc In (ug/Nm3)	Std Dev (ug/Nm3)	N	Bias	Perturb	Mean Conc Out (ug/Nm3)	Std Dev (ug/Nm3)	N	Bias	Perturb	Sensitivity In Gas Conc	Sensitivity Out Gas Conc	Sens*Sphar In Gas Conc	Sens*Sphar Out Gas Conc	Sr	Vr	t	Br
Particulate	97.4	1.3	1.58E+03	4.67E+02	3	0.00E+00	2.69E+02	4.03E+01	8.18E+00	3	0.00E+00	4.72E+00	1.39E-03	-6.35E-02	3.74E-01	-3.00E-01	4.79E-01	3.818	2.776	0.00E+00
Arsenic	94.5	8.7	2.09E+02	2.30E+02	3	0.00E+00	1.33E+02	1.14E+01	8.32E+00	3	0.00E+00	4.80E+00	1.60E-02	-4.79E-01	2.12E+00	-2.30E+00	3.13E+00	3.973	2.776	0.00E+00
Beryllium	93.8	5.8	6.07E+01	4.03E+00	3	0.00E+00	2.33E+00	3.76E+00	1.41E+00	3	0.00E+00	8.12E-01	9.83E-02	-1.65E+00	2.29E-01	-1.34E+00	1.36E+00	2.117	4.303	0.00E+00
Cadmium	89.3	31.7	2.66E+01	3.46E+00	3	0.00E+00	2.00E+00	2.85E+00	3.38E+00	3	0.00E+00	1.95E+00	3.75E-01	-3.76E+00	7.49E-01	-7.34E+00	7.38E+00	2.042	4.303	0.00E+00
Chromium	94.2	4.4	3.70E+02	8.41E+01	3	0.00E+00	4.85E+01	2.14E+01	7.71E+00	3	0.00E+00	4.45E+00	1.38E-02	-2.70E-01	6.71E-01	-1.20E+00	1.38E+00	3.136	3.182	0.00E+00
Manganese	94.6	5.5	5.97E+02	2.02E+02	3	0.00E+00	1.17E+02	3.24E+01	1.54E+01	3	0.00E+00	8.89E+00	7.62E-03	-1.68E-01	8.88E-01	-1.49E+00	1.73E+00	3.263	3.182	0.00E+00
Nickel	94.3	3.8	2.18E+03	4.30E+02	3	0.00E+00	2.48E+02	1.24E+02	3.91E+01	3	0.00E+00	2.26E+01	2.34E-03	-4.59E-02	5.82E-01	-1.04E+00	1.19E+00	3.147	3.182	0.00E+00
Lead	93.5	6.4	2.09E+03	2.76E+02	3	0.00E+00	1.59E+02	1.36E+02	5.13E+01	3	0.00E+00	2.96E+01	2.88E-03	-4.78E-02	4.58E-01	-1.41E+00	1.49E+00	2.414	4.303	0.00E+00
Selenium	-969.2	–	3.58E+01	4.39E+01	3	0.00E+00	2.53E+01	3.83E+02	2.17E+02	3	0.00E+00	1.25E+02	1.75E+01	-2.79E+00	4.43E+02	-3.50E+02	5.65E+02	3.797	2.776	0.00E+00
Mercury	27.4	82.8	9.86E+00	2.56E+00	3	0.00E+00	1.48E+00	7.17E+00	4.14E+00	3	0.00E+00	2.39E+00	6.41E+00	-1.01E+01	9.45E+00	-2.43E+01	2.60E+01	2.594	3.182	0.00E+00
Reburn Substance																				
Particulate	99.2	1.5	3.05E+03	1.91E+02	3	0.00E+00	1.10E+02	2.51E+01	1.83E+01	3	0.00E+00	1.06E+01	2.61E-04	-3.28E-02	2.87E-02	-3.46E-01	3.48E-01	2.027	4.303	0.00E+00
Arsenic	94.6	9.6	2.32E+02	2.61E+02	3	0.00E+00	1.51E+02	1.24E+01	2.82E+00	3	0.00E+00	1.63E+00	1.40E-02	-4.32E-01	2.11E+00	-7.04E-01	2.23E+00	2.439	4.303	0.00E+00
Beryllium	97.8	3.7	5.53E+01	7.80E+01	3	0.00E+00	4.50E+01	1.24E+00	8.16E-01	3	0.00E+00	4.71E-01	2.24E-02	-1.81E+00	1.01E+00	-8.51E-01	1.32E+00	3.892	2.776	0.00E+00
Cadmium	98.2	5.6	3.16E+01	4.98E+01	3	0.00E+00	2.87E+01	5.77E-01	8.34E-01	3	0.00E+00	4.81E-01	3.02E-02	-3.16E+00	8.67E-01	-1.52E+00	1.75E+00	3.176	3.182	0.00E+00
Chromium	97.1	4.8	2.48E+02	3.37E+02	3	0.00E+00	1.95E+02	7.14E+00	3.43E+00	3	0.00E+00	1.98E+00	6.50E-03	-4.03E-01	1.27E+00	-7.98E-01	1.50E+00	3.374	3.182	0.00E+00
Manganese	95.9	6.3	5.69E+02	6.58E+02	3	0.00E+00	3.80E+02	2.35E+01	1.07E+01	3	0.00E+00	6.18E+00	4.35E-03	-1.76E-01	1.65E+00	-1.09E+00	1.98E+00	3.456	3.182	0.00E+00
Nickel	96.8	5.1	1.62E+03	2.23E+03	3	0.00E+00	1.29E+03	5.19E+01	3.24E+01	3	0.00E+00	1.87E+01	1.10E-03	-6.15E-02	1.41E+00	-1.15E+00	1.82E+00	3.845	2.776	0.00E+00
Lead	94.2	11.3	1.53E+03	2.06E+03	3	0.00E+00	1.19E+03	8.79E+01	1.97E+01	3	0.00E+00	1.14E+01	2.12E-03	-6.55E-02	2.52E+00	-7.46E-01	2.63E+00	2.348	4.303	0.00E+00
Selenium	-50.4	–	1.55E+02	9.12E+01	3	0.00E+00	5.27E+01	2.33E+02	2.13E+02	3	0.00E+00	1.23E+02	7.24E-01	-6.45E-01	3.81E+01	-7.91E+01	8.78E+01	2.881	3.182	0.00E+00
Mercury	14.6	90.8	6.79E+00	2.08E+00	3	0.00E+00	1.20E+00	5.79E+00	3.00E+00	3	0.00E+00	1.73E+00	1.07E+01	-1.47E+01	1.28E+01	-2.55E+01	2.85E+01	2.953	3.182	0.00E+00

Material Balance Closure Results

Site 114
Baseline

Substance	Material Balance Mat. Bal. Mean	95% CI About Mean	Coal Mean Conc (mg/kg)	Coal Std Dev (mg/kg)	Coal N	Coal Bias	Coal Perturb	Rock Mean Conc (ug/Nm3)	Rock Std Dev (ug/Nm3)	Rock N	Rock Bias	Rock Perturb	Bottom Ash Mean Conc (mg/kg)	Bottom Ash Std Dev (mg/kg)	Bottom Ash N	Bottom Ash Bias	Bottom Ash Perturb	ESP Ash Mean Conc (mg/kg)	ESP Ash Std Dev (mg/kg)	ESP Ash N	ESP Ash Bias	ESP Ash Perturb	Sensitivity Coal Conc	Sensitivity Coal Flow
ESP in Gas Flow (Nm3/hr)	400,167	36,494		14,700	3	0	8,487																		
Stack Gas Flow (Nm3/hr)	386,300	35,000		14,100	3	0	8,141																		
Coal Rate (lb/hr, dry)	100,029	18,718		7,540	3	5,001	5,001																		
ESP inlet particulate (mg/Nm3)	1,573	1,159		467	3	0	269																		
ESP outlet particulate (mg/Nm3)	40.34	20.30		8.18	3	0.00	4.72																		
Coal Ash (%)	8.67	3.06		1.23	3	0.00	0.71																		
Arsenic	33.90	9.42E+01	1.21E+01	9.42E+00	3	0.00E+00	5.44E+00	1.14E+01	8.92E+00	3	0.00E+00	4.80E+00	< 1.00E+00	–		3	5.00E-01	5.00E-01	2.87E+02	4.77E+01	3	0.00E+00	2.75E+01	-1.91E+00	-3.12E-04
Beryllium	25.72	4.76E-01	3.64E+00	1.45E-01	3	0.00E+00	8.39E-02	3.76E+00	1.41E+00	3	0.00E+00	8.12E-01	6.40E+00	1.31E+00	3	0.00E+00	7.54E-01	3.13E+01	1.10E+01	3	0.00E+00	6.37E+00	-6.91E+00	-9.53E-05
Cadmium	1.58	3.03E+00	3.85E+01	6.48E+01	3	0.00E+00	3.74E+01	2.85E+00	5.38E+00	3	0.00E+00	1.95E+00	3.78E+00	1.51E+00	3	0.00E+00	7.56E-01	< 1.70E+01	–	3	0.00E+00	0.00E+00	-1.82E-02	-5.00E-06
Chromium	69.48	4.63E+01	1.12E+01	4.64E+00	3	0.00E+00	2.68E+00	2.14E+01	7.71E+00	3	0.00E+00	4.45E+00	6.86E+01	2.22E+01	3	0.00E+00	1.28E+01	1.91E+02	1.99E+01	3	0.00E+00	1.15E+01	-5.01E+00	-1.55E-04
Manganese	138.52	3.97E+01	2.63E+01	2.62E+00	3	0.00E+00	1.51E+00	3.24E+01	1.54E+01	3	0.00E+00	8.89E+00	4.45E+02	1.30E+01	3	0.00E+00	7.51E+00	2.99E+02	2.08E+01	3	0.00E+00	1.20E+01	-4.94E+00	6.63E-05
Nickel	164.55	2.22E+02	2.75E+01	2.04E+01	3	0.00E+00	1.18E+01	1.24E+02	5.91E+01	3	0.00E+00	2.26E+01	3.98E+02	2.31E+01	3	0.00E+00	1.33E+01	1.17E+03	8.36E+01	3	0.00E+00	4.83E+01	-4.23E+00	-3.92E-04
Lead	38.48	2.86E+01	3.65E+01	1.60E+01	3	0.00E+00	9.25E+00	1.36E+02	5.13E+01	3	0.00E+00	2.96E+01	5.11E+00	6.30E+00	3	0.00E+00	3.75E+00	9.25E+02	1.05E+02	3	0.00E+00	6.09E+01	-8.41E-01	-3.55E-04
Selenium	ERR	ERR	ND(1.2)	–		3	0.00E+00	0.00E+00	9.83E+02	2.17E+02	3	0.00E+00	1.25E+02	9.83E+00	5.77E+00	3	0.00E+00	5.33E+00	< 3.40E+01	–		3	0.00E+00	0.00E+00	ERR	ERR
Mercury	ERR	ERR	ND(0.12)	–		3	0.00E+00	0.00E+00	7.17E+00	4.14E+00	3	0.00E+00	2.39E+00	< 5.00E-01	–		3	0.00E+00	0.00E+00	< 5.00E-01	–		3	0.00E+00	0.00E+00	ERR	ERR

Reburn
Substance

Substance																									
ESP in Gas Flow (Nm3/hr)	382,233	16,299		6,565	3	0	3,790																		
Stack Gas Flow (Nm3/hr)	375,700	34,800		14,000	3	0	8,083																		
Coal Rate (lb/hr, dry)	96,338	5,575		1,440	3	4,817	4,817																		
ESP inlet particulate (mg/Nm3)	3,049	475		191	3	0	110																		
ESP outlet particulate (mg/Nm3)	25.12	45.42		18.30	3	0.00	10.56																		
Coal Ash (%)	8.94	1.58		0.64	3	0.00	0.37																		
Arsenic	93.13	1.00E+02	8.10E+00	4.36E+00	3	0.00E+00	2.52E+00	1.24E+01	2.82E+00	3	0.00E+00	1.63E+00	< 1.00E+00	–		3	5.00E-01	5.00E-01	2.79E+02	9.44E+01	3	0.00E+00	1.99E+01	-8.77E+00	-9.10E-04
Beryllium	52.07	3.75E+00	3.26E+00	1.90E-01	3	0.00E+00	1.10E-01	1.24E+00	8.16E-01	3	0.00E+00	4.71E-01	4.48E+00	2.05E-01	2	0.00E+00	1.45E-01	2.85E+01	9.24E-01	3	0.00E+00	5.33E-01	-9.52E+00	-1.96E-04
Cadmium	1.33	1.95E+00	4.69E+01	4.10E+01	3	0.00E+00	2.37E+01	5.77E-01	8.34E-01	3	0.00E+00	4.81E-01	2.27E+00	7.07E-01	2	0.00E+00	5.00E-01	< 1.80E+01	–	3	0.00E+00	0.00E+00	-1.89E-02	-8.87E-06
Chromium	77.44	3.40E+01	9.43E+00	9.07E-01	3	0.00E+00	5.24E-01	7.14E+00	3.45E+00	3	0.00E+00	1.98E+00	5.52E+01	2.43E+01	3	0.00E+00	1.40E+01	1.43E+02	1.35E+01	3	0.00E+00	7.77E+00	-7.78E+00	-2.48E-04
Manganese	124.91	5.31E+01	2.71E+01	5.80E+00	3	0.00E+00	3.35E+00	2.93E+01	1.07E+01	3	0.00E+00	6.18E+00	4.12E+02	1.01E+02	3	0.00E+00	5.84E+01	2.95E+02	8.72E+01	3	0.00E+00	5.04E+01	-4.10E+00	1.09E-04
Nickel	92.38	9.05E+01	4.63E+01	8.50E+00	3	0.00E+00	4.91E+00	5.19E+01	9.24E+01	3	0.00E+00	1.87E+01	2.98E+02	2.07E+01	3	0.00E+00	1.19E+01	8.95E+02	5.37E+01	3	0.00E+00	3.10E+01	-1.80E+00	-3.45E-04
Lead	111.66	5.58E+01	1.53E+01	4.61E+00	3	0.00E+00	2.66E+00	8.79E+01	1.97E+01	3	0.00E+00	1.14E+01	8.29E+00	1.53E+00	3	0.00E+00	8.83E-01	6.08E+02	4.73E+01	3	0.00E+00	2.73E+01	-4.14E+00	-1.06E-03
Selenium	ERR	ERR	ND(1.1)	–		3	0.00E+00	0.00E+00	2.35E+02	2.13E+02	3	0.00E+00	1.23E+02	< 1.00E+00	–		3	0.00E+00	0.00E+00	< 5.00E-01	–		3	0.00E+00	0.00E+00	ERR	ERR
Mercury	ERR	ERR	ND(0.11)	–		3	0.00E+00	0.00E+00	5.79E+00	3.00E+00	3	0.00E+00	1.73E+00	< 5.00E-01	–		3	0.00E+00	0.00E+00	< 5.00E-01	–		3	0.00E+00	0.00E+00	ERR	ERR

Run 114
Baseline

Substance	Sensitivity Stack Conc	Sensitivity Stack Flow	Sensitivity Coal Ash	Sensitivity ESP In Flow	Sensitivity ESP In PL	Sensitivity SA Conc	Sensitivity Stack PL	Sensitivity CFA Conc	Sens*Splsr Coal Conc	Sens*Splsr Coal Flow	Sens*Splsr Stack Conc	Sens*Splsr Stack Flow	Sens*Splsr Coal Ash	Sens*Splsr ESP In Flow	Sens*Splsr ESP In PL	Sens*Splsr SA Conc	Sens*Splsr Stack PL	Sens*Splsr CFA Conc	Sr	Vr	t	Br
ESP In Gas Flow (Nm3/hr)																						
Stack Gas Flow (Nm3/hr)																						
Coal Rate (lb/hr, dry)																						
ESP inlet particulate (mg/Nm3)																						
ESP outlet particulate (mg/Nm3)																						
Coal Ash (%)																						
Arsenic	7.035-02	-3.726-08	8.265+00	8.205-05	2.085-02	4.618-01	-2.025-02	1.125-01	-1.045+01	-1.345+00	3.385-01	-3.035-04	5.875-02	4.965-01	3.618+00	0.000+00	-9.525-02	3.065+00	1.335+01	3.599	2.776	1.365+00
Beryllium	2.345-01	1.315-06	1.815+02	2.335-05	5.985-03	2.005+00	-3.315-03	3.725-01	-5.795-01	-4.155-01	1.905-01	1.235-02	1.295+00	2.005-01	1.615+00	1.515+00	-3.435-02	2.375+00	3.375+00	0.999	ERR	4.765-01
Cadmium	2.215-02	1.245-07	9.845+00	1.195-04	3.035-04	1.895-01	-3.745-04	3.525-02	-6.795-01	-2.105-03	4.115-03	1.015-03	6.995-03	1.015-02	8.165-02	1.435-01	-1.775-03	9.005+00	7.045-01	2.305	4.303	2.305-02
Chromium	7.615-02	2.705-04	6.145+02	3.805-03	9.655-03	4.525-01	-1.435-02	1.315-01	-1.345+01	-6.735-01	5.595-01	2.205-02	4.365+00	3.225-01	2.605+00	8.345+00	-4.505-02	1.395+00	1.675+01	4.098	2.776	7.735-01
Manganese	3.215-02	1.695-04	1.685+02	-1.905-05	-4.835-03	2.755-01	-9.615-03	5.115-02	-7.485+00	2.885-01	2.855-01	1.395-02	1.195+01	-1.615-01	-1.305+00	2.005+00	-4.505-02	6.145-01	1.455+01	2.381	3.566	3.315-01
Nickel	3.095-02	6.145-06	1.445+02	9.695-05	2.445-02	2.645-01	-3.605-02	4.925-02	-4.995+01	-1.705+00	6.975-01	3.005-02	1.035+01	8.225-01	6.635+00	3.535+00	-1.705-01	2.375+00	9.165+01	2.381	4.303	1.905+00
Lead	2.335-02	5.935-06	1.405+01	2.225-02	2.005-01	3.715-02	-2.135-02	3.715-02	-1.785+00	-1.345+00	6.905-01	4.835-02	9.955-02	7.425-01	5.965+00	7.485-01	-1.025-01	2.265+00	1.035+01	4.445	2.776	1.775+00
Selenium	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
Mercury	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR

Baseline
Substance

Substance	Sensitivity Stack Conc	Sensitivity Stack Flow	Sensitivity Coal Ash	Sensitivity ESP In Flow	Sensitivity ESP In PL	Sensitivity SA Conc	Sensitivity Stack PL	Sensitivity CFA Conc	Sens*Splsr Coal Conc	Sens*Splsr Coal Flow	Sens*Splsr Stack Conc	Sens*Splsr Stack Flow	Sens*Splsr Coal Ash	Sens*Splsr ESP In Flow	Sens*Splsr ESP In PL	Sens*Splsr SA Conc	Sens*Splsr Stack PL	Sens*Splsr CFA Conc	Sr	Vr	t	Br
ESP In Gas Flow (Nm3/hr)																						
Stack Gas Flow (Nm3/hr)																						
Coal Rate (lb/hr, dry)																						
ESP inlet particulate (mg/Nm3)																						
ESP outlet particulate (mg/Nm3)																						
Coal Ash (%)																						
Arsenic	1.065-01	1.525-04	1.335+01	2.595-04	3.005-02	7.145-01	-3.965-02	3.265-01	-2.215+01	-7.585-01	1.795-01	1.235-02	4.545-02	9.075-01	3.305+00	0.000+00	-5.135-01	6.455+00	3.335+01	2.451	4.303	4.405+00
Beryllium	2.655-01	3.995-07	1.375+02	5.145-05	6.435-03	1.925+00	-7.345-03	8.115-01	-1.045+00	-1.435-01	1.245-01	2.995-03	3.055-01	1.935-01	7.105-01	2.795-01	-7.655-02	4.325-01	1.485+00	6.217	2.447	9.435-01
Cadmium	1.835-02	4.085-09	4.835+00	2.345-06	2.935-04	1.345-01	-3.185-04	1.445-02	-4.475-01	-3.375-03	8.835-03	4.915-05	1.785-02	2.445-01	3.235-02	6.495-02	-3.505-03	0.005+00	4.535-01	2.121	4.303	4.275-02
Chromium	9.115-02	8.995-07	3.845+02	6.495-05	8.135-03	6.655-01	-1.135-02	2.805-01	-4.075+00	-3.045-01	1.805-01	6.945-03	2.135+00	2.445-01	8.935-01	9.345+00	-1.525-01	2.185+00	1.075+01	3.288	5.182	1.205+00
Manganese	3.175-02	1.365-04	1.325+02	-3.035-05	-3.795-03	2.315-01	-9.005-03	9.755-02	-1.375+01	9.095-02	1.965-01	1.105-02	3.605+00	-1.155-01	-4.185-01	1.535+01	-4.505-02	4.915+00	2.075+01	3.171	2.531	5.275-01
Nickel	1.835-02	1.455-04	6.435+02	8.995-05	1.135-02	1.335-01	-1.605-02	5.705-02	-2.875-01	-8.835-01	5.475-01	1.175-02	2.375+00	3.415-01	1.245+00	1.415+00	-1.695-01	1.175+00	9.375+00	2.709	5.182	1.665+00
Lead	5.535-02	1.075-03	3.545+01	2.495-04	3.375-02	4.045-01	-3.245-02	1.705-01	-1.635+01	-8.795-01	6.305-01	8.645-02	1.965-01	1.025+00	3.715+00	3.575-01	-5.425-01	4.655+00	1.735+01	2.583	5.182	5.095+00
Selenium	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
Mercury	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR

APPENDIX F:
QUALITY ASSURANCE AND QUALITY CONTROL

This section presents QA/QC results for the gas and solid stream samples. The blank analyses are presented as well as quality control results and reporting limits.

Table F-1 presents the results of blank analyses for gas stream samples. Field blank analyses were performed for metals and anions. A reagent blank was taken for the aldehydes.

Tables F-2 and F-3 present recovery results for a water and ash standard used for coal, bottom ash, and collected fly ash analyses.

Table F-4 presents spike recoveries for different organics sampled at Site 114.

Table F-1
Summary of Blank Sample Results

Method	Number of Blank Samples Analyzed	Number of Detects	Quantity Detected (μg)	Reporting Limit (μg/dscm)
Multi-Metals			**Field Blank**	
Arsenic	1	1	3.6	0.3
Beryllium	1	1	1	0.03 to 6.2
Cadmium	1	1	12.5	0.03 to 6.2
Chromium	1	1	5	0.03 to 6.2
Manganese	1	1	8.6	0.03 to 6.2
Nickel	1	1	10	0.03 to 6.2
Lead	1	1	5.1	0.03 to 6.2
Selenium	1	1	3.3	0.3
Mercury	1	1	2	0.03 to 6.2
Anions				
Chloride	2	0	NR(100)	100 μg
Fluoride	2	0	--	--[a]
Aldehydes			**Reagent Blank**	
Formaldehyde	1	0	NR(0.5)	0.5 μg
Acetaldehyde	1	0	NR(0.5)	0.5 μg

[a]Reporting limit not available.

Table F-2
Summary of Quality Control Sample Results for Coal, Bottom Ash, and Collected Fly Ash (Diluted Aqueous Solution)

Parameter	Certified Measurement (μg/L) NIST SRM Metals Solution	Recovery %
Arsenic	200	110
Beryllium	10	80
Cadmium	100	96
Chlorine	1,000	86
Chromium	100	95
Lead	100	67
Manganese	100	91
Nickel	100	108
Selenium	500	114

Table F-3
Summary of Quality Control Sample Results for Coal, Bottom Ash, and Collected Fly Ash

Parameter	Certified Measurement (ppm) NIST SRM Fly Ash	Recovery %
Arsenic	145	66.2
Cadmium	1.0	Below Reporting Limit
Chromium	196	77.6
Lead	72	58.3
Manganese	179	88.6
Mercury	0.16	Below Reporting Limit
Nickel	127	89
Selenium	10	Below Reporting Limit

Table F-4
Summary of Isotopic Recovery Results

Compound	Mean Spike Recovery (%)	Measured Precision (% CV)	No. of Spikes
Stack Gas			
Volatile Organics			
Benzene-d6	37	108	40
PAHs			
Benzo(a)pyrene-d12	93	3	--[a]
Aldehydes (trip spikes)			
Formaldehyde	95	--	4
Acetaldehyde	90	--	4
Lab Spikes			
Volatile Organics			
Toluene-d8	97	10.3	--
Benzene (15L breakthrough check)	95	--	--
PAHs			
Nitrobenzene-d5	91	13.2	--
2-Fluorobiphenyl	95	5	--
Terphenyl-d12	92	5	--
Aldehydes			
Formaldehyde	100	--	--
Acetaldehyde	87	--	--

[a]Data not available.