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FIELD CHEMICAL EMISSIONS MONITORING PROJECT:

SITES 19 EMISSIONS MONITORING

EPRI Project RP3177-7

April 1993

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FIELD CHEMICAL EMISSIONS MONITORING PROJECT: SITE 19 EMISSIONS REPORT

PRELIMINARY REVIEW DRAFT

Prepared for:

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21 April 1993

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

April 21, 1993

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 at least 24 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 19. Site 19 consists of a pulverized coal-fired boiler burning a bituminous coal and an electrostatic precipitator (ESP). The Site 19 sampling and analysis project was equally sponsored by EPRI and the host utility. The project budget was not sufficient to complete the entire PISCES sampling and analytical protocol. The primary interest was a select group of the trace metals and anions at the ESP outlet. **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 19 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 19 with the results from previous utility sites.

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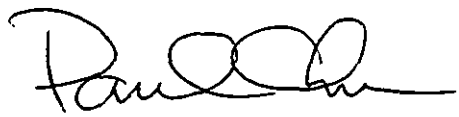
Generic conclusions and recommendations were not drawn concerning the effectiveness of an electrostatic precipitator as a potential control technology for trace elements; however, removal efficiencies were calculated where possible. Nor does this site report attempt to address the environmental and health 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 Control
Environment Division

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Section 1

INTRODUCTION

This report summarizes data gathered by Radian Corporation at a power plant designated Site 19. This program was sponsored by the Electric Power Research Institute (EPRI) and the host utility. The objective of the Field Chemical Emissions Monitoring Project (FCEM) sponsored by EPRI (RP-3177) is to measure the concentrations of selected inorganic and organic substances in the process and discharge streams of power plants. These data are being used to determine the fate and control of these substances.

The primary objectives of this report are to provide information on fuel composition and stack emissions and to evaluate these data according to the criteria outlined below. The information is presented in a format suitable for the U.S. Environmental Protection Agency (EPA) to use to study emissions from fossil-fuel-fired power plants, as mandated by the Clean Air Act Amendments (CAAA) of 1990. This report summarizes fuel and stack gas concentration data measured during the operation of an opposed wall-fired boiler burning low-sulfur bituminous coal. Emissions were controlled by an electrostatic precipitator. Sampling was conducted during March of 1992.

The Site 19 sampling and analysis effort was equally funded by EPRI and the host utility. The budget was not sufficient to allow for the complete FCEM sampling and analytical protocol. The primary interest was a select group of trace metals and anions at the ESP outlet.

Table 1-1 lists the substances of interest to the FCEM project. The substances chosen for study at Site 19 are identified with an asterisk in Table 1-1. Unlike most of the other FCEM sites, only coal and flue gas samples were collected at Site 19; therefore, material balances could not be performed. In addition, the target analyte list for Site 19 did not include any of the organic compounds measured in other FCEM sampling efforts. Radian Corporation conducted the testing and has prepared this report using the following procedures to evaluate the data:

- The type and quantity of quality assurance samples were reviewed to determine the confidence that can be placed in the results; and
- The QA/QC results were compared with data quality objectives to evaluate precision and accuracy.

Results are presented for each substance by individual run and as an averaged total. To demonstrate data variability, the 95% confidence interval about the mean is also

Table 1-1

FCEM Substances of Interest

Elements	Organic Compounds
Arsenic*	Benzene
Barium	Toluene
Beryllium	Formaldehyde
Cadmium*	Polycyclic Organic Matter (POM) [a]
Chlorine (as chloride)*	
Chromium*	
Cobalt	
Copper*	
Fluorine (as fluoride)*	
Lead	
Manganese*	
Mercury*	
Molybdenum	
Nickel*	
Phosphorus	
Selenium*	
Vanadium	

[a] Also referred to as semivolatile organic compounds. Includes polynuclear aromatic hydrocarbons (PAHs).

*Denotes a target substance for the Site 19 study. (Data for other substances are also available because of the multi-element techniques employed.)

presented. The confidence interval incorporates the combined process, sampling, and analytical variabilities.

Process Operation

The unit operated at full load during each test run. No unusual process upsets were encountered, and particulate emissions were well below compliance limits. By all indications, process operation during testing was representative of normal operation for this unit.

Sampling and Analysis Protocol

The sampling and analysis protocol for Site 19 is described in Appendix A. The methods used are comparable to those used at other FCEM sites sampled by Radian, with the following exceptions:

- In addition to INAA analysis (employed at other FCEM sites), coal samples were analyzed for metals by ICP-AES and GFAAS.
- In addition to ICP-AES analysis (employed at other FCEM sites), flue gas samples were analyzed for chromium and nickel using GFAAS.

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

The completeness of the quality assurance data was reviewed to judge whether the quality of the measurement data could be evaluated with the available information. In general, the results of the QC checks available for Site 19 indicate that the samples are well characterized. An evaluation of the accuracy, precision, and bias of the data, even if only on a qualitative level, is considered to be an important part of the data evaluation. A full discussion of each of these components can be found in Section 4.

Standard QA/QC checks for this type of sampling program involve the use of: 1) replicate tests, duplicate field samples and lab analyses, and matrix spike and lab control duplicates to determine precision; 2) matrix spikes, surrogate spikes, and laboratory control samples to determine accuracy; and 3) field blanks, trip blanks, method blanks, and reagent blanks to determine if any of the samples were contaminated during collection or analysis. Most of these standard QA/QC checks were used on samples from Site 19, except for surrogate spikes (which do not apply to metals and anions analyses) and the duplicate analysis of samples. The absence of any of these "standard" quality control checks does not necessarily reflect poorly on the quality of the data but does limit the ability to measure the various components of measurement error.

Data Quality

The QA/QC results were compared to the data quality objectives shown in Section 4. QA/QC results outside the data quality objectives are noted and discussed, other quality

assurance values are evaluated, and the potential effect on data quality is noted. Based on the detailed information presented in Section 4, the following conclusions can be made:

- Cadmium concentrations in flue gas particulate samples may be biased low, leading to a potential underestimate of particulate phase cadmium emissions.

- Arsenic and selenium concentrations measured in the coal by GFAAS may be biased low; therefore, INAA was selected as the primary technique for analyzing for these elements in the coal.

- Measured concentrations of vapor phase manganese may be artifacts, caused by the contamination of impinger solutions; therefore, the vapor phase results were excluded from the manganese emission calculations.

Report Organization

Section 2 of this report briefly describes the plant and the sample locations. Section 3 discusses the chemical analysis of the coal and stack gas. Section 4 presents QA/QC and engineering evaluations of the data. Section 5 presents example calculations, and a glossary of terms is provided in Section 6. The appendices contain information on sampling and analytical methods, stream concentrations, sampling data, error propagation equations, and detailed QA/QC data.

Section 2

SITE DESCRIPTION

The FCEM project has a policy of giving a site code to each plant sampled. This plant has been designated Site 19. The test site and the sampling locations are described in this section.

Facility Information

Two coal-fired units are located at Site 19. Testing was performed on Unit 1; the configuration of the unit is summarized in Table 2-1. The opposed wall-fired, super-critical boiler was designed by Babcock and Wilcox. The furnace consists of a single chamber with no partition.

Figure 2-1 is a process flow diagram of Unit 1. The plant burns bituminous coal from western Virginia and Kentucky. Historically, some of the coal is cleaned by flotation at the mines by the vendors to maintain consistent quality. The delivered coal has a typical ash content of less than 10% and a typical sulfur content of less than one percent. Four different mines supplied the coal during the test period, and the coal shipments received (and burned) during testing are summarized in Table 2-2.

Bottom ash is removed from the boiler by an ash sluicing system, and electrostatic precipitators (ESPs) remove fly ash from the flue gas. The flue gas treatment and ash removal facilities are described in greater detail below.

Flue Gas Treatment Facilities

Unit 1 is equipped with two cold-side ESPs, with weighted wire discharge electrodes. The design specific collection area (SCA) is 305 $ft^2/10^3$ acfm. Each ESP has two outlet ducts through which flue gas flows to induced draft fans (four fans in all) and into the Unit 1 stack. The unit is equipped with a conditioning system that injects SO_3 into the flue gas upstream of the ESPs to improve performance. The SO_3 injection is operated automatically with a computer-controlled feedback system that maintains an ESP spark rate of about ten per minute. The injection rate was not regularly monitored, but typical injection levels during the test period were between 4 and 11 ppmv SO_3 based on several random readings. Separate conditioning systems are used for the A-side and B-side ESPs.

Ash Removal Facilities

Dry fly ash collected by the ESPs is pneumatically conveyed to ash silos. A portion of the ash is sold and the remainder is trucked to a nearby landfill. Lake water is used to

Table 2-1

Unit 1 Summary

Maximum Gross Electrical Output (MW):	1,160
Particulate Emission Limits (lb/10^6 Btu):	0.15
SO_2 Emission Limits (lb/10^6 Btu):	2.3
Air Pollution Controls:	Cold-Side ESPs
ESP Design SCA ($ft^2/10^3$ acfm):	305
Design ESP Efficiency (%):	99.7
Boiler Type:	Opposed Wall-Fired, Supercritical
Boiler Additives:	None
NO_x Control:	None
Design Fuel Feed Rate (ton/hr, dry):	350
Fuel Type:	Bituminous Coal
Fuel Sulfur Content (% dry):	0.9[a]
Fuel Ash Content (% dry):	9[a]
Fuel Heating Value (Btu/lb, dry):	13,500[a]
Fly Ash Disposal:	Landfill
Bottom Ash Disposal:	Pond
Bottom Ash Sluice Water Source:	Lake
Cooling Water System:	Once Through
Cooling Water Source:	Lake

[a]Mean values measured during sampling.

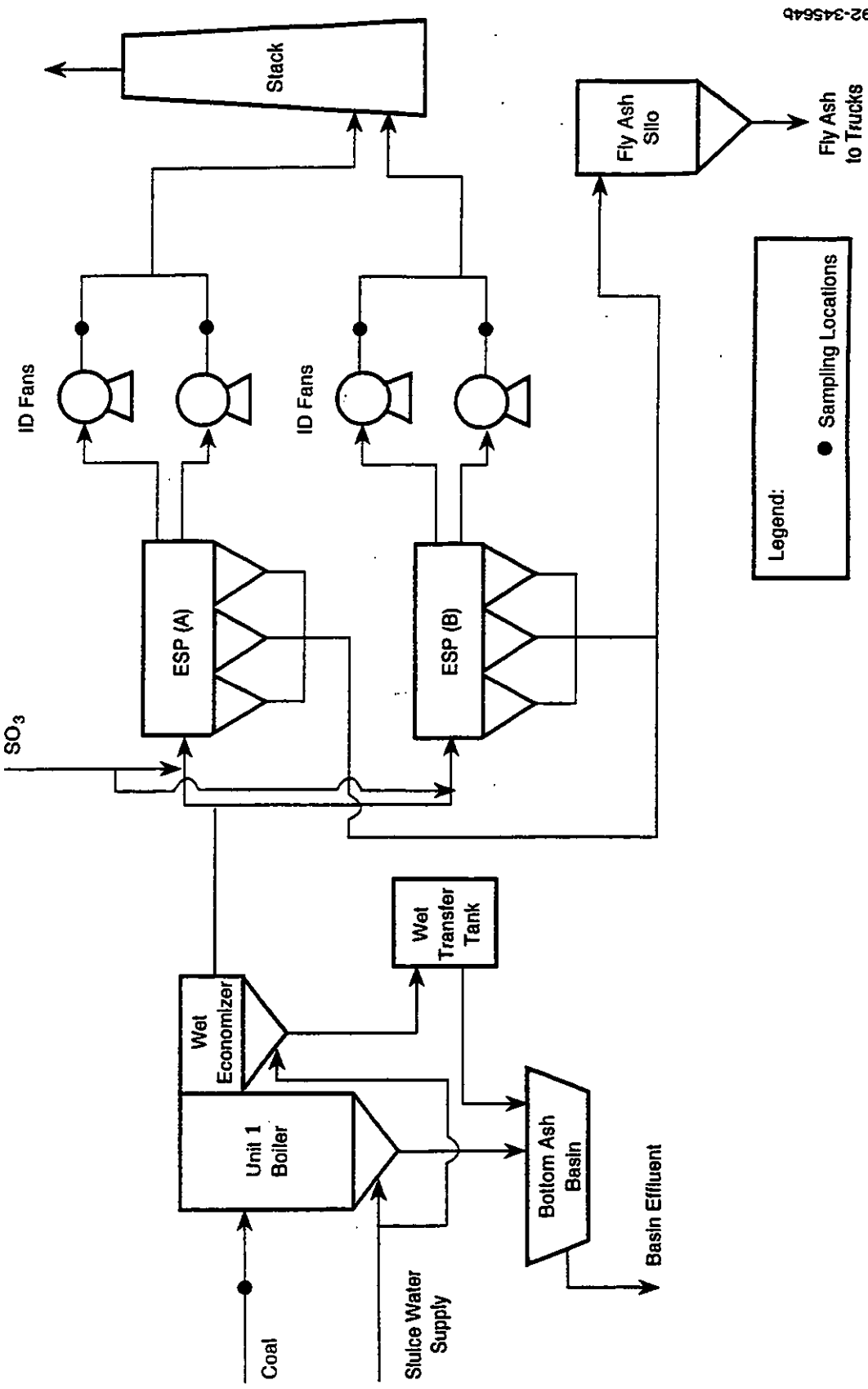


Figure 2-1. Process Flow Diagram and Sampling Locations for Site 19

Table 2-2

Coal Shipments Received and Fired During Testing[a]

Date	Source	Moisture, %	Ash, %	Sulfur, %	Btu/lb
3/09/92	Mine #1	6.85	8.40	0.76	12,364
3/10/92	Mine #2	8.35	8.76	0.76	12,490
3/11/92	Mine #1	6.71	8.32	0.83	12,468
3/11/92	Mine #3	8.37	8.09	1.18	12,601
3/12/92	Mine #1	6.11	8.75	0.81	12,493
3/12/92	Mine #4	7.95	9.52	0.90	12,709
3/13/92	Mine #1	5.72	8.12	0.83	12,669

[a]All values are reported on an as-received (wet) basis.

sluice bottom ash from the boiler to an ash basin. Ash collected in the economizer and primary air heater is also sluiced to the ash basin, along with the pyrites rejected from the coal pulverizers.

Sampling Locations

Samples of two streams (coal and ESP outlet gas) were collected from Unit 1. The sampling locations are identified on the process flow diagram, Figure 2-1.

- Coal samples were collected from the two belts that convey coal into the top of the storage bunkers for each of the ten mills. Because the samples were collected upstream of the mills, they were taken before the rejection of pyrites. Coal samples taken from this location are considered to be more representative than the plant daily composite, which would have included coal fed to the other unit as well as coal fed during long periods of operation when flue gas samples were not collected.

- Samples of the flue gas exiting the ESPs were collected from the vertical ducts (four ports in each duct) atop each of the four induced-draft fans. These ports are used by the plant for particulate compliance testing; no ports were available on the stack.

The procedures for collecting, pretreating, and analyzing the samples are discussed in Appendix A. Table 2-3 presents an overview of the types of analyses performed on these streams.

Table 2-3

Process Stream Analyses Performed

Stream	Metals[a]	Anions[b]
Coal	✓	✓
ESP Outlet Gas	✓	✓

[a]"Metals" include the target species arsenic, cadmium, chromium, copper, manganese, mercury, nickel, and selenium. Data for other species are also available because of the multi-element techniques employed.

[b]"Anions" include the target analytes chloride and fluoride, as well as sulfate.

Section 3

RESULTS

This section summarizes the results of the coal characterization and gas stream analyses. Sampling, preparation, and analytical methods are summarized in Appendix A. Detailed analytical data can be found in Appendices B and C.

Sampling Schedule

Site 19 was sampled in March, 1992. Two types of sampling trains were used to collect flue gas samples from the ESP outlet ducts. Multi-metals trains were used to traverse each of the four ducts during each sampling run. Anions trains were used to collect samples at single points of average velocity in each of the four ducts.

Figure 3-1 presents the actual sampling schedule. As shown in the figure, three valid runs (numbered Runs 2-4) of multi-metals and anions trains were completed. Sampling problems voided Run 1 multi-metals and anions samples.

Data Treatment

Several conventions have been developed for treating the test data and developing average concentrations of substances in the various streams.

To determine the total gas concentration for each run, both the solid and vapor phase contributions were considered. However, the absence of some reportable concentrations in either (or both) phases required that conventions be developed for dealing with these data and formulating emission factors. These conventions are summarized below.

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

Case 1: The concentrations in both the solid and vapor phases are above reporting limits.

Case 2: The concentrations of both the solid and vapor phase are below the reporting limits.

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

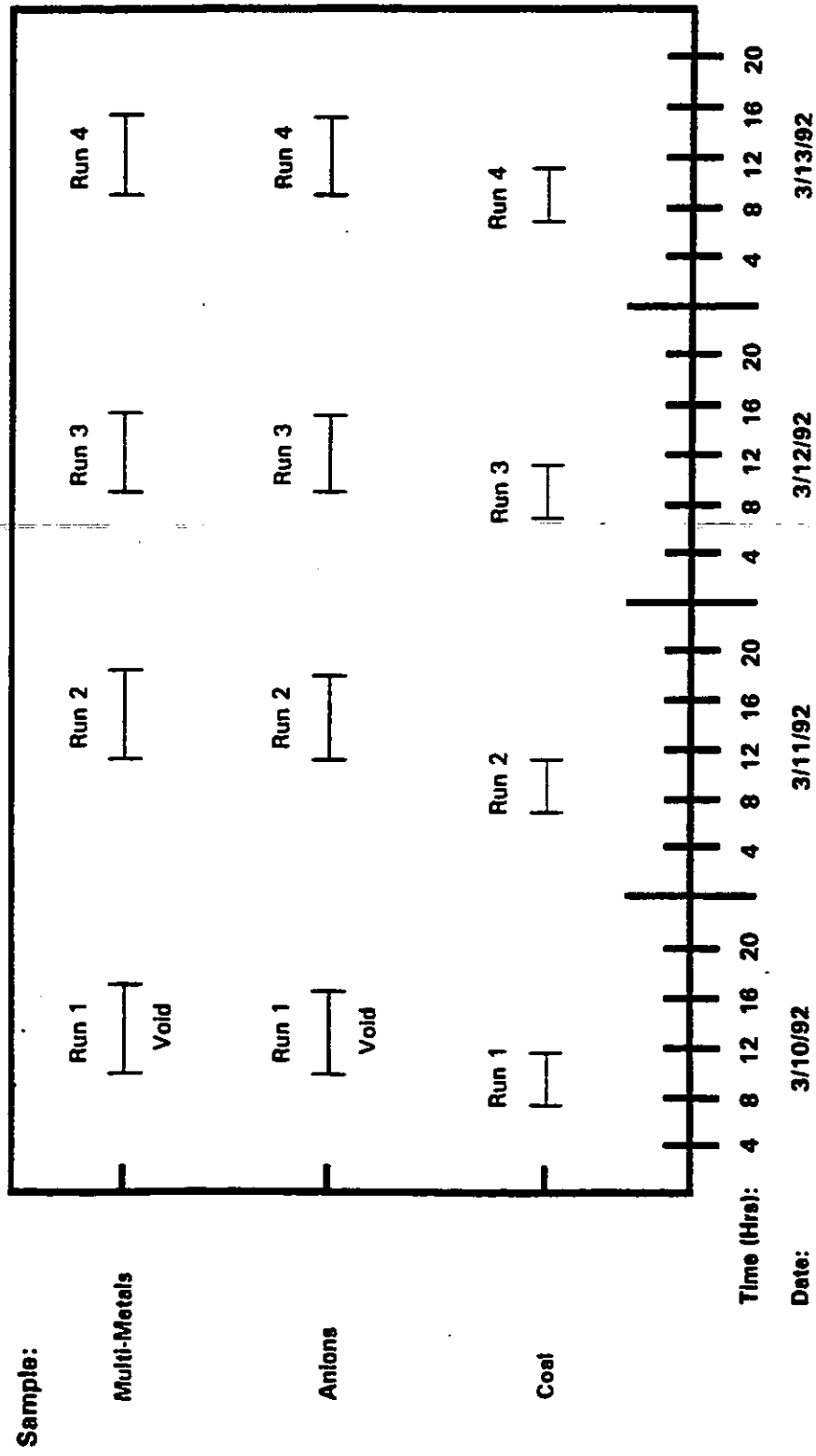


Figure 3-1. Sampling Schedule for Site 19

For constituents of interest other than HCl, HF, and mercury, the flue gas stream data from previous studies of coal-fired power plants have indicated that most of the material is present in the solid phase and that only a small fraction is generally found in the vapor phase. Thus, the following conventions were selected for defining the total gas stream concentrations:

For Case 1, the total concentration is the sum of the concentrations in the vapor and solid phases.

For example, the total chromium concentration in the ESP outlet gas for Run 2 is calculated as follows:

Cr in solid phase = 14 $\mu g/Nm^3$

Cr in vapor phase = 1.9 $\mu g/Nm^3$

Total Cr in ESP outlet gas = 15.9 $\mu g/Nm^3$

For Case 2, the total concentration is considered to be the reporting limit in the solid phase. (This case is not represented by the data in this report.)

For Case 3, the total concentration is considered to be the one above the reporting limit, regardless of which phase this represents.

For example, the arsenic concentration in the ESP outlet gas is calculated as follows for Run 2:

As in solid phase = 8.6 $\mu g/Nm^3$

As in vapor phase = NR(0.98 $\mu g/Nm^3$)

Total As in ESP outlet gas = 8.6 $\mu g/Nm^3$

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

Testing at several sites has indicated that HCl, HF, and mercury are present primarily in the vapor phase. For Case 2, then, the total concentration is considered to be the reporting limit in the vapor phase. For Cases 1 and 3, the methodologies are unchanged from those described above.

The following criteria were used when averaging the results of different runs:

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

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

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

By convention, the calculated mean is not allowed to be smaller than the largest reporting limit value. In the following example, using one-half the reporting limit would yield a calculated mean of 2.8. This is less than the highest reporting level obtained, so the reported mean is NR(4).

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

- When all analytical results for a given variable are below the reporting limit, the mean is reported as NR(x), where x is the largest reporting limit. The bias estimate (used in calculating confidence intervals for other parameters) is one-half of the reporting level, and no confidence interval is reported.

None of the data contained in this report have been corrected for the blank results. Blank values were very low compared with the concentrations found in actual samples; therefore, blank correction was not warranted. Detailed information on blank samples can be found in Appendix F.

Coal

Table 3-1 shows the analytical results for the coal samples. Appendix A presents the analytical method used for each combination of substance and stream. The concentrations reported here were measured using what Radian considered to be the best method for each matrix. Typically, the method with the lowest reporting limit was chosen, except when QA/QC data indicated significant problems with precision or bias for a particular technique. For each substance, a mean concentration has been calculated, along with the 95% confidence interval about the mean. The confidence interval is the range about the mean wherein the probability is 95% that the true mean lies. For example, it can be said, with 95% certainty, that the true mean arsenic concentration in the coal is between 1.8 and 9.6 mg/kg, according to the three results shown in Table 3-1. The calculation of this confidence interval is discussed in Section 5 and in Appendix E.

Arsenic and selenium concentrations in the coal were measured using instrumental neutron activation analysis (INAA). Cadmium, chromium, copper, manganese, and nickel concentrations were measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Chloride concentrations were measured by potentiometric

Table 3-1

Site 19 Coal Composition (mg/kg Unless Noted)

Substance	Run 2	Run 3	Run 4	Mean	95% CI
Gross Load (MWe)[a]	1,161	1,157	1,164	1,161	15
Coal Rate (lb/hr, dry)	698,000	692,000	692,000	694,000	8,600
HHV (Btu/lb, dry)	13,459	13,504	13,437	13,467	85
Ash (%, dry)	8.3	8.9	10	9.1	2.1
Moisture (%)	6.3	5.8	6.1	6.1	0.6
Sulfur (%, dry)	0.82	1.0	0.98	0.94	0.25
Arsenic	4.2	5.6	7.3	5.7	3.9
Cadmium	NR(0.40)[b]	NR(0.40)	NR(0.40)	NR(0.40)	--
Chloride	610	840	640	700	310
Chromium	14	15	17	15	3.8
Copper	16	16	18	17	2.9
Fluoride	130	90	53	91	93
Manganese	5.0	6.0	11	7.3	8.0
Mercury	0.10	0.10	0.11	0.10	0.014
Nickel	12	12	12	12	0
Selenium	3.7	4.0	4.0	3.9	0.46

[a] Full load is approximately 1,160 MW.

[b] NR = Below reporting limit; the reporting limit is shown in parentheses. The "reporting limit" is the concentration below which results are not routinely reported. The reporting limit is set at a concentration representing an upper tolerance for the method detection limit (MDL). As described in Appendix B to 40 CFR 136, the MDL is a value that is calculated from a series of measurements made at a particular point in time under a particular set of conditions; it is not an intrinsic characteristic of a method. Thus, for a given method, the numerical value of the MDL will vary somewhat with each determination. Likewise, MDLs would be expected to vary somewhat among instruments, among analysts, and among laboratories all using the same method. Thus, the reporting limit, as the upper tolerance for the MDL, represents a laboratory-specific value below which the MDL would be expected to fall for any determination in that particular laboratory, regardless of instrument, analyst, etc. An individual laboratory reporting limit cannot be used for regulatory applications, because it does not include the random bias inherent in a multi-laboratory method evaluation.

CI = Confidence interval.

titration. Fluoride concentrations were measured using an ion selective electrode. Mercury concentrations were measured using double gold amalgamation (DGA) with cold vapor atomic absorption spectrophotometry (CVAAS).

For those substances that could not be quantified, the notation "NR(x)" is used. This term means "not reported at a concentration of x." The reporting limit can vary according to sample size, sample preparation, and analytical method (see footnote in Table 3-1 for additional details about the reporting limit).

ESP Outlet Gas

Table 3-2 presents the concentration of the target analytes in the ESP outlet gas. All four ESP outlet ducts were sampled during each test run; samples were combined before analysis to obtain emissions representative of the unit as a whole. The data are presented as solid and vapor compositions, along with the mean concentrations and confidence intervals of the combined phases. Five of the target metals (chromium, manganese, mercury, nickel, and selenium) show measurable concentrations in the vapor phase. However, the measured manganese concentrations are believed to have resulted from contamination of the multi-metals impinger solutions. This is discussed more fully in Section 4. Vapor phase manganese results are not considered valid, and they have been excluded from calculation of the mean concentration and the emission factor for manganese.

Arsenic, cadmium, chromium, nickel, and selenium concentrations in the flue gas were measured using GFAAS. Copper and manganese concentrations were measured using ICP-AES. Chloride concentrations were measured using ion chromatography, and fluoride levels were measured using an ion selective electrode. Mercury concentrations were measured by CVAAS.

Table 3-3 presents the emission factors, on a unit energy basis, for the target analytes. Mean particulate emissions were 0.036 $lb/10^6$ Btu. Chloride (75,000 $lb/10^{12}$ Btu) and fluoride (5,800 $lb/10^{12}$ Btu) have the highest emission factors, which is expected because the vapor-phase species (HCl and HF) are not effectively removed by the ESP, and because the concentrations of chloride and fluoride in the coal are higher than the other target species.

Other Species Detected

Other substances not on the target analyte list, but which are listed in Title III of the Clean Air Act Amendments of 1990, were also measured. Additional Title III substances include antimony, beryllium, and cobalt. The concentrations of these elements in the coal and ESP outlet gas are shown in Table 3-4. These elements were measured as part of the multi-element techniques used to measure the target elements.

Table 3-2

Site 19 ESP Outlet Gas Composition
($\mu g/Nm^3$ Unless Noted)

	Solid Phase			Vapor Phase				
Substance	Run 2	Run 3	Run 4	Run 2	Run 3	Run 4	Mean	95% CI
Gross Load (MWe)	1,161	1,157	1,164				1,161	15
Gas Flow (dscfm)[a]	2,460,000	2,570,000	2,560,000				2,530,000	150,000
Gas Flow (Nm^3/hr)[b]	3,890,000	4,070,000	4,050,000				4,000,000	240,000
Particulate (lb/hr)	390	350	290				340	130
Particulate (mg/Nm^3)	45	39	32				39	16
Arsenic	8.6	9.5	7.1	NR(0.98)	NR(1.1)	NR(0.99)	8.4	3.0
Cadmium	0.10	0.24	0.078	NR(0.25)	NR(0.28)	NR(0.25)	0.14	0.21
Chloride	NR(0.97)[c]	53	78	64,000	105,000	68,000	79,000	56,000
Chromium	14	12	10	1.9	2.0	1.8	14	5.3
Copper	14	13	10	NR(4.9)	NR(5.5)	NR(5.0)	13	5.2
Fluoride	19	63	93	5,700	5,000	7,500	6,100	3,200
Manganese	6.4	4.9	5.9	100[d]	16[d]	12[d]	5.7	1.9
Mercury	0.0062	0.0069	0.0074	7.2	6.4	6.0	6.6	1.5
Nickel	8.8	7.8	7.1	1.4	NR(0.83)	NR(0.75)	8.4	4.1
Selenium	5.8	6.6	4.0	226	140	430	270	370

[a] 1 atm, 68°F (dry).
[b] 1 atm, 0°C (dry).
[c] NR = Below reporting limit. Reporting limit is shown in parentheses.
[d] Apparent vapor phase manganese may be due to contamination. Values have been excluded from statistical calculations. See Section 4 for discussion.
CI = Confidence interval.

Table 3-3

Site 19 Emission Factors
(lb/10^{12} Btu Unless Noted)

Substance	Combined Mean	95% CI
Gas Flow (dscfm)	2,530,000	150,000
Gas Flow (Nm^3/hr)	4,000,000	240,000
Coal Flow (lb/hr, dry)	694,000	8,600
Heating Value (Btu/lb, dry)	13,467	85
Particulate (lb/10^6 Btu)	0.036	0.014
Arsenic	7.9	2.9
Cadmium	0.13	0.20
Chloride	75,000	53,000
Chromium	13	5.1
Copper	12	5.0
Fluoride	5,800	3,100
Manganese	5.4[a]	1.8
Mercury	6.2	1.5
Nickel	7.9	4.0
Selenium	260	350

[a]Does not include vapor phase manganese results, which are suspected to be contaminated.

CI = Confidence interval.

Table 3-4

Other Elements Detected

Substance	Solid Phase Run 2	Solid Phase Run 3	Solid Phase Run 4	Vapor Phase Run 2	Vapor Phase Run 3	Vapor Phase Run 4	Mean	95% CI
ESP Outlet Gas ($\mu g/Nm^3$)								
Antimony	0.47	0.39	0.35	NR(0.76)	1.9	1.7	0.41	0.15
Beryllium	1.1	1.0	0.72	NR(0.49)	0.55	0.50	0.95	0.53
Cobalt	4.3	4.2	2.8	NR(2.5)	2.8	2.5	3.8	2.1
Coal (mg/kg)								
Antimony	0.60	0.53	0.76				0.63	0.29
Cobalt	6.6	6.5	6.1				6.4	0.64

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 19, three methods were used to evaluate data quality. First, the process data were examined to determine if the unit was operating at normal, steady-state conditions during the sampling periods. Second, the QA/QC protocol for sampling and analytical procedures used at Site 19 (i.e., equipment calibration and leak checks, duplicates, blanks, spikes, standards, etc.) were evaluated. Site 19 QA/QC data were compared with FCEM project objectives. Third, the feed rates of substances in the fuel were compared with the emission rates of those substances. For those substances that are almost completely vaporized within the boiler and remain in the vapor phase of the flue gas, such as chloride, fluoride, and mercury, the emission rates should be comparable to the feed rates. For those substances primarily associated with the particulate matter, emission rates should be much lower than the feed rates, because of the removal of particulate matter by the ESP.

Process Operation

Process operation data were examined to ensure that operation was stable during sampling periods. Measurements were available from two sources: 1) the plant computerized data acquisition system, which stored parameters every two minutes, and 2) flue gas sampling data sheets. The key parameters are shown in Table 4-1. The coefficients of variation (CVs) were calculated (for each of the parameters available in two-minute intervals) to determine process variability. In addition, process trend plots are included in Appendix G.

No major process upsets were encountered during the sampling effort. The unit maintained steady, full-load operation throughout each of the test runs. Boiler operation was stable, as indicated by the low CVs for the gross load, coal feed rate, and economizer outlet O_2 concentration. The ESPs were performing well, maintaining opacities in each ESP outlet duct well below compliance limits, and opacity CVs were less than 20 percent.

Sample Collection

Several factors indicate acceptable sample collection. Key components of the sampling equipment--pitot tubes, thermocouples, orifice meters, dry gas meters, and sampling nozzles--were calibrated before use in the field, and those calibrations were checked at the end of sampling. These calibrations are on file at Radian Corporation. The methods used to collect metal and anion samples were comparable to those used at

Table 4-1

Summary of Process Monitoring Data

	3/11/92		3/12/92		3/13/92	
	Mean	CV [b] (%)	Mean	CV (%)	Mean	CV (%)
Data from Plant Acquisition System (2-min. intervals)						
Gross Load (MWe)	1,161	0.66	1,157	1.4	1,164	0.35
Coal Feed Rate (lb/hr wet)	745,000	0.80	735,000	1.8	737,000	0.90
Economizer Outlet O_2 Concentration (%)	2.5	2.6	2.5	3.6	2.5	3.5
ESP Outlet Duct Opacities (%):						
Duct A	9.8	9.0	8.5	9.7	8.2	7.2
Duct B	7.8	15	8.6	13	6.2	15
Duct C	12	17	13	15	9.2	18
Duct D	14	9.0	14	11	9.8	8.1
Data from Flue Gas Sampling						
ESP Outlet Duct Temperatures (°F):						
Duct A	303	--[a]	312	--	300	--
Duct B	280	--	277	--	275	--
Duct C	255	--	285	--	277	--
Duct D	256	--	254	--	257	--
ESP Outlet Duct O_2 Concentrations (%):						
Duct A	5.5	--	6.0	--	5.0	--
Duct B	5.5	--	6.0	--	5.0	--
Duct C	5.5	--	5.5	--	5.5	--
Duct D	5.5	--	5.5	--	5.5	--

[a]Single measurements.

[b]The coefficient of variance (CV) is the standard deviation divided by the mean. It is expressed here as a percentage.

other FCEM sites sampled by Radian. The sampling runs were well documented, and all flue gas samples were collected at rates of between 90 and 110% of the isokinetic rates. Sufficient data were collected using standard sampling and analysis methods to ensure acceptable data completeness and the comparability of the measurements.

Flue gas samples were collected from all four of the ESP outlet ducts. The samples were combined before analysis so that the measured emissions would represent the unit as a whole. Samples were collected from ports on the vertical ducts directly above the discharge of each of the four I.D. fans. These ports are used by the plant for particulate compliance testing; no ports were available on the stack.

Coal samples are considered to be representative of the coal fired during flue gas sampling. Coal samples were collected from the two belts that convey coal into the top of the storage bunkers for each of the ten coal mills. The residence time is approximately four hours in these bunkers, and coal sampling was started before flue gas sampling to account for this lag time. Coal samples were collected from the belts in preference to using the plant daily composite, which might have included coal being fed to the other unit, and which would have included long periods of operation during which flue gas samples were not collected.

The measured flow rates of flue gas and coal agree with a combustion calculation that uses the mean coal composition, the mean coal flow rate, and the mean oxygen concentration in the ESP outlet gas to predict a "theoretical" flue gas flow rate. This calculated flow rate agreed with the measured ESP outlet flow rate within 10 percent. In addition, the heat rate of the unit during the test period was calculated from the mean coal flow rate, the mean heating value of the coal, and the mean net electrical load. This heat rate, approximately 8,500 Btu/kw-hr, is in agreement with plant performance data.

Analytical Quality Control Results

Generally, the type of quality control information obtained pertains to measurement precision, accuracy (which included precision and bias), and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure 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

Table 4-2

Types of Quality Control Samples

QC Activity	Characteristic Measured
Precision	
Replicate samples collected over time under the same conditions	Total variability, including process or temporal, sampling, and analytical, but not bias.
Duplicate field samples collected simultaneously	Sampling plus analytical variability at the actual sample concentrations.
Duplicate analyses of a single sample	Analytical variability at the actual sample concentrations.
Matrix- or media-spiked duplicates	Sampling plus analytical variability at an established concentration.
Laboratory control sample duplicates	Analytical variability in the absence of sample matrix effects.
Surrogate-spiked sample sets	Analytical variability in the sample matrix but at an established concentration.
Accuracy (Including 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 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 analytical method, including reagents and equipment.
Reagent Blank	Blank effects from reagents used.

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. The precision and accuracy objectives are not necessarily derived from analyses of the same types of samples being investigated. 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 objectives 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. The results of these analyses can be found in Appendix F. Table 4-4 presents a summary of precision and accuracy estimates. Almost all of the quality control results met the project objectives.

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

- A standard fly ash sample (NIST 1633a) was submitted blind as a performance evaluation sample. Cadmium recovery in this sample was only 5% when analyzed by GFAAS. This may indicate a low bias for cadmium in flue gas particulate samples.

- A standard coal sample (SARM 20) was also submitted as a performance evaluation sample. The recoveries of arsenic and selenium in this sample were low when analyzed by GFAAS (68% and 50%, respectively). Therefore, INAA (which showed good recovery of arsenic and selenium in a standard coal sample) was selected as the primary analytical technique for arsenic and selenium in the coal.

- Selenium showed virtually no spike recovery in impinger solutions analyzed by GFAAS. However, the spike level was too low compared to the native level in the sample, so the recovery value is not meaningful.

A discussion of the overall measurement precision, accuracy, and blank effects is presented below for each measurement type.

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).

Table 4-3

Types of Quality Control Data Reported

Analysis	Precision					Accuracy				Blank			
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Standard Reference Material	Field Blank	Trip Blank	Method Blank	Reagent Blank
(Grouped by Source/Matrix)													
ESP Outlet Gas													
Metals - Vapor Phase	✓			✓	✓	✓		✓		✓	✓	✓	
Metals - Solid Phase	✓				✓			✓	✓	✓		✓	
Anions - Vapor Phase	✓			✓	✓	✓		✓		✓	✓	✓	
Anions - Solid Phase	✓				✓			✓				✓	
Coal													
Metals	✓	✓							✓				
Anions	✓	✓		✓	✓	✓		✓				✓	

Table 4-4

Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured	Objectives		Measured	
		Precision (% RPD)	Accuracy (% Recovery)	Precision (% RPD)	Accuracy (% Recovery)
Metals in Coal by INAA	Precision - Duplicate Samples Accuracy - Standard Reference Material				
Antimony		20	75-125	16	83
Arsenic		20	75-125	6.8	102
Cadmium		20	75-125	NC	NC
Chromium		20	75-125	7.3	95
Cobalt		20	75-125	7.0	92
Copper		20	75-125	NC	NC
Manganese		20	75-125	24	88
Nickel		20	75-125	NC	NC
Selenium		20	75-125	8.1	109
Metals in Coal by ICP-AES	Precision - Duplicate Samples Accuracy - Standard Reference Material				
Cadmium		20	75-125	NC	NA
Chromium		20	75-125	24	97
Copper		20	75-125	12	NA
Manganese		20	75-125	0	96
Nickel		20	75-125	15	100
Metals in Coal by GFAAS and CVAAS	Precision - Duplicate Samples Accuracy - Standard Reference Material				
Arsenic		20	75-125	20	68
Mercury		20	75-125	0	100
Selenium		20	75-125	20	50
Anions in Coal	Precision - Matrix-Spiked Duplicates Accuracy - Matrix Spikes				
Chloride		20	80-120	6.2	98
Fluoride		20	80-120	1.3	84

Table 4-4 (Continued)

Measurement Parameter	How Measured	Objectives: Precision (% RPD)	Objectives: Accuracy (% Recovery)	Measured: Precision (% RPD)	Measured: Accuracy (% Recovery)
Metals In ESP Outlet Solid Phase - ICP-AES	Precision - Replicate Runs Accuracy - Standard Reference Material				
Antimony		20	75-125	NC	86
Arsenic		20	75-125	9.2% CV	114
Beryllium		20	75-125	22% CV	98
Chromium		20	75-125	18% CV	99
Cobalt		20	75-125	22% CV	91
Copper		20	75-125	17% CV	99
Manganese		20	75-125	13% CV	87
Nickel		20	75-125	12% CV	96
Metals in ESP Outlet Solid Phase - GFAAS and CVAAS	Precision - Replicate Runs Accuracy - Standard Reference Material				
Antimony		20	75-125	15% CV	99
Arsenic		20	75-125	14% CV	100
Cadmium		20	75-125	61% CV	93
Chromium		20	75-125	17% CV	93
Mercury		20	75-125	8.9% CV	95
Nickel		20	75-125	11% CV	85
Selenium		20	75-125	24% CV	91
Metals in ESP Outlet Vapor Phase - ICP-AES	Precision - Matrix-Spiked Duplicates Accuracy - Matrix Spikes				
Antimony		20	75-125	3.0	94
Arsenic		20	75-125	0.87	91
Beryllium		20	75-125	1.3	96
Chromium		20	75-125	1.4	94
Cobalt		20	75-125	1.2	94
Copper		20	75-125	1.3	94
Manganese		20	75-125	1.3	94
Nickel		20	75-125	0.74	89

Table 4-4 (Continued)

Measurement Parameter	How Measured	Objectives		Measured	
		Precision (% RPD)	Accuracy (% Recovery)	Precision (% RPD)	Accuracy (% Recovery)
Metals in ESP Outlet Vapor Phase - GFAAS and CVAAS	Precision - Matrix-Spiked Duplicates Accuracy - Matrix Spikes				
Antimony		20	75-125	0.85	94
Arsenic		20	75-125	9.6	95
Cadmium		20	75-125	1.0	98
Chromium		20	75-125	1.9	93
Mercury		20	75-125	14	88
Nickel		20	75-125	3.7	89
Selenium		20	75-125	NC	0
Anions in ESP Outlet Gas	Precision - Matrix-Spiked Duplicates Accuracy - Matrix Spikes				
Chloride		20	80-120	12	88
Fluoride		20	80-120	20	94

NA = Not available.

NC = Not calculated; analyte concentration below reporting limit in two or more runs.

RPD = Relative percent difference.

CV = Coefficient of variance.

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

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

Representativeness expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition. The representativeness criterion is based on making certain that sampling locations 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 reporting analytical results in appropriate units. Data sets can be compared with confidence when the precision and accuracy are known.

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

Metals

Precision. The precision of metals analyses was estimated for coal samples using duplicate samples, which include a component of sampling variability. The precision objectives were met for all of the metals analyzed by INAA. For the metals analyzed by ICP-AES, GFAAS, and CVAAS, six out of eight met the precision objective of 20% RPD. The exceptions were chromium (24% RPD) and arsenic (29% RPD), indicating that, for these substances, the field samples may show greater variability than expected.

The precision of solid-phase metals analyses was estimated for ESP outlet particulate samples using replicate runs, which include a component of process variability as well as sampling variability. For the metals analyzed by ICP-AES, six out of eight met the precision objective, with only beryllium and chromium (both 22% CV) slightly above the objective. Five out of seven metals analyzed by GFAAS and CVAAS met the precision objective; the exceptions were cadmium (61% CV) and selenium (24% CV).

The precision of the vapor phase metals analyses was estimated for the ESP outlet gas samples using matrix-spiked duplicates. All of the analyses by ICP-AES, GFAAS, and CVAAS met the precision objective of 20% RPD.

Accuracy. The accuracy of the metals analyses was estimated for coal samples using standard reference coal samples. All of the metals analyzed by INAA in the reference sample were within the 75-125% accuracy objective. For metals analyzed by ICP-AES, GFAAS, and CVAAS, four out of six results met the accuracy objective. Potential accuracy problems were identified for arsenic (68%) and selenium (50%) analysis using GFAAS.

Matrix spikes were used to estimate the accuracy of metals analyses in ESP outlet vapor-phase samples. All eight of the metals analyzed by ICP-AES met the accuracy objective. For the metals analyzed by GFAAS and CVAAS, six out of seven results met the accuracy objective. Virtually no spike recovery was seen for selenium by GFAAS, but the spike levels were too low compared to the native levels in the samples, so the recovery data are not meaningful.

The accuracy of metals analyses was estimated for flue gas particulate samples using standard reference material (NIST 1633a fly ash). The matrix of the standard is not identical to that of the samples, especially since flue gas particulate samples are digested along with the filters. However, no better estimates of accuracy are available for these samples. The results show that the recoveries of all the metals analyzed by ICP-AES, GFAAS, and CVAAS were within the 75-125% accuracy objective.

Blank Effects. None of the target metals were detected above reporting limits in the trip or field blank impinger solutions used in the multi-metals sampling trains. No blank contamination problems were identified, thus no blank correction was applied to the vapor phase metals results.

Although no manganese contamination was identified in the field blank impinger solutions from Site 19, there is other evidence that the vapor phase manganese concentrations measured in this study may be artifacts of contamination. Most of the manganese was found in the second HNO_3/H_2O_2 impinger of the multi-metals train (rather than the first, as might be expected for a vapor-phase metal). Because the second HNO_3/H_2O_2 impinger is followed by impingers containing $KMnO_4$, manganese found in the HNO_3/H_2O_2 impinger may be due to back-mixing in the trains during sampling. Field blank results from another FCEM site (Site 18) have identified this potential problem; therefore, the vapor-phase manganese concentrations measured in this study are not considered valid.

Field blank filters and probe/nozzle rinses were analyzed for metals to determine possible contamination in the solid phase fraction of the ESP outlet gas samples. Of the target metals, only chromium was detected above the reporting limits, but the chromium level in the field blank is less than five times the reporting limit. The levels of target

metals in the field blank are not significant compared to the levels of these same metals in the actual samples; therefore, no blank correction was applied.

Anions

Precision. The precision of anions analyses of coal samples was estimated using matrix-spiked duplicates. The precision estimates for both chloride and fluoride met the objective of 20% RPD. The precision of anions analyses of ESP outlet gas samples was also estimated using matrix-spiked duplicates, and both chloride and fluoride analyses met the 20% precision objectives.

Accuracy. Matrix spikes were used to estimate the accuracy of anions analyses of coal samples. Both chloride and fluoride accuracy met the 80-120% objective. Matrix spikes were also used to estimate the accuracy of anions analyses of the ESP outlet gas samples, and both chloride and fluoride results met the 80-120% accuracy objective.

Blank Effects. Field blank and trip blank impinger solutions were analyzed for chloride and fluoride. Fluoride concentrations were below reporting limits in all blanks. Very low levels of chloride (less than twice the reporting limit) were found in the field blank H_2O_2 and $Na_2CO_3/NaHCO_3/H_2O_2$ impingers used in the anions sampling train. However, these concentrations were insignificant when compared to actual sample concentrations. There appear to be no blank contamination problems for anions.

Comparison of Inlet and Outlet Mass Rates

Because only samples of the coal and ESP outlet flue gas were collected at Site 19, material balances around the plant could not be performed. However, it is useful to compare the measured emission rates of the target substances with the mass rates of those substances entering the system with the coal. Table 4-5 shows this comparison. For substances that vaporize almost completely within the boiler and that are not expected to condense to a significant degree (such as chloride, fluoride, and mercury), the mass rates of substances in the coal and ESP outlet gas should be comparable, and for the Site 19 data, they are. A high percentage of the inlet selenium is also emitted, owing to its predominance in the vapor phase. For species primarily concentrated in the particulate phase, and which are effectively removed by the ESP, the percent of the inlet mass emitted should approach the percentage of total ash emitted. Arsenic, chromium, copper, manganese, and nickel show this type of behavior.

Table 4-5 also shows the estimated ESP efficiencies for removing the target species. Because no measurements were made on the ESP inlet gas, the mass rates of substances entering the ESP were assumed to be equal to the mass rates of the substances in the coal for chloride, fluoride, mercury, and selenium. For the other (less volatile) elements and total ash, 80% of the mass rate in the coal was assumed for the ESP inlet mass rate. This is consistent with an 80:20 fly ash-to-bottom ash ratio, which is typical for this type of boiler.

Table 4-5

Percent Emitted and Estimated Removal Efficiency for Target Substances

Substance	Percent Emitted (Out/In, %)	95% CI(%)	Estimated ESP Removal Efficiency (%)[a]
Ash	0.54	0.18	99.3
Arsenic	1.9	1.0	98
Cadmium	NC[b]	--	NC
Chloride	140	87	0[c]
Chromium	1.2	0.39	98.5
Copper	0.96	0.32	98.8
Fluoride	86	62	14
Manganese	1.0[d]	0.69	98.8
Mercury	81	15	19
Nickel	0.89	0.44	98.9
Selenium	88	120	12

[a]No measurements were made on the ESP inlet gas. Instead, the ESP inlet flow rates were estimated from the coal measurements. It was assumed that for total ash and the less volatile elements (all except Cl, F, Hg, and Se), 80% of the mass rate in the coal partitions to the ESP inlet gas. For Cl, F, Hg, and Se, the ESP inlet rate was assumed to be 100% of the mass rate in the coal.

[b]Not calculated because substance was below reporting limits in the coal.

[c]Calculated control efficiency was negative but is shown as zero.

[d]Does not include vapor-phase manganese results, which are suspected to be contaminated.

CI = Confidence interval.

Section 5

EXAMPLE CALCULATIONS

This section presents the methodology and sample calculations used to develop the results discussed in Section 3. Specifically, the calculation of stream flow rates, emission factors, mean values, and confidence intervals are presented.

Stream Flow Rates

Appendix D contains information about the stream flow rates measured at Site 19 during the sampling period. Coal feed rates were determined directly from plant meters, and values at two-minute intervals were obtained from the plant's computerized data acquisition system. The flow rates in the ESP outlet ducts were measured directly during sampling.

Means and Confidence Intervals for Stream Concentrations

The mean concentration and 95% confidence interval (CI) about the mean were calculated for each target substance in the coal and ESP outlet gas. The means were calculated according to the conventions listed in Section 3. Equations used to calculate 95% confidence intervals are presented in Appendix E. Example calculations are presented here for arsenic in the ESP outlet gas; these results were shown in Table 3-2.

The concentration data (in $\mu g/Nm^3$) given for arsenic, as shown in Table 3-2, are:

	Run 2	Run 3	Run 4
Solid Phase	8.6	9.5	7.1
Vapor Phase	NR(0.98)	NR(1.1)	NR(0.99)
Total	8.6	9.5	7.1

The mean is calculated from the individual run totals:

Mean = (8.6 + 9.5 + 7.1)/3

= 8.4

The sample standard deviation of the individual run totals is calculated:

$$S_p = \sqrt{\left[(8.6-8.4)^2 + (9.5-8.4)^2 + (7.1-8.4)^2\right] / 2}$$

$$= \quad 1.21$$

The standard deviation of the average is calculated according to Equation 6 in Appendix E for N = 3:

$$S_{\bar{p}} = 1.21/\sqrt{3}$$

$$= \quad 0.699$$

The bias error is found by root-sum-squaring the product of the bias error and the sensitivity from each run (see Equation 2 in Appendix E). According to the conventions listed in Section 3, no bias error is assigned to values above reporting limits, whereas a bias error of one-half the reporting limit is assigned to values below reporting limits. The sensitivity of the mean to each run in this case is 1/3.

$$\beta_r = \sqrt{(1/3 \times 0)^2 + (1/3 \times 0)^2 + (1/3 \times 0)^2}$$

$$= \quad 0$$

The total uncertainty in the result is found from Equation 1 in Appendix E:

$$U_r = \sqrt{\beta_r^2 + \left(t \times S_{\bar{p}}\right)^2}$$

$$= \sqrt{0^2 + (4.3 \times 0.699)^2}$$

$$= \quad 3.0$$

Thus, the result is reported as $8.4 \pm 3.0\ \mu g/Nm^3$.

Unit Energy Emission Factors

In addition to the gas-phase concentrations, unit-energy-based emission factors have been developed for each target substance. These values were determined by calculating the mass flow of a substance in the ESP outlet gas (mean concentration times mean flow rate) and dividing by the mean heat input to the boiler during testing. The mean heat input is the product of the mean coal flow rate and the mean higher heating value (HHV) of the coal.

As an example, the calculation of the emission factor for arsenic is presented. The mean coal flow rate is 694,000 lb/hr on a dry basis. The mean HHV of the coal is 13,467 Btu/lb on a dry basis. Multiplying the coal flow rate by the HHV gives a mean heat input of 9.3×10^9 Btu/hr. The mean arsenic mass flow through the stack (the product of the mean concentration, $8.4\ \mu g/Nm^3$, and the mean gas flow rate, 4,000,000 Nm^3/hr) is $3.4 \times 10^7\ \mu g$/hr or 0.074 lb/hr. When the mean mass flow rate is divided by the mean heat input, an emission factor of 7.9 lb/10^{12} Btu is obtained, as presented in Table 3-3.

The 95% confidence intervals for emission factors were calculated according to the equations presented in Appendix E. For each parameter (flue gas flow rate, concentration, coal flow rate, and HHV) the mean, standard deviation, number of points, and bias estimates were used to calculate the combined uncertainty in the mean emission factors.

Section 6

GLOSSARY

Btu	British Thermal Unit
CAAA	Clean Air Act Amendments
CVAAS	Cold Vapor Atomic Absorption Spectrophotometry
DGA	Double Gold Amalgamation
DQO	Data Quality Objective
dscfm	Dry Standard Cubic Feet per Minute (1 atm, 68°F)
ESP	Electrostatic Precipitator
FCEM	Field Chemical Emissions Monitoring
GFAAS	Graphite Furnace Atomic Absorption Spectrophotometry
HHV	Higher Heating Value
IC	Ion Chromatography
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
ID	Induced Draft
INAA	Instrumental Neutron Activation Analysis
ISE	Ion Selective Electrode
MDL	Method Detection Limit
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MW	Megawatt
NBS	National Bureau of Standards
NC	Not Calculated
Nm^3	Dry Normal Cubic Meter (0°C, 1 atm)
NR	Not Reported (below reporting limit)
PAH	Polynuclear Aromatic Hydrocarbons
POM	Polycyclic Organic Matter
QA/QC	Quality Assurance/Quality Control
RPD	Relative Percent Difference
RSD	Relative Standard Deviation

Appendix A

Detailed Sample Collection/Preparation/Analysis Tables

This appendix presents the methods used to collect and analyze each type of sample. Summary tables showing collection times and important observations for each of the samples are also included.

Multi-Metals Sampling Trains

Multi-metals samples were collected according to the procedure described in Section 3.1 of 40 CFR, Part 266, Appendix IX, with modifications as noted here. This method provides for the collection of a flue gas sample at isokinetic conditions while traversing the duct according to EPA Method 1. Particulate matter is collected on a filter (which is also used to determine particulate loading) and the vapor phase species are absorbed in an impinger train consisting of:

- Two impingers containing 5% HNO_3/10% H_2O_2, which are analyzed for all metals of interest; and
- Two impingers containing 4% $KMnO_4$/10% H_2SO_4, which are analyzed for mercury only.

The multi-metals method specifies that HNO_3/H_2O_2 impinger solutions be evaporated to near dryness prior to analysis. However, due to concern over the possible loss of volatile metals, this procedure was not followed. Instead, the impinger solutions were analyzed as recovered to avoid any loss of volatile metals. Filters were digested and combined with the digested probe and nozzle rinses prior to analysis.

The multi-metals method specifies that particulate matter be collected according to the extractive Method 5. However, space limitations at the ESP outlet prevented the use of a Method 5 probe. Instead, particulate matter was collected with an in situ Method 17 filter at the ESP outlet. A Teflon® transfer line connected the filter holder to the impinger train.

One train was used to collect a composite sample from the A and B ducts (i.e., the ducts were sampled sequentially with the same train). A second train was used to collect a composite sample from the C and D ducts. This allowed determination of separate particulate loadings in each pair of ducts. The corresponding fractions from each sampling train were combined before analysis.

After sampling, the glass nozzle was rinsed first with acetone, then with dilute nitric acid according to the multi-metals method. The Teflon® transfer line was rinsed with dilute nitric acid, and this rinse was added to the contents of the first impinger.

Anions Sampling Trains

Anions samples were collected using a Radian procedure designed for collection of HCl, HF, and SO_2. Particulate matter is captured on a filter and the acid gases are absorbed in an impinger train consisting of:

- Two impingers containing 10% H_2O_2; and
- Two impingers containing 2.5% Na_2CO_3/2.5% $NaHCO_3$/3% H_2O_2.

An in-situ Method 17 filter was used to collect anions samples at the ESP outlet. A Teflon® transfer line connected the filter holder to the impinger train. One train was used to collect a composite sample from the A and B ducts during each run. A second train was used to collect a composite sample from the C and D ducts. Single points of average velocity were sampled in each duct.

After sampling, the glass nozzle from each train was rinsed with a Na_2CO_3/$NaHCO_3$ buffer solution. The Teflon® transfer line was rinsed with a dilute H_2O_2, and this rinse was added to the contents of the first impinger.

The corresponding fractions from each train were combined before analysis. Filters were leached with the nozzle rinse solutions, and these solutions were analyzed for chloride, fluoride, and sulfate to determine particulate phase concentrations. Vapor phase concentrations were determined from analysis of the impinger solutions.

Coal Sample Collection

Coal samples were collected from the two belts which convey coal into the top of the storage bunkers for each of the ten mills. A single grab sample consisted of two scoops (approximately one pound per scoop) from each of the two belts. This procedure was repeated at periodic intervals during the test run, and the grab samples were combined to obtain a representative composite for each run.

Detailed Sample Collection/Preparation/Analysis Tables

Table A-1 lists the techniques used to collect, preserve, and handle the samples at Site 19. Analytical methods applied to coal samples are listed in Table A-2. Analytical methods for all other samples are listed in Table A-3.

Sample Collection Times

Table A-4 provides a summary of the flue gas samples collected during each day of testing, the time periods during which the samples were collected, and comments related to the samples. Table A-5 shows similar information regarding the collection of coal samples.

Table A-1

Sample Collection, Preservation, and Handling Techniques for Site 19

Stream	Collection Method	Fraction Description	Sample Handling & Preservation	Comments
Flue Gas Samples				
ESP Outlet Gas	Specified in Section 3.1 of 40 CFR, Part 266, Appendix IX [a]	Metals Probe and Nozzle Rinse	Acetone portion dried and weighed; nitric acid portion sealed and kept at ambient temperature.	Digested probe and nozzle rinses combined with digested filters prior to analysis.
		Metals Filter	Desiccated at room temperature to constant weight.	Separate filters used for A/B and C/D ESP outlet ducts; combined prior to analysis.
		Metals Impingers 1 & 2	Sealed and kept at ambient temperature.	
		Metals Impingers 3 & 4	Sealed and kept at ambient temperature.	Analyzed for mercury only.
	Radian Method	Anions Train	Sealed and kept at ambient temperature.	Analyzed for chloride, fluoride, and sulfate.
Solid Samples				
Coal	Grab/Composite	Ultimate, Proximate	Kept in sealed container; submitted "as collected."	Multiple grab samples collected during the test period were composited directly into buckets, coned and quartered to reduce sample size.
		Mercury	Kept in sealed container; submitted "as collected."	
		Metals except Mercury; Cl, F	Placed in sealed container in the field; air dried, ground prior to analysis.	

[a] 40 CFR, Part 266, Appendix IX, Section 3.1, "Methodology for the Determination of Metals Emissions from Hazardous Waste Incineration and Similar Combustion Processes," 1991.

Table A-2

Preparation Procedures and Chemical Analysis Methods Applied to Coal at Site 19

Component	Method Reference
Ultimate Analysis of Coal	
Ash	ASTM D3174
Carbon	ASTM D3178
Hydrogen	ASTM D3178
Nitrogen	ASTM D3179
Sulfur	ASTM D4239
Heating Value	ASTM D2015
Proximate Analysis of Coal	
Moisture	ASTM D3173
Ash	ASTM D3174
Volatiles	ASTM D3175
Fixed Carbon	Calculated
Target Elements by INAA	
Preparation	
Analysis by INAA	
Arsenic	Karr, Chapters 12 and 46
Cadmium	Karr, Chapters 12 and 46
Chromium	Karr, Chapters 12 and 46
Chlorine	Karr, Chapters 12 and 46
Copper	Karr, Chapters 12 and 46
Manganese	Karr, Chapters 12 and 46
Mercury	Karr, Chapters 12 and 46
Nickel	Karr, Chapters 12 and 46
Selenium	Karr, Chapters 12 and 46
Chlorine and Fluorine Analysis in Coal	
Preparation	
Oxygen Bomb Digestion	ASTM D2361/ASTM D3761
Analysis by Potentiometric Titration	
Chloride	SM 407C
Analysis by Ion Selective Electrode	
Fluoride	ASTM D3761
Cd, Cr, Cu, Mn, Ni in Coal	
Preparation	
Ashing at 500° C/Acid Digestion	EPA 340.2

Table A-2 (Continued)

Component	Method Reference
Analysis by ICP-AES	
Chromium	SW 6010
Copper	SW 6010
Manganese	SW 6010
Nickel	SW 6010
Analysis by GFAAS	
Cadmium	SW 7131
Arsenic and Selenium in Coal	
Preparation	
Oxygen Bomb Combustion/Acid Digestion	ASTM D3684
Analysis by GFAAS	
Arsenic	SW 7060
Selenium	SW 7740
Mercury Analysis in Coal	
Preparation	
Double Gold Amalgamation	Karr, Chapter 14
Analysis by CVAAS	
Mercury	Karr, Chapter 14
Additional Inorganic Analytes in Coal	
Preparation	
Analysis by INAA	
Aluminum	Karr, Chapters 12 and 46
Antimony	Karr, Chapters 12 and 46
Calcium	Karr, Chapters 12 and 46
Cobalt	Karr, Chapters 12 and 46
Iron	Karr, Chapters 12 and 46
Magnesium	Karr, Chapters 12 and 46
Potassium	Karr, Chapters 12 and 46
Sodium	Karr, Chapters 12 and 46
Titanium	Karr, Chapters 12 and 46
Zinc	Karr, Chapters 12 and 46

Karr, C. Jr., (ed)., "Analytical Methods for Coal and Coal Products."
SW is EPA SW-846, "Test Methods for Evaluating Solid Waste".
SM is "Standard Methods for the Examination of Water and Wastewater," 16th Edition.
ASTM is the American Society for Testing and Materials.

Table A-3

Preparation Procedures and Chemical Analysis Methods for Inorganic Chemical Components in Flue Gas at Site 19

Component	Method Reference	ESP Outlet Solids	Metals Impingers 1 & 2	Metals Impingers 3 & 4	Anions Impingers
Target Elements by ICP-AES					
Preparation					
MW Digestion for Filters	CEM-F	X			
Analysis by ICP-AES					
Arsenic	SW 6010	X	X		
Cadmium	SW 6010	X	X		
Chromium	SW 6010	X	X		
Copper	SW 6010	X	X		
Manganese	SW 6010	X	X		
Nickel	SW 6010	X	X		
Target Elements by GFAAS					
Preparation					
MW Digestion for Filters	CEM-F	X			
Analysis by GFAAS					
Arsenic	SW 7060	X	X		
Cadmium	SW 7131	X	X		
Chromium	SW 7191	X	X		
Nickel	EPA 249.2	X	X		
Selenium	SW 7740	X	X		
Mercury by CVAAS					
Preparation					
MW Digestion for Filters	CEM-F	X			
Analysis by CVAAS					
Mercury	SW 7470	X	X	X	

Table A-3 (Continued)

Component	Method Reference	ESP Outlet Solids	Metals Impingers 1 & 2	Metals Impingers 3 & 4	Anions Impingers
Acid-Forming Anions					
Aqueous Extraction of Solids	Radian	X			
Chloride by IC	EPA 300.0	X			X
Fluoride by ISE	EPA 340.2	X			X
Additional Inorganic Analytes by ICP-AES					
Preparation					
MW Digestion for Filters	CEM-F	X			
Analysis by ICP-AES					
Aluminum	SW 6010	X	X		
Antimony	SW 6010	X	X		
Beryllium	SW 6010	X	X		
Calcium	SW 6010	X	X		
Cobalt	SW 6010	X	X		
Iron	SW 6010	X	X		
Magnesium	SW 6010	X	X		
Potassium	SW 6010	X	X		
Titanium	SW 6010	X	X		
Zinc	SW 6010	X	X		

ASTM is American Society for Testing and Materials.

EPA is EPA Methods for Chemical Analysis of Water and Wastes, 1983.

SW EPA is SW-846, "Test Methods for Evaluating Solid Waste", 3rd ed.

CEM-F CEM Corporation, Matthews, NC Procedure for microwave digestion of glass or quartz filters.

Table A-4

Site 19 Flue Gas Samples Collection Time Periods

Sample Dates & Tests Conducted	Unit 1 ESP Outlet Fan Ducts A & B Start Time	A & B Stop Time	C & D Start Time	C & D Stop Time	Comments
Monday, 3/9/92					
Velocity Profile	1500	1530	1309	1406	Preliminary Data - "B" and "D" outlet ducts only.
Tuesday, 3/10/92					
Anions	1035	1606	1032	1635	One of the two filter holders was improperly assembled causing the anions test to be voided.
Metals	1048	1717	1030	1718	One of the metals filters appeared to be contaminated with material scraped from the inside of the port, causing the metals test to be voided.
Wednesday, 3/11/92					
Anions	1123	1630	1110	1700	
Metals	1130	1759	1120	1825	
Thursday, 3/12/92					
Anions	0915	1355	0907	1351	
Metals	0935	1515	0910	1517	
Friday, 3/13/92					
Anions	0900	1400	0910	1405	
Metals	0905	1526	0910	1523	

Table A-5

Site 19 Coal Sample Collection Times

Sample Dates	Collection Time(s)	Comments
Tuesday, 3/10/92	0730, 0830, 0945, 1100	
Wednesday, 3/11/92	0700, 0815, 1030, 1130	The Unit 1 coal feed belts were off-line for repair between 0830 and 1030, which prevented sampling during this time.
Thursday, 3/12/92	0700, 0815, 1000, 1100	A duplicate coal sample was also collected on this day at the same sampling times.
Friday, 3/13/92	0700, 0815, 0930, 1100	

Appendix B

Data Used in Calculations

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
coal	Aluminum	INAA	ug/g, dry	16504	14449	14501	18070
ESP outlet gas, particulate	Aluminum	JA5SSAXX	mg/kg	95301	110832		97378
ESP outlet gas, solid phase	Aluminum	JA5SSAXX	ug/Nm3	4287	4378		3112
ESP outlet gas, vapor phase	Aluminum	JA5SWAHS	ug/Nm3	<49.0	<55.3		<49.7
coal	Antimony	INAA	ug/g, dry	0.598	0.534	0.628	0.761
ESP outlet gas, particulate	Antimony	SBGSSA00	mg/kg	10.5@	9.98@		11.0@
ESP outlet gas, solid phase	Antimony	SBGSSA00	ug/Nm3	0.473@	0.394@		0.351@
ESP outlet gas, vapor phase	Antimony	SBGSWA00	ug/Nm3	<0.765	<1.94		<1.74
coal	Arsenic	INAA	ug/g, dry	4.18	5.61	5.24	7.35
ESP outlet gas, particulate	Arsenic	ASGSSA00	mg/kg	191	241		222
ESP outlet gas, solid phase	Arsenic	ASGSSA00	ug/Nm3	8.57	9.51		7.10
ESP outlet gas, vapor phase	Arsenic	ASGSWA00	ug/Nm3	<0.981	<1.11		<0.994
coal	Ash	ASTM D3172	%, dry	8.25	8.90	9.61	10.1
ESP outlet gas, particulate	Beryllium	JA5SSAXX	mg/kg	25.1	25.3		22.4
ESP outlet gas, solid phase	Beryllium	JA5SSAXX	ug/Nm3	1.13	0.998		0.716
ESP outlet gas, vapor phase	Beryllium	JA5SWAHS	ug/Nm3	<0.490	<0.553		<0.497
coal	Cadmium	ICP	ug/g, dry	<0.400	<0.400	0.400	<0.400
ESP outlet gas, particulate	Cadmium	CDGSSA00	mg/kg	2.29	5.97		2.45@
ESP outlet gas, solid phase	Cadmium	CDGSSA00	ug/Nm3	0.103	0.236		0.0784@
ESP outlet gas, vapor phase	Cadmium	CDGSWA00	ug/Nm3	<0.245	<0.277		<0.248
coal	Calcium	INAA	ug/g, dry	1015	949	1054	1601
ESP outlet gas, particulate	Calcium	JA5SSAXX	mg/kg	13387	12141		19351
ESP outlet gas, solid phase	Calcium	JA5SSAXX	ug/Nm3	602	480		618
ESP outlet gas, vapor phase	Calcium	JA5SWAHS	ug/Nm3	<245	<277		<248
coal	Carbon	ASTM D3176	%, dry	76.3	76.5	75.8	76.5
coal	Chloride	CLARSA00	mg/kg, dry	613	844	827	640
ESP outlet gas, particulate	Chloride	CLIEWN00	mg/kg	<36.8	2207		4377
ESP outlet gas, solid phase	Chloride	CLIEWN00	ug/Nm3	<0.973	52.6		77.8

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
ESP outlet gas, vapor phase	Chloride	CLIEWN00	ug/Nm3	63744	104812		68101
coal	Chromium	ICP	ug/g, dry	14.0	15.0	19.0	17.0
ESP outlet gas, particulate	Chromium	CRGSSA00	mg/kg	315	310		315
ESP outlet gas, solid phase	Chromium	CRGSSA00	ug/Nm3	14.2	12.2		10.1
ESP outlet gas, vapor phase	Chromium	CRGSWN00	ug/Nm3	1.91@	2.00@		1.78@
coal	Cobalt	INAA	ug/g, dry	6.61	6.48	6.04	6.12
ESP outlet gas, particulate	Cobalt	JA5SSAXX	mg/kg	96.6	105		88.6
ESP outlet gas, solid phase	Cobalt	JA5SSAXX	ug/Nm3	4.35	4.16		2.83
ESP outlet gas, vapor phase	Cobalt	JA5SWAHS	ug/Nm3	<2.45	<2.77		<2.48
coal	Copper	ICP	ug/g, dry	16.0	16.0	18.0	18.0
ESP outlet gas, particulate	Copper	JA5SSAXX	mg/kg	321	325		322
ESP outlet gas, solid phase	Copper	JA5SSAXX	ug/Nm3	14.5	12.9		10.3
ESP outlet gas, vapor phase	Copper	JA5SWAHS	ug/Nm3	<4.90	<5.53		<4.97
coal	Fixed Carbon	ASTM D3172	%, dry	54.4	54.9	55.0	55.5
coal	Fluoride	F_SESA00	mg/kg, dry	128	90.3	97.3	53.4
ESP outlet gas, particulate	Fluoride	F_SEWA00	mg/kg	723	2630		5236
ESP outlet gas, solid phase	Fluoride	F_SEWA00	ug/Nm3	19.1	62.6		93.1
ESP outlet gas, vapor phase	Fluoride	F_SEWA00	ug/Nm3	5676	5007		7477
coal	Heating Value	ASTM D3172	Btu/lb, dry	13459	13504	13426	13437
coal	Hydrogen	ASTM D3176	%, dry	5.05	4.91	4.96	4.98
coal	Iron	INAA	ug/g, dry	2869	3855	3872	4492
ESP outlet gas, particulate	Iron	JA5SSAXX	mg/kg	36215	41374		41698
ESP outlet gas, solid phase	Iron	JA5SSAXX	ug/Nm3	1629	1634		1333
ESP outlet gas, vapor phase	Iron	JA5SWAHS	ug/Nm3	35.6@	15.4@		19.7@
coal	Magnesium	INAA	ug/g, dry	660	507	501	776
ESP outlet gas, particulate	Magnesium	JA5SSAXX	mg/kg	4051	5015		6117
ESP outlet gas, solid phase	Magnesium	JA5SSAXX	ug/Nm3	182	198		196
ESP outlet gas, vapor phase	Magnesium	JA5SWAHS	ug/Nm3	<245	<277		<248

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
coal	Manganese	ICP	ug/g, dry	5.00	6.00	6.00	11.0
ESP outlet gas, particulate	Manganese	JA5SSAXX	mg/kg	142	124		185
ESP outlet gas, solid phase	Manganese	JA5SSAXX	ug/Nm3	6.38	4.89		5.93
ESP outlet gas, vapor phase	Manganese	JA5SWAHS	ug/Nm3	104	16.2@		12.4@
coal	Mercury	DGA/CVAA	ug/g, dry	0.1000	0.1000	0.1000	0.110
ESP outlet gas, particulate	Mercury	HGC_SN00	mg/kg	0.137@	0.176@		0.231@
ESP outlet gas, solid phase	Mercury	HGC_SN00	ug/Nm3	0.00618@	0.00693@		0.00738@
ESP outlet gas, vapor phase	Mercury	HGCSWN00	ug/Nm3	7.22	6.42		6.03
coal	Moisture	ASTM D3172	%	6.29	5.83	6.22	6.10
coal	Nickel	ICP	ug/g, dry	12.0	12.0	14.0	12.0
ESP outlet gas, particulate	Nickel	NIGESA00	mg/kg	196	199		221
ESP outlet gas, solid phase	Nickel	NIGESA00	ug/Nm3	8.81	7.84		7.06
ESP outlet gas, vapor phase	Nickel	NIGEWA00	ug/Nm3	1.45@	<0.830		<0.745
coal	Nitrogen	ASTM D3176	%, dry	1.53	1.46	1.46	1.55
coal	Oxygen	ASTM D3176	%, dry	8.01	7.19	7.14	5.89
coal	Potassium	INAA	ug/g, dry	<1223	<1094	<1281	2163
ESP outlet gas, particulate	Potassium	JA5SSAXX	mg/kg	13608	15697		15231
ESP outlet gas, solid phase	Potassium	JA5SSAXX	ug/Nm3	612	620		487
ESP outlet gas, vapor phase	Potassium	JA5SWAHS	ug/Nm3	<735	<830		<745
coal	Selenium	INAA	ug/g, dry	3.70	4.05	4.39	3.99
ESP outlet gas, particulate	Selenium	SEGSSA00	mg/kg	129	167		127
ESP outlet gas, solid phase	Selenium	SEGSSA00	ug/Nm3	5.80	6.60		4.05
ESP outlet gas, vapor phase	Selenium	SEGSWA00	ug/Nm3	226	140		430
coal	Sodium	INAA	ug/g, dry	148	180	151	329
ESP outlet gas, particulate	Sodium	JA5SSAXX	mg/kg	9441	10732		12484
ESP outlet gas, solid phase	Sodium	JA5SSAXX	ug/Nm3	425	424		399
ESP outlet gas, vapor phase	Sodium	JA5SWAHS	ug/Nm3	<109	<107		<248
ESP outlet gas, particulate	Sulfate	SFIEWN00	mg/kg	42656	42502		49862

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
ESP outlet gas, solid phase	Sulfate	SFIEWN00	ug/Nm3	1127	1012		887
ESP outlet gas, vapor phase	Sulfate	SFIEWN00	ug/Nm3	2650693	3045438		2604668
coal	Sulfur	ASTM D3176	%, dry	0.820	1.01	0.990	0.980
coal	Titanium	INAA	ug/g, dry	854	831	902	1086
ESP outlet gas, particulate	Titanium	JA5SSAXX	mg/kg	9353	9478		8739
ESP outlet gas, solid phase	Titanium	JA5SSAXX	ug/Nm3	421	374		279
ESP outlet gas, vapor phase	Titanium	JA5SWAHS	ug/Nm3	<12.3	<13.8		<12.4
coal	Volatiles	ASTM D3172	%, dry	37.4	36.2	35.4	34.4

Key to Data Flags

Flag	Description
@	Concentration is less than five times the reporting limit.
E	Estimated analyte result greater than calibration range.
NA	Not analyzed.
R	Reported in blank, corrected in sample result.
S	Result obtained by using Method of Standard Additions.
<	Less than the reporting limit.

Methods Key

Method Code	Method Description
ASGSSA00	Graphite Furnace Atomic Absorption Spectrophotometry
ASGSWA00	Graphite Furnace Atomic Absorption Spectrophotometry
ASTM D3172	Proximate Analysis
ASTM D3176	Ultimate Analysis
CDGSSA00	Graphite Furnace Atomic Absorption Spectrophotometry
CDGSWA00	Graphite Furnace Atomic Absorption Spectrophotometry
CLARSA00	Potentiometric Titration
CLIEWN00	Ion Chromatography
CRGSSA00	Graphite Furnace Atomic Absorption Spectrophotometry
CRGSWN00	Graphite Furnace Atomic Absorption Spectrophotometry
DGA/CVAA	Double Gold Amalgamation/Cold Vapor Atomic Absorption Spectrophotometry
F_SESA00	Ion Selective Electrode
F_SEWA00	Ion Selective Electrode
GFAA	Graphite Furnace Atomic Absorption Spectrophotometry
HGCSWN00	Cold Vapor Atomic Absorption Spectrophotometry
HGC_SN00	Cold Vapor Atomic Absorption Spectrophotometry
ICP	Inductively Coupled Plasma Atomic Emission Spectroscopy
INAA	Neutron Activation Analysis
JA5SSAXX	Inductively Coupled Plasma Atomic Emission Spectroscopy
JA5SWAHS	Inductively Coupled Plasma Atomic Emission Spectroscopy
NIGESA00	Graphite Furnace Atomic Absorption Spectrophotometry
NIGEWA00	Graphite Furnace Atomic Absorption Spectrophotometry
SBGSSA00	Graphite Furnace Atomic Absorption Spectrophotometry
SBGSWA00	Graphite Furnace Atomic Absorption Spectrophotometry
SEGSSA00	Graphite Furnace Atomic Absorption Spectrophotometry
SEGSWA00	Graphite Furnace Atomic Absorption Spectrophotometry
SFIEWN00	Ion Chromatography

Appendix C

Data Not Used in Calculations

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
ESP outlet gas, particulate	Antimony	JA5SSAXX	mg/kg	<44.3	<50.2		<62.4
ESP outlet gas, solid phase	Antimony	JA5SSAXX	ug/Nm3	<1.99	<1.98		<2.00
ESP outlet gas, vapor phase	Antimony	JA5SWAHS	ug/Nm3	<10.9	<27.7		<10.4
coal	Arsenic	GFAA	ug/g, dry	2.90	3.50	4.70	4.30
ESP outlet gas, particulate	Arsenic	JA5SSAXX	mg/kg	218@	206@		278@
ESP outlet gas, solid phase	Arsenic	JA5SSAXX	ug/Nm3	9.79@	8.14@		8.90@
ESP outlet gas, vapor phase	Arsenic	JA5SWAHS	ug/Nm3	<73.5	<32.1		<31.1
coal	Barium	INAA	ug/g, dry	66.1	68.4	77.5	109
ESP outlet gas, particulate	Barium	JA5SSAXX	mg/kg	1037	1545		1542
ESP outlet gas, solid phase	Barium	JA5SSAXX	ug/Nm3	46.7	61.0		49.3
ESP outlet gas, vapor phase	Barium	JA5SWAHS	ug/Nm3	<2.45	<2.77		<2.48
ESP outlet gas, vapor phase	Boron	JA5SWAHS	ug/Nm3	3902	2783		1704
coal	Bromine	INAA	ug/g, dry	9.22	11.4	10.9	8.11
coal	Cadmium	INAA	ug/g, dry	<2.75	<2.84	<2.56	<2.74
ESP outlet gas, particulate	Cadmium	JA5SSAXX	mg/kg	<2.22	3.73@		<3.12
ESP outlet gas, solid phase	Cadmium	JA5SSAXX	ug/Nm3	<0.0997	0.147@		<0.0998
ESP outlet gas, vapor phase	Cadmium	JA5SWAHS	ug/Nm3	<1.23	<1.38		<1.24
coal	Cerium	INAA	ug/g, dry	15.5	12.7	12.6	13.8
coal	Cesium	INAA	ug/g, dry	0.649	0.595	0.719	0.953
coal	Chlorine	INAA	ug/g, dry	527	762	761	568
coal	Chromium	INAA	ug/g, dry	16.9	15.8	17.0	18.1
ESP outlet gas, particulate	Chromium	JA5SSAXX	mg/kg	299	292		291
ESP outlet gas, solid phase	Chromium	JA5SSAXX	ug/Nm3	13.5	11.5		9.30
ESP outlet gas, vapor phase	Chromium	JA5SWAHS	ug/Nm3	<2.45	<2.77		<2.48
coal	Copper	INAA	ug/g, dry	<28.9	<31.1	<32.8	59.1
coal	Europium	INAA	ug/g, dry	0.377	0.324	0.354	0.379
coal	Hafnium	INAA	ug/g, dry	0.720	0.673	0.790	0.962
coal	Iodine	INAA	ug/g, dry	1.70	2.05	2.11	<1.26

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
coal	Lanthanum	INAA	ug/g, dry	9.57	9.30	8.34	10.7
ESP outlet gas, vapor phase	Lead	JA5SWAHS	ug/Nm3	14.6@	<13.8		<12.4
coal	Lutetium	INAA	ug/g, dry	0.135	0.105	<0.00764	0.150
coal	Manganese	INAA	ug/g, dry	5.39	5.52	7.01	14.6
coal	Mercury	INAA	ug/g, dry	<0.265	<0.242	<0.213	<0.256
coal	Molybdenum	INAA	ug/g, dry	3.91	<1.35	3.83	5.16
ESP outlet gas, particulate	Molybdenum	JA5SSAXX	mg/kg	89.1@	90.8@		115@
ESP outlet gas, solid phase	Molybdenum	JA5SSAXX	ug/Nm3	4.01@	3.59@		3.67@
ESP outlet gas, vapor phase	Molybdenum	JA5SWAHS	ug/Nm3	<12.3	<5.35		<12.4
coal	Neodymium	INAA	ug/g, dry	8.19	6.15	7.10	7.88
coal	Nickel	INAA	ug/g, dry	<21.5	23.4	<22.3	28.3
ESP outlet gas, particulate	Nickel	JA5SSAXX	mg/kg	191	189		210
ESP outlet gas, solid phase	Nickel	JA5SSAXX	ug/Nm3	8.57	7.45		6.72
ESP outlet gas, vapor phase	Nickel	JA5SWAHS	ug/Nm3	<4.90	<5.53		<4.97
coal	Rubidium	INAA	ug/g, dry	9.07	8.10	9.97	11.5
coal	Samarium	INAA	ug/g, dry	1.86	1.69	1.53	1.92
coal	Scandium	INAA	ug/g, dry	4.02	3.57	3.85	4.18
coal	Selenium	GFAA	ug/g, dry	3.60	2.60	3.20	3.60
ESP outlet gas, particulate	Selenium	JA5SSAXX	mg/kg	<133	<150		<187
ESP outlet gas, solid phase	Selenium	JA5SSAXX	ug/Nm3	<5.98	<5.94		<5.99
ESP outlet gas, vapor phase	Selenium	JA5SWAHS	ug/Nm3	259@	297@		262@
ESP outlet gas, vapor phase	Silicon	JA5SWAHS	ug/Nm3	<245	<277		<248
coal	Silver	INAA	ug/g, dry	<0.538	<0.437	<0.511	<0.522
ESP outlet gas, particulate	Silver	JA5SSAXX	mg/kg	<4.43	<5.02		<6.24
ESP outlet gas, solid phase	Silver	JA5SSAXX	ug/Nm3	<0.199	<0.198		<0.200
ESP outlet gas, vapor phase	Silver	JA5SWAHS	ug/Nm3	<2.45	<2.77		<2.48
coal	Strontium	INAA	ug/g, dry	109	95.9	99.3	156
ESP outlet gas, particulate	Strontium	JA5SSAXX	mg/kg	869	1209		1186

Stream	Substance	Method	UOM	Run 2	Run 3	Run 3D	Run 4
ESP outlet gas, solid phase	Strontium	JA5SSAXX	ug/Nm3	39.1	47.7		37.9
ESP outlet gas, vapor phase	Strontium	JA5SWAHS	ug/Nm3	<0.735	<0.321		<0.745
ESP outlet gas, particulate	Sulfur	JA5SSAXX	mg/kg	12456	10732@		12859@
ESP outlet gas, solid phase	Sulfur	JA5SSAXX	ug/Nm3	560	424@		411@
coal	Tantalum	INAA	ug/g, dry	0.186	0.203	0.189	0.288
coal	Terbium	INAA	ug/g, dry	22.4	0.191	0.220	0.254
ESP outlet gas, particulate	Thallium	JA5SSAXX	mg/kg	<44.3	<50.2		<62.4
ESP outlet gas, solid phase	Thallium	JA5SSAXX	ug/Nm3	<1.99	<1.98		<2.00
ESP outlet gas, vapor phase	Thallium	JA5SWAHS	ug/Nm3	<24.5	<27.7		<24.8
coal	Thorium	INAA	ug/g, dry	2.70	2.55	2.80	3.63
coal	Tin	INAA	ug/g, dry	<3.85	<3.81	<3.90	<4.23
coal	Tungsten	INAA	ug/g, dry	<1.92	<1.90	<1.95	<2.11
coal	Uranium	INAA	ug/g, dry	1.17	1.35	1.26	1.76
coal	Vanadium	INAA	ug/g, dry	32.1	30.4	29.7	37.4
ESP outlet gas, particulate	Vanadium	JA5SSAXX	mg/kg	567	522		537
ESP outlet gas, solid phase	Vanadium	JA5SSAXX	ug/Nm3	25.5	20.6		17.2
ESP outlet gas, vapor phase	Vanadium	JA5SWAHS	ug/Nm3	<4.90	<2.14		<2.08
coal	Ytterbium	INAA	ug/g, dry	0.887	0.758	0.853	0.926
coal	Zinc	INAA	ug/g, dry	10.9	<2.27	14.1	13.6
ESP outlet gas, particulate	Zinc	JA5SSAXX	mg/kg	935	517		874
ESP outlet gas, solid phase	Zinc	JA5SSAXX	ug/Nm3	42.1	20.4		27.9
ESP outlet gas, vapor phase	Zinc	JA5SWAHS	ug/Nm3	26.9	9.04@		6.06@
coal	Zirconium	INAA	ug/g, dry	<34.1	33.2	<32.3	34.2

Appendix D

Flue Gas Sampling Data

Multi–Metals, ESP Outlet – Run 2

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/11/92	3/11/92	3/11/92
Dry Standard Meter Volume	90.802 DSCF	99.277 DSCF	190.079 DSCF
Percent Flue Gas Moisture	7.31 %	7.3 %	N/A %
Flue Gas Molecular Weight (wet)	29.7 g/g–mole	29.7 g/g–mole	N/A g/g–mole
Average Gas Velocity	58.12 ft/sec	62.68 ft/sec	60.4 ft/sec
Average Flue Gas Flow Rate	1,820,176 ACFM	2,000,681 ACFM	3,820,857 ACFM
Average Flue Gas Flow Rate	1,140,365 DSCFM	1,317,909 DSCFM	2,458,274 DSCFM
Isokinetic Sampling Rate	103.27 %	99.99 %	N/A %
Oxygen Concentration	5.5 %	5.5 %	N/A %
CO2 Concentration	15.0 %	15.0 %	N/A %
Stack Temperature	291 Degrees F	256 Degrees F	274 Degrees F
Filter Tare Weight	0.1465 grams	0.1471 grams	0.2936 grams
Total Mass of Particulate Solids Collected	0.0779 grams	0.1477 grams	0.2256 grams
Particulate Concentration	0.0132 gr/DSCF	0.023 gr/DSCF	0.0183 gr/DSCF
Particulate Emissions	129.43 lb/hr	259.40 lb/hr	388.83 lb/hr
Mass of Particulate Analyzed	0.0779 grams	0.1477 grams	0.2256 grams
Impinger 1 Mass (HNO3)	N/A grams	N/A grams	1229.4 grams
Impinger 2 Mass (HNO3)	N/A grams	N/A grams	547.9 grams
Impinger 3 Mass (KMNO4)	N/A grams	N/A grams	623.3 grams
Impinger 4 Mass (KMNO4)	N/A grams	N/A grams	621 grams
HCl Rinse Impinger 3	N/A grams	N/A grams	201.1 grams
HCl Rinse Impinger 4	N/A grams	N/A grams	205.4 grams

Multi–Metals, ESP Outlet – Run 3

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/12/92	3/12/92	N/A
Dry Standard Meter Volume	92.796 DSCF	98.541 DSCF	191.337 DSCF
Percent Flue Gas Moisture	7.14 %	7.12 %	N/A %
Flue Gas Molecular Weight (wet)	29.59 g/g–mole	29.72 g/g–mole	N/A g/g–mole
Average Gas Velocity	61.21 ft/sec	64.75 ft/sec	62.98 ft/sec
Average Flue Gas Flow Rate	1,953,729 ACFM	2,066,793 ACFM	4,020,522 ACFM
Average Flue Gas Flow Rate	1,227,004 DSCFM	1,343,730 DSCFM	2,570,734 DSCFM
Isokinetic Sampling Rate	100.38 %	97.34 %	N/A %
Oxygen Concentration	6.00 %	5.5 %	N/A %
CO2 Concentration	14.0 %	15.0 %	N/A %
Stack Temperature	295 Degrees F	270 Degrees F	283 Degrees F
Filter Tare Weight	0.1455 grams	0.1465 grams	0.292 grams
Total Mass of Particulate Solids Collected	0.0689 grams	0.1305 grams	0.1994 grams
Particulate Concentration	0.0110 gr/DSCF	0.0204 gr/DSCF	0.0160 gr/DSCF
Particulate Emissions	120.53 lb/hr	235.43 lb/hr	355.96 lb/hr
Mass of Particulate Analyzed	0.0689 grams	0.1305 grams	0.1994 grams
Impinger 1 Mass (HNO3)	N/A grams	N/A grams	1396.8 grams
Impinger 1 Mass (HNO3)	N/A grams	N/A grams	539.7 grams
Impinger 3 Mass (KMNO4)	N/A grams	N/A grams	628.2 grams
Impinger 4 Mass (KMNO4)	N/A grams	N/A grams	675.3 grams
HCl Rinse Impinger 3	N/A grams	N/A grams	204.5 grams
HCl Rinse Impinger 4	N/A grams	N/A grams	201.7 grams

Multi–Metals, ESP Outlet – Run 4

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/13/92	3/13/92	N/A
Dry Standard Meter Volume	96.071 DSCF	93.902 DSCF	189.973 DSCF
Percent Flue Gas Moisture	7.01 %	7 %	N/A %
Flue Gas Molecular Weight (wet)	29.72 g/g–mole	29.74 g/g–mole	N/A g/g–mole
Average Gas Velocity	61.9 ft/sec	62.30 ft/sec	62.1 ft/sec
Average Flue Gas Flow Rate	1,975,799 ACFM	1,988,643 ACFM	3,964,442 ACFM
Average Flue Gas Flow Rate	1,254,956 DSCFM	1,300,873 DSCFM	2,555,829 DSCFM
Isokinetic Sampling Rate	101.61 %	95.81 %	N/A %
Oxygen Concentration	5.00 %	5.5 %	N/A %
CO2 Concentration	15.0 %	15.0 %	N/A %
Stack Temperature	287 Degrees F	267 Degrees F	277 Degrees F
Filter Tare Weight	0.1456 grams	0.1446 grams	0.2902 grams
Total Mass of Particulate Solids Collected	0.0479 grams	0.1123 grams	0.1602 grams
Particulate Concentration	0.0077 gr/DSCF	0.0185 gr/DSCF	0.0130 gr/DSCF
Particulate Emissions	82.78 lb/hr	206.00 lb/hr	288.78 lb/hr
Mass of Particulate Analyzed	0.0479 grams	0.1123 grams	0.1602 grams
Impinger 1 Mass (HNO3)	N/A grams	N/A grams	1245.4 grams
Impinger 1 Mass (HNO3)	N/A grams	N/A grams	520.1 grams
Impinger 3 Mass (KMNO4)	N/A grams	N/A grams	613.3 grams
Impinger 4 Mass (KMNO4)	N/A grams	N/A grams	608 grams
HCl Rinse Impinger 3	N/A grams	N/A grams	211 grams
HCl Rinse Impinger 4	N/A grams	N/A grams	211.4 grams

Anions, ESP Outlet – Run 2

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/11/92	3/11/92	3/11/92
Dry Standard Meter Volume	68.017 DSCF	79.226 DSCF	147.243 DSCF
Percent Flue Gas Moisture	7.83 %	7.11 %	N/A %
Flue Gas Molecular Weight (wet)	29.47 g/g–mole	29.56 g/g–mole	N/A g/g–mole
Average Gas Velocity	59.04 ft/sec	65.04 ft/sec	62.04 ft/sec
Average Flue Gas Flow Rate	1,849,175 ACFM	2,037,215 ACFM	3886390 ACFM
Average Flue Gas Flow Rate	1,134,543 DSCFM	1,349,139 DSCFM	2483682 DSCFM
Isokinetic Sampling Rate	97.04 %	96.79 %	N/A %
Oxygen Concentration	7.0 %	7.0 %	N/A %
CO2 Concentration	13.5 %	13.5 %	N/A %
Stack Temperature	302 Degrees F	254 Degrees F	278 Degrees F
Filter Tare Weight	0.1424 grams	0.1400 grams	0.2824 grams
Mass of Filter Particulate Solids Collected	0.0368 grams	0.0658 grams	0.1026 grams
Particulate Concentration *	0.00835 gr/DSCF	0.0128 gr/DSCF	0.0107 gr/DSCF
PNR Mass	50.2 grams	95.2 grams	145.4 grams
Impinger 1 Mass (HCO3)	N/A grams	N/A grams	903.3 grams
Impinger 2 Mass (HCO3)	N/A grams	N/A grams	513 grams
Impinger 3 Mass (H2O2)	N/A grams	N/A grams	508 grams
Impinger 4 Mass (H2O2)	N/A grams	N/A grams	522.5 grams

* Anions particulate concentrations are not representative of entire duct.

Anions, ESP Outlet – Run 3

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/12/92	3/12/92	3/12/92
Dry Standard Meter Volume	69.761 DSCF	80.171 DSCF	149.932 DSCF
Percent Flue Gas Moisture	7.39 %	6.84 %	N/A %
Flue Gas Molecular Weight (wet)	29.52 g/g–mole	29.55 g/g–mole	N/A g/g–mole
Average Gas Velocity	59.26 ft/sec	68.22 ft/sec	63.74 ft/sec
Average Flue Gas Flow Rate	1,856,171 ACFM	2,136,764 ACFM	3992935 ACFM
Average Flue Gas Flow Rate	1,168,512 DSCFM	1,394,982 DSCFM	2563494 DSCFM
Isokinetic Sampling Rate	96.64 %	94.73 %	N/A %
Oxygen Concentration	7 %	8 %	N/A %
CO2 Concentration	13.5 %	13.5 %	N/A %
Stack Temperature	291 Degrees F	269 Degrees F	280 Degrees F
Filter Tare Weight	0.1433 grams	0.1459 grams	0.2892 grams
Mass of Filter Particulate Solids Collected	0.0264 grams	0.0678 grams	0.0942 grams
Particulate Concentration *	0.0058 gr/DSCF	0.0131 gr/DSCF	0.0097 gr/DSCF
PNR Mass	73.2 grams	185.1 grams	258.3 grams
Impinger 1 Mass (HCO3)	N/A grams	N/A grams	993.4 grams
Impinger 2 Mass (HCO3)	N/A grams	N/A grams	540 grams
Impinger 3 Mass (H2O2)	N/A grams	N/A grams	528.1 grams
Impinger 4 Mass (H2O2)	N/A grams	N/A grams	551.2 grams

* Anions particulate concentrations are not representative of entire duct.

Anions, ESP Outlet – Run 4

PARAMETER	Duct A & B	Duct C & D	Combined
Date	3/13/92	3/13/92	3/13/92
Dry Standard Meter Volume	73.484 DSCF	72.088 DSCF	145.572 DSCF
Percent Flue Gas Moisture	6.98 %	6.52 %	N/A %
Flue Gas Molecular Weight (wet)	29.57 g/g–mole	29.72 g/g–mole	N/A g/g–mole
Average Gas Velocity	61.63 ft/sec	63.39 ft/sec	62.51 ft/sec
Average Flue Gas Flow Rate	1,967,186 ACFM	1,985,439 ACFM	3952625 ACFM
Average Flue Gas Flow Rate	1,244,325 DSCFM	1,344,471 DSCFM	2588796 DSCFM
Isokinetic Sampling Rate	97.42 %	88.37 %	N/A %
Oxygen Concentration	7.0 %	5.5 %	N/A %
CO2 Concentration	13.5 %	14.5 %	N/A %
Stack Temperature	292 Degrees F	269 Degrees F	281 Degrees F
Filter Tare Weight	0.147 grams	0.1462 grams	0.2932 grams
Mass of Filter Particulate Solids Collected	0.0225 grams	0.0458 grams	0.0683 grams
Particulate Concentration *	0.0047 gr/DSCF	0.0098 gr/DSCF	0.0072 gr/DSCF
PNR Mass	47.8 grams	141.4 grams	189.2 grams
Impinger 1 Mass (HCO3)	N/A grams	N/A grams	952.8 grams
Impinger 2 Mass (HCO3)	N/A grams	N/A grams	530.2 grams
Impinger 3 Mass (H2O2)	N/A grams	N/A grams	522.2 grams
Impinger 4 Mass (H2O2)	N/A grams	N/A grams	542.7 grams

* Anions particulate concentrations are not representative of entire duct.

Appendix E

Uncertainty Analysis

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 through 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.

This method 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 uncertainty;
β_r = Bias component of result uncertainty;
t = Student "t" factor (two-tailed distribution at 95% confidence);
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:

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

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

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

$$S_r = \sqrt{\sum_{i=1}^{j} (\theta_i * S_{\bar{pi}})^2} \quad (3)$$

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

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

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

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

Equation 5 was applied to the calculations in this report. The perturbation selected for each parameter was the larger of the normalized standard deviation, $S_{\bar{pi}}$, or the bias, β_{pi}.

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

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

The degrees of freedom for each parameter is found from

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

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

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

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

The precision error terms are easily generated from the collected data. The bias error terms are more difficult to quantify. The following conventions were used for this report:

- 5% bias on coal flow rates.
- No bias in gas flow rates.
- No bias in analytical results if the result is greater than the reporting limit. One-half of the reporting limit is used for both the parameter value and its bias in calculations if the result is below the reporting limit.

Assignment of the flow rate bias values is based on 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 detection limit may be especially large. The uncertainty values calculated for this report are, therefore, subject to these limitations.

The calculations assume that the population distribution of each measurement is normal 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.

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

Appendix F

Quality Assurance/Quality Control Data

This appendix presents the detailed QA/QC results for the coal and flue gas samples.

Table F-1 shows the results of blank analyses.

Table F-2 shows the analytical results for laboratory check samples (LCS).

Table F-3 shows the results for spiked and duplicate spiked samples.

Table F-4 shows the results from the analysis of duplicate coal samples.

Table F-5 shows the analytical results for performance audit samples.

Table F-1

Summary of Blank Sample Results for Site 19

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Laboratory (Method) Blanks				
ICP-AES Metals				
Aluminum	1	0		0.2 mg/L
Antimony	1	0		0.1 mg/L
Arsenic	1	1	0.0146 mg/L	0.3 mg/L
Barium	1	1	0.00015 mg/L	0.01 mg/L
Beryllium	1	0		0.002 mg/L
Boron	1	1	0.00184 mg/L	0.6 mg/L
Cadmium	1	1	0.00011 mg/L	0.005 mg/L
Calcium	1	1	0.0348 mg/L	1 mg/L
Chromium	1	0		0.01 mg/L
Cobalt	1	1	0.0017 mg/L	0.01 mg/L
Copper	1	1	0.00266 mg/L	0.02 mg/L
Iron	1	0		0.05 mg/L
Lead	1	0		0.05 mg/L
Magnesium	1	1	0.013 mg/L	1 mg/L
Manganese	1	0		0.01 mg/L
Molybdenum	1	0		0.05 mg/L
Nickel	1	1	0.00142 mg/L	0.02 mg/L
Potassium	1	1	0.0418 mg/L	3 mg/L
Selenium	1	1	0.0254 mg/L	0.3 mg/L
Silicon	1	1	0.0607 mg/L	1 mg/L
Silver	1	1	0.00111 mg/L	0.01 mg/L
Sodium	1	1	0.127 mg/L	1 mg/L
Strontium	1	1	0.0006 mg/L	0.003 mg/L
Thallium	1	1	0.0308 mg/L	0.1 mg/L
Titanium	1	0		0.05 mg/L
Vanadium	1	1	0.00057 mg/L	0.02 mg/L
Zinc	1	1	0.0031 mg/L	0.02 mg/L
Laboratory (Method) Blanks				
GFAAS and CVAAS Metals				
Arsenic	1	0		0.004 mg/L
Antimony	1	0		0.007 mg/L
Cadmium	1	1	0.00013 mg/L	0.001 mg/L

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Chromium	1	1	0.0015 mg/L	0.003 mg/L
Mercury	4	4	0.018-0.284 µg/L	0.18 µg/L
Nickel	1	0		0.003 mg/L
Selenium	1	1	0.0037 mg/L	0.005 mg/L
Laboratory (Method) Blank				
Anions				
Chloride (EPA 300)	2	0		0.026 mg/L
Chloride (SM 4500)	1	0		
Fluoride (EPA 340.2)	6	4	0.0161-0.298 mg/L	0.1 mg/L
Sulfate (EPA 300)	1	0		0.05 mg/L
Trip Blanks- Reagent Water				
ICP-AES Metals				
Aluminum	4	1	0.0029 mg/L	0.2 mg/L
Antimony	4	3	0.00404-0.0248 mg/L	0.1 mg/L
Arsenic	4	0		0.3 mg/L
Barium	4	3	0.00015-0.00061 mg/L	0.01 mg/L
Beryllium	4	4	0.0002-0.00032 mg/L	0.002 mg/L
Boron	4	2	0.00092-0.0046 mg/L	0.6 mg/L
Cadmium	4	1	0.00049 mg/L	0.005 mg/L
Calcium	4	1	0.060 mg/L	1 mg/L
Chromium	4	0		0.01 mg/L
Cobalt	4	1	0.00048 mg/L	0.01 mg/L
Copper	4	1	0.00057 mg/L	0.02 mg/L
Iron	4	0		0.05 mg/L
Lead	4	0		0.05 mg/L
Magnesium	4	1	0.00627 mg/L	1 mg/L
Manganese	4	4	0.00018-0.00056 mg/L	0.01 mg/L
Molybdenum	4	0		0.05 mg/L
Nickel	4	4	0.00194-0.0115 mg/L	0.02 mg/L
Potassium	4	1	0.125 mg/L	3 mg/L
Selenium	4	3	0.00748-0.0132 mg/L	0.3 mg/L
Silicon	4	4	0.0455-0.0808 mg/L	1 mg/L
Silver	4	0		0.01 mg/L
Sodium	4	2	0.00749-0.0116 mg/L	1 mg/L
Strontium	4	0		0.003 mg/L
Thallium	4	0		0.1 mg/L

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Titanium	4	3	0.00017-0.00035 mg/L	0.05 mg/L
Vanadium	4	0		0.02 mg/L
Zinc	4	4	0.00139-0.00331 mg/L	0.02 mg/L
Trip Blanks - Reagent Water				
Anions	4			
Chloride	4	0		0.026 mg/L
Fluoride	4	4	0.0248-0.0277 mg/L	0.1 mg/L
Sulfate	4	0		
Trip Blanks - H_2O_2/HNO_3 Impinger Solutions				
ICP-AES Metals				
Aluminum	1	1	0.0328 mg/L	0.2 mg/L
Antimony	1	0		0.1 mg/L
Arsenic	1	1	0.00092 mg/L	0.3 mg/L
Barium	1	1	0.00092 mg/L	0.01 mg/L
Beryllium	1	1	0.00005 mg/L	0.002 mg/L
Boron	1	1	0.00923 mg/L	0.6 mg/L
Cadmium	1	0		0.005 mg/L
Calcium	1	1	0.157 mg/L	1 mg/L
Chromium	1	1	0.00227 mg/L	0.01 mg/L
Cobalt	1	1	0.00072 mg/L	0.01 mg/L
Copper	1	1	0.00312 mg/L	0.02 mg/L
Iron	1	1	0.0367 mg/L	0.05 mg/L
Lead	1	1	0.03 mg/L	0.05 mg/L
Magnesium	1	1	0.00034 mg/L	1 mg/L
Manganese	1	1	0.00868 mg/L	0.01 mg/L
Molybdenum	1	0		0.05 mg/L
Nickel	1	0		0.02 mg/L
Potassium	1	0		3 mg/L
Selenium	1	0		0.3 mg/L
Silicon	1	1	0.15 mg/L	1 mg/L
Silver	1	1	0.00112 mg/L	0.01 mg/L
Sodium	1	1	0.523 mg/L	1 mg/L
Strontium	1	1	0.00045 mg/L	0.003 mg/L
Thallium	1	0		0.1 mg/L
Titanium	1	1	0.00260 mg/L	0.05 mg/L

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Vanadium	1	1	0.00149 mg/L	0.02 mg/L
Zinc	1	1	0.0228 mg/L	0.02 mg/L
Trip Blanks - H_2O_2/HNO_3 Impinger Solutions				
GFAAS and CVAAS Metals				
Arsenic	1	1	0.0001 mg/L	0.004 mg/L
Antimony	1	0		0.007 mg/L
Cadmium	1	1	0.00022 mg/L	0.001 mg/L
Chromium	1	1	0.0024 mg/L	0.003 mg/L
Mercury	1	1	0.130 µg/L	0.18 µg/L
Nickel	1	0		0.003 mg/L
Selenium	1	0		0.005 mg/L
Trip Blanks - $H_2SO_4/KMnO_4$ Impinger Solutions				
Mercury	1	1	0.0240 µg/L	0.18 µg/L
Trip Blanks - H_2O_2 Impinger Solutions				
Anions				
Chloride (EPA 300)	1	0		1 mg/L
Fluoride (EPA 340.2)	1	1	0.0326 mg/L	0.1 mg/L
Trip Blanks - $Na_2CO_3/NaHCO_3/H_2O_2$ Impinger Solutions				
Anions				
Chloride (EPA 300)	1	0		1 mg/L
Fluoride (EPA 340.2)	1	1	0.0363 mg/L	0.1 mg/L
Sulfate (EPA 300)	1	0		0.05 mg/L
Field Blanks - ESP Outlet Gas - H_2O_2/HNO_3 Impinger Solutions				
ICP-AES Metals				
Aluminum	2	2	0.0285-0.0391 mg/L	0.2 mg/L
Antimony	2	1	0.00667 mg/L	0.1 mg/L
Arsenic	2	2	0.00608-0.0131 mg/L	0.3 mg/L
Barium	2	2	0.00077-0.00169 mg/L	0.01 mg/L
Beryllium	2	1	0.0001 mg/L	0.002 mg/L
Boron	2	2	0.0175-0.0359 mg/L	0.6 mg/L
Cadmium	2	2	0.00006-0.00047 mg/L	0.005 mg/L
Calcium	2	2	0.0178-0.0364 mg/L	1 mg/L
Chromium	2	2	0.00299-0.00474 mg/L	0.01 mg/L

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Cobalt	2	2	0.00024-0.0017 mg/L	0.01 mg/L
Copper	2	2	0.00205-0.00307 mg/L	0.02 mg/L
Iron	2	2	0.0155-0.0213 mg/L	0.05 mg/L
Lead	2	2	0.0186-0.025 mg/L	0.05 mg/L
Magnesium	2	2	0.00329-0.0211 mg/L	1 mg/L
Manganese	2	2	0.00584-0.00697 mg/L	0.01 mg/L
Molybdenum	2	0		0.05 mg/L
Nickel	2	0		0.02 mg/L
Potassium	2	1	0.684 mg/L	3 mg/L
Selenium	2	0		0.3 mg/L
Silicon	2	2	0.107-0.195 mg/L	1 mg/L
Silver	2	1	0.00155 mg/L	0.01 mg/L
Sodium	2	2	0.0277-0.134 mg/L	1 mg/L
Strontium	2	0		0.003 mg/L
Thallium	2	1	0.0195 mg/L	0.1 mg/L
Titanium	2	2	0.00121-0.00138 mg/L	0.05 mg/L
Vanadium	2	1	0.00310 mg/L	0.02 mg/L
Zinc	2	2	0.00567-0.00752	0.02 mg/L
Field Blanks - ESP Outlet Gas - H_2O_2/HNO_3 Impinger Solutions				
GFAAS and CVAAS Metals				
Arsenic	2	0		0.004 mg/L
Antimony	2	0		0.007 mg/L
Cadmium	2	2	0.00023-0.00071 mg/L	0.001 mg/L
Chromium	2	2	0.0021-0.0022 mg/L	0.003 mg/L
Mercury	2	2	0.160-0.402 µg/L	0.18 µg/L
Nickel	2	1	0.0049 mg/L	0.003 mg/L
Selenium	2	2	0.0005-0.0039 mg/L	0.005 mg/L
Field Blanks - ESP Outlet Gas - $H_2SO_4/KMnO_4$ Impinger Solutions				
Mercury	2	2	0.062-0.13 µg/L	0.18 µg/L
Field Blanks - ESP Outlet Gas - HCl Rinses				
Mercury	2	2	0.094-0.096 µg/L	0.18 µg/L

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Field Blanks - ESP Outlet Gas - H_2O_2 Impinger Solutions				
Anions				
Chloride (EPA 300)	2	1	1.95 mg/L	1 mg/L
Fluoride (EPA 340.2)	2	2	0.0313-0.0336 mg/L	0.1 mg/L
Field Blanks - ESP Outlet Gas - $Na_2CO_3/NaHCO_3/H_2O_2$				
Anions				
Chloride (EPA 300)	2	1	0.0987-1.14 mg/L	1 mg/L
Fluoride (EPA 340.2)	2	2	0.046-0.0677 mg/L	0.1 mg/L
Sulfate (EPA 300)	2	2	4.02-11.8 mg/L	0.05 mg/L
Field Blank - ESP Outlet Gas - Probe and Nozzle Rinse Plus Filter				
ICP-AES Metals				
Aluminum	1	1	213 µg	20 µg
Antimony	1	0		10 µg
Arsenic	1	0		30 µg
Barium	1	1	11.7 µg	1 µg
Beryllium	1	1	0.032 µg	0.2 µg
Cadmium	1	1	0.184 µg	0.5 µg
Calcium	1	1	259 µg	100 µg
Chromium	1	1	1.94 µg	1 µg
Cobalt	1	1	0.326	1 µg
Copper	1	1	0.849 µg	2 µg
Iron	1	1	17.3 µg	5 µg
Lead	1	1	1.32 µg	5 µg
Magnesium	1	1	97.4 µg	100 µg
Manganese	1	1	0.303 µg	1 µg
Molybdenum	1	1	4.84 µg	5 µg
Nickel	1	1	0.444 µg	2 µg
Potassium	1	1	73.7 µg	300 µg
Selenium	1	0		30 µg
Silicon	1	1	57300 µg	100 µg
Silver	1	0		1 µg
Sodium	1	1	762 µg	100 µg
Strontium	1	1	0.553 µg	0.3 µg

Table F-1 (Continued)

Parameter	No. of Blank Analyzed	No. of Detects	Range of Compounds Detected	Reporting Limits
Thallium	1	1	4.73 μg	10 μg
Titanium	1	1	1.93 μg	5 μg
Vanadium	1	1	0.378 μg	2 μg
Zinc	1	1	8.7 μg	2 μg
Field Blank - ESP Outlet Gas - Probe and Nozzle Rinse Plus Filter				
GFAAS and CVAAS Metals				
Arsenic	1	1	0.37 μg	0.4 μg
Antimony	1	1	0.07 μg	0.7 μg
Cadmium	1	0		0.1 μg
Chromium	1	1	1.2 μg	0.3 μg
Mercury	1	1	0.017 μg	0.018 μg
Nickel	1	1	0.31 μg	0.3 μg
Selenium	1	1	0.041 μg	0.5 μg

Table F-2

Summary of Laboratory Check Sample (LCS) Results for Site 19

Parameter	No. of LCS	Mean % Rec.	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
Metals by ICP-AES - Water						
Aluminum	2	97.35	0.1	0	0	90-110%
Antimony	2	93.9	1.06	0	0	90-110%
Arsenic	2	94.2	0.32	0	0	90-110%
Barium	2	96.2	0.52	0	0	90-110%
Beryllium	2	95.6	0.31	0	0	90-110%
Boron	2	100.6	8.85	0	0	90-110%
Cadmium	2	94.4	0.32	0	0	90-110%
Calcium	2	99.6	0.9	0	0	90-110%
Chromium	2	95.5	0.21	0	0	90-110%
Cobalt	2	94.6	0.32	0	0	90-110%
Copper	2	95.3	1.21	0	0	90-110%
Iron	2	97	0.52	0	0	90-110%
Lead	2	97.6	2.15	0	0	90-110%
Magnesium	2	96.4	1.04	0	0	90-110%
Manganese	2	94.8	0.32	0	0	90-110%
Molybdenum	2	96.5	0.62	0	0	90-110%
Nickel	2	95	0.32	0	0	90-110%
Potassium	2	97.4	1.23	0	0	90-110%
Selenium	2	99	4	0	0	90-110%
Silicon	2	102	1.96	0	0	90-110%
Silver	2	93	0.32	0	0	90-110%
Sodium	2	98.6	0.32	0	0	90-110%
Strontium	2	96.4	0.52	0	0	90-110%
Thallium	2	95	2.53	0	0	90-110%
Titanium	2	96.4	0.1	0	0	90-110%
Vanadium	2	94.1	0.64	0	0	90-110%
Zinc	2	94.75	0.11	0	0	90-110%

Table F-2 (Continued)

Parameter	No. of LCS	Mean % Rec.	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
Metals by GFAAS and CVAAS - Water						
Antimony	2	103	0	0	0	85-115%
Arsenic	2	93.3		0	0	85-115%
Cadmium	2	92.9	0.22	0	0	85-115%
Chromium	2	103	1.9	0	0	85-115%
Mercury	6	104	2.37	0	0	80-120%
Selenium	2	101.5	0.98	0	0	85-115%
Anions - Water						
Chloride	8	98.1	1.86	0	0	90-110%
Fluoride	14	98.8	5.96	0	2	90-110%
Anions - Solids						
Chloride	6	95	3.4	0	0	90-110%
Fluoride	7	83	3.0	7	0	90-110%
Metals by ICP-AES - NIST 1633a Fly Ash Standard						
Aluminum	6	85.0	4.76	1	0	80-120%
Antimony	2	85.5	12.94	2	0	80-120%
Arsenic	2	114	14.14	0	0	80-120%
Barium	6	78.4	3.71	4	0	80-120%
Beryllium	6	97.5	4.54	0	0	80-120%
Calcium	6	84.8	3.96	0	0	80-120%
Chromium	6	98.6	8.52	0	0	80-120%
Cobalt	6	90.7	5.76	0	0	80-120%
Copper	6	98.6	7.78	0	0	80-120%
Iron	6	95.5	5.76	0	0	80-120%
Lead	6	75.9	39.52	2	0	80-120%
Magnesium	6	73.2	8.12	5	0	80-120%
Manganese	6	87.2	3.08	0	0	80-120%
Molybdenum	2	83.4	4.24	0	0	80-120%
Nickel	6	95.8	12.63	0	0	80-120%
Potassium	6	102	9.19	0	0	80-120%
Silicon	2	85.4	1.48	0	0	80-120%
Silver	3	43	45.15	2	0	80-120%
Sodium	6	93.5	5.9	0	0	80-120%

Table F-2 (Continued)

Parameter	No. of LCS	Mean % Rec.	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
Strontium	5	81.7	5.08	1	0	80-120%
Thallium	3	92.7	10.33	0	0	80-120%
Titanium	6	100.1	5.26	0	0	80-120%
Vanadium	6	96.93	6.28	0	0	80-120%
Zinc	6	92.35	4.42	0	0	80-120%
GFAAS and CVAAS Metals - NIST 1633a Fly Ash Standard						
Antimony	8	99.3	9.96	0	0	75-125%
Arsenic	6	99.7	3.9	0	0	75-125%
Cadmium	2	92.7	0.14	0	0	75-125%
Chromium	6	93.52	11.7	0	0	75-125%
Mercury	2	94.8	0.99	0	0	75-125%
Nickel	6	85.1	3.11	0	0	75-125%
Selenium	6	91.1	8.82	0	0	75-125%
Metals by ICP-AES - ECH Fly Ash Standard						
Aluminum	4	80.4	5.18	1	0	80-120%
Barium	4	91.9	5.74	0	0	80-120%
Beryllium	4	52.4	0.44	4	0	80-120%
Calcium	4	81.4	4.4	1	0	80-120%
Chromium	4	104.8	11.65	0	1	80-120%
Cobalt	4	98.4	2.51	0	0	80-120%
Copper	4	96.8	1.52	0	0	80-120%
Iron	4	96.5	1.38	0	0	80-120%
Lead	4	78.2	57.5	1	1	80-120%
Magnesium	4	64.4	9.43	4	0	80-120%
Manganese	4	87.2	2.67	0	0	80-120%
Nickel	4	101.9	8.86	0	0	80-120%
Potassium	4	88.6	3.02	0	0	80-120%
Sodium	4	94.2	2.74	0	0	80-120%
Strontium	4	83.5	6.08	1	0	80-120%
Titanium	4	96.2	0.55	0	0	80-120%
Vanadium	4	101.8	3.72	0	0	80-120%
Zinc	4	93.8	1.83	0	0	80-120%

Table F-2 (Continued)

Parameter	No. of LCS	Mean % Rec.	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
GFAAS Metals - ECH Fly Ash Standard						
Antimony	6	112	11.79	0	1	75-125%
Arsenic	4	102.8	0.96	0	0	75-125%
Chromium	4	109.5	14.46	0	1	75-125%
Nickel	6	97.4	13.35	0	0	75-125%
CVAAS Metals - ERA 212 Mercury Standard						
Mercury	5	94.3	6.8	0	0	80-120%

Table F-3

Summary of Spiked Sample Results for Site 19

Compound	No. of Spikes	Mean Rec. %	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
Metals by ICP-AES - Impingers						
Aluminum	2	95.8	0.31	0	0	75-125%
Antimony	2	93.8	2.98	0	0	75-125%
Arsenic	2	91.4	0.87	0	0	75-125%
Barium	2	96.6	1.35	0	0	75-125%
Beryllium	2	96.3	1.25	0	0	75-125%
Boron	2	154	2.6	0	2	75-125%
Cadmium	2	91.4	1.2	0	0	75-125%
Calcium	2	98.2	0.71	0	0	75-125%
Chromium	2	94.2	1.38	0	0	75-125%
Cobalt	2	93.8	1.17	0	0	75-125%
Copper	2	93.8	1.28	0	0	75-125%
Iron	2	96	0.94	0	0	75-125%
Lead	2	88	0	0	0	75-125%
Magnesium	2	94.2	0.53	0	0	75-125%
Manganese	2	94.3	1.27	0	0	75-125%
Molybdenum	2	95	0.94	0	0	75-125%
Nickel	2	89.2	0.74	0	0	75-125%
Potassium	2	95.3	1.05	0	0	75-125%
Selenium	2	113	1.77	0	0	75-125%
Silicon	2	105.5	10.43	0	0	75-125%
Silver	2	90.7	1.32	0	0	75-125%
Sodium	2	98.2	1.93	0	0	75-125%
Strontium	2	96.6	1.34	0	0	75-125%
Thallium	2	91.8	7.08	0	0	75-125%
Titanium	2	96.2	1.24	0	0	75-125%
Vanadium	2	93.2	1.83	0	0	75-125%
Zinc	2	91.5	0.66	0	0	75-125%

Table F-3 (Continued)

Compound	No. of Spikes	Mean Rec. %	Mean RPD/ Std. Dev.	No. Below Limits	No. Above Limits	Data Quality Objective for Recovery
Metals by GFAAS and CVAAS - Impingers						
Mercury	4	87.8	14.15	1	0	75-125%
Antimony	2	93.8	0.85	0	0	75-125%
Arsenic	2	95.4	9.6	0	0	75-125%
Cadmium	2	98.3	1.02	0	0	75-125%
Chromium	2	92.9	1.94	0	0	75-125%
Nickel	2	89.2	3.7	0	0	75-125%
Selenium	2	0 [a]	NC	2	0	75-125%
Anions - Impingers	2					
Chloride	8	88.4	11.59	2	0	80-120%
Fluoride	8	93.9	20.7	2	0	80-120%
Sulfate	4	104.8	8.95	0	0	80-120%
Anions - Coal						
Chloride	3	98	6.2	0	1	80-120%
Fluoride	3	84	1.3	0	0	80-120%

[a]Selenium was spiked at a concentration too low compared to the native level in the sample.

Table F-4

Summary of Duplicate Coal Sample Results - Site 19

Parameter	No. of Pairs	Mean	RPD
Ultimate/Proximate - Coal (percent, dry weight)			
Ash	1	9.3	7.7
Fixed Carbon	1	55	0.22
Heating Value (Btu/lb)	1	13,465	0.58
Moisture	1	6	6.5
Volatiles	1	35.8	2.32
Carbon	1	76.2	0.91
Hydrogen	1	4.9	1.01
Nitrogen	1	1.5	0
Oxygen	1	7.2	0.7
Sulfur	1	1	2
Anions - Coal (mg/kg)			
Chloride	1	836	2
Fluoride	1	93.8	7.5
ICP-AES Metals - Coal (μg/g)			
Cadmium	1	0.4	NC
Chromium	1	17	23.5
Copper	1	17	11.7
Manganese	1	6	0
Nickel	1	13	15.4
GFAAS and CVAAS Metals - Coal (μg/g)			
Arsenic	1	4.1	29.3
Selenium	1	2.9	20.7
Mercury	1	0.10	0
INAA Metals - Coal (μg/g)			
Aluminum	1	14,475	0.36
Antimony	1	0.58	16
Arsenic	1	5.4	6.8
Barium	1	73	12
Bromine	1	11	4.5
Cadmium	1	<2.8	NC
Calcium	1	1,002	10

Table F-4 (Continued)

Parameter	No. of Pairs	Mean	RPD
Cerium	1	12.7	1.5
Cesium	1	0.66	19
Chlorine	1	762	0.13
Chromium	1	16	7.3
Cobalt	1	6.3	7.0
Copper	1	<33	NC
Europium	1	0.34	8.9
Hafnium	1	0.73	16
Iodine	1	2.1	2.9
Iron	1	3,864	0.44
Lanthanum	1	8.8	11
Lutetium	1	0.054	186
Magnesium	1	504	1.2
Manganese	1	6.3	24
Mercury	1	<0.24	NC
Molybdenum	1	2.2	140
Neodymium	1	6.6	14
Nickel	1	<22	NC
Potassium	1	<1281	NC
Rubidium	1	9.0	21
Samarium	1	1.6	9.9
Scandium	1	3.7	7.5
Selenium	1	4.2	8.1
Silver	1	<0.51	NC
Sodium	1	166	18
Strontium	1	98	3.5
Tantalum	1	0.20	7.1
Terbium	1	0.21	14
Thorium	1	2.7	9.3
Tin	1	<3.9	NC
Titanium	1	867	8.2
Tungsten	1	<2.0	NC
Uranium	1	1.3	6.9
Vanadium	1	30	2.3
Ytterbium	1	0.81	12
Zinc	1	7.6	170
Zirconium	1	<32	NC

Table F-5

Summary of Audit Sample Results - Site 19

Parameter	Certified Value* µg/g	Result µg/g	Recovery, %
NIST 1632b Coal - INAA Metals			
Aluminum	8,550	8,648	101.2
Antimony	(0.24)	0.2	(83.3)
Arsenic	3.72	3.8	102.2
Barium	67.5	69.1	102.4
Bromine	(17)	15.8	(92.9)
Cadmium	0.0573	NR(2.2)	NC
Calcium	2,040	1091.7	53.5
Cerium	(9)	6.8	(75.6)
Cesium	(0.44)	0.5	(113.6)
Chlorine	(1,260)	988.8	(78.5)
Chromium	(11)	10.4	(94.5)
Cobalt	2.29	2.1	91.7
Copper	6.28	NR(21.3)	NC
Europium	(0.17)	0.1	(58.8)
Hafnium	(0.43)	0.4	(93.0)
Iodine		1.0	
Iron	7,590	7093.1	93.4
Lanthanum	(5.1)	4.1	(80.4)
Lutetium		0.1	
Magnesium	383	365.1	95.3
Manganese	12.4	10.9	87.9
Mercury		NR(0.2)	
Molybdenum	(0.9)	NR(1.1)	NC
Neodymium		3.2	
Nickel	6.10	NR(9.7)	NC
Potassium	748	1042.0	139.3
Rubidium	5.05	4.8	95.0
Samarium	(0.87)	0.7	(80.4)

Table F-5 (Continued)

Parameter	Certified Value* µg/g	Result µg/g	Recovery, %
Scandium	(1.9)	1.9	(100)
Selenium	1.29	1.4	108.5
Silver		NR(0.4)	
Sodium	515	457.6	88.8
Strontium	(102)	135.1	(132.4)
Tantalum		0.1	
Terbium		0.1	
Thorium	1.342	1.3	96.9
Tin		NR(4.1)	
Titanium	454	426.3	93.9
Tungsten	(0.48)	NR(2.0)	NC
Uranium	0.436	0.3	
Vanadium	(14)	14.3	(102.1)
Ytterbium		0.3	
Zinc	11.89	5.8	48.8
Zirconium		NR(24.4)	
SARM20 - Coal			
Mercury (DGA/CVAAS)	0.25	0.25	100
Arsenic (GFAAS)	4.7	3.2	68
Chromium (ICP-AES)	(67)	65	97
Manganese (ICP-AES)	80	77	96
Nickel (ICP-AES)	25	25	100
Selenium (GFAAS)	0.8	0.4	50
NIST 1633a Coal Fly Ash - ICP-AES Metals[a]			
Aluminum	14.3	13.9	97.2
Arsenic	145	281	194
Barium (%)	(0.15)	0.134	89.3
Beryllium	(12)	12.8	107
Cadmium	1	<5	NC
Calcium (%)	1.11	1.11	100
Chromium	196	198	101
Cobalt	(46)	47	102

Table F-5 (Continued)

Parameter	Certified Value* µg/g	Result µg/g	Recovery, %
Copper	118	121	102
Iron (%)	9.4	9.32	99.1
Lead	72.4	110	152
Magnesium (%)	0.455	0.436	95.8
Manganese	179	173	96.6
Molybdenum	(29)	18.5	63.8
Nickel	127	125	98.4
Potassium (%)	1.88	1.92	102
Sodium	0.17	0.171	100
Strontium	830	826	99.5
Thallium	5.7	56	982
Titanium (%)	(0.8)	0.86	108
Vanadium	297	309	104
Zinc	220	207	94.1
NIST 1633a Coal Fly Ash - GFAAS and CVAAS Metals*			
Arsenic	145	120	82.8
Cadmium	1.00	0.05	5.0
Chromium	196	179	91.3
Mercury	0.16	0.17	106
Nickel	127	115	90.5
Antimony	6.8	7.12	105
Selenium	10.3	11.7	114
ERA 2779 Coal - Ultimate/ Proximate (% dry)			
Ash	9.1	8.7	95.6
Volatile Matter	37.91	37.89	99.9
Fixed Carbon	52.99	53.1	100
Sulfur	1.95	1.78	91.3
Carbon	72.68	72.55	99.8
Hydrogen	5.23	4.76	91
Nitrogen	1.52	1.64	108
Heating Value (Btu)	12,941	12,810	99

*This fly ash standard was submitted as an audit sample. It is a different analysis from the NIST 1633a fly ash results presented in Table F-2, which were analyzed as laboratory control samples.
*Results in parentheses are not certified.
NC = Not able to calculate.

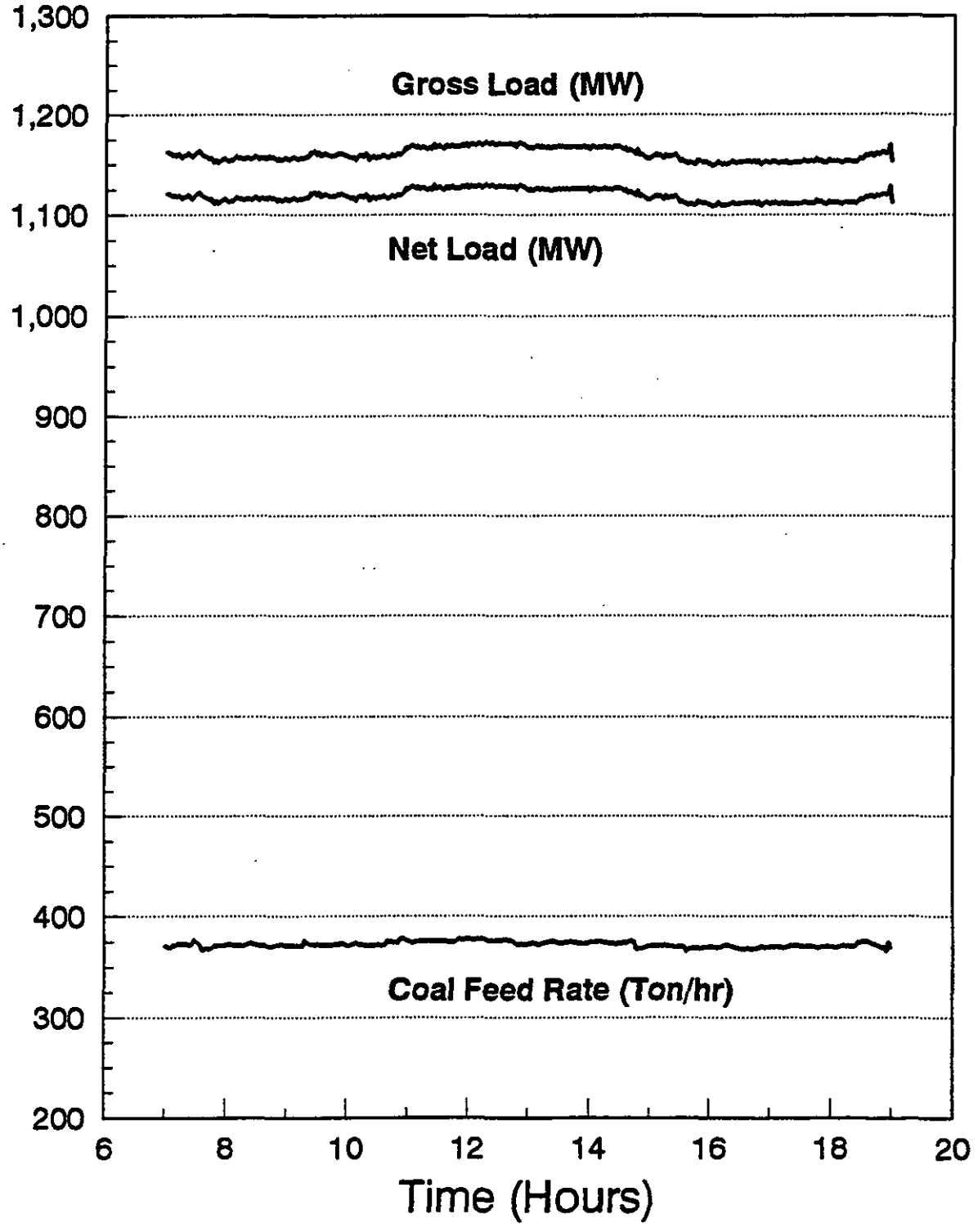
Appendix G

Process Data Trend Plots

Unit 1

Power Generation and Coal Feed

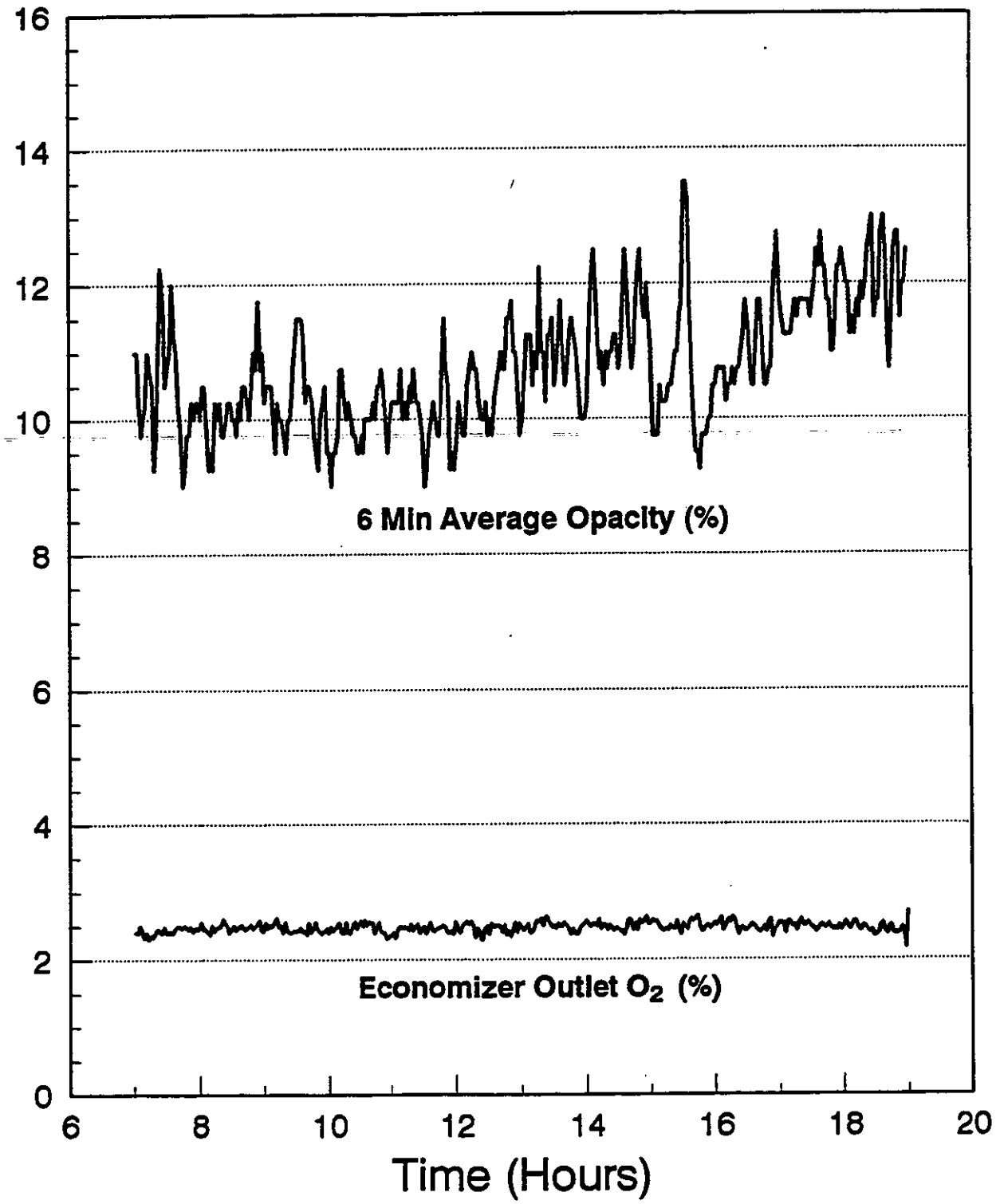
3/11/92



Unit 1

Opacity and Economizer Outlet O_2

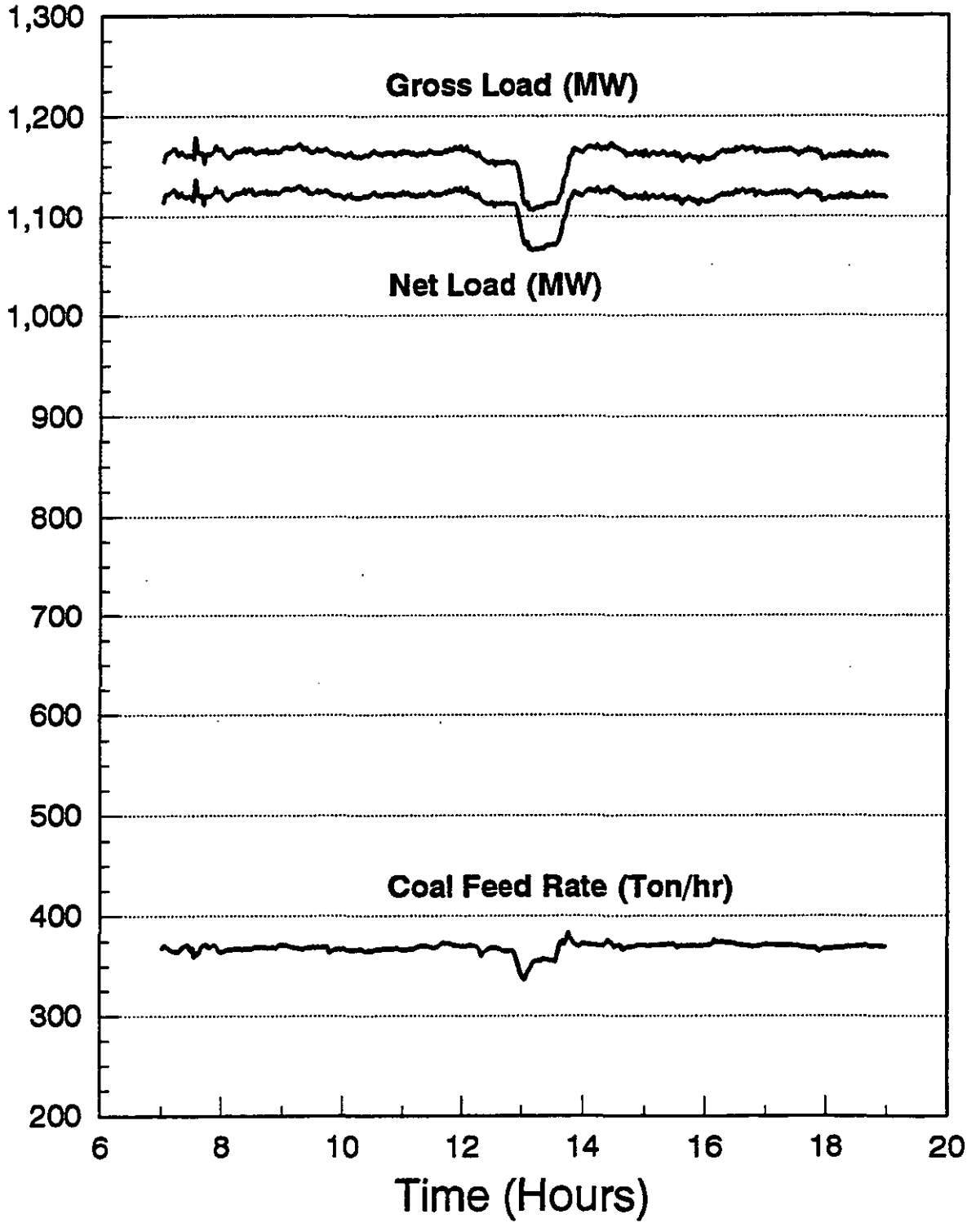
3/11/92



Unit 1

Power Generation and Coal Feed

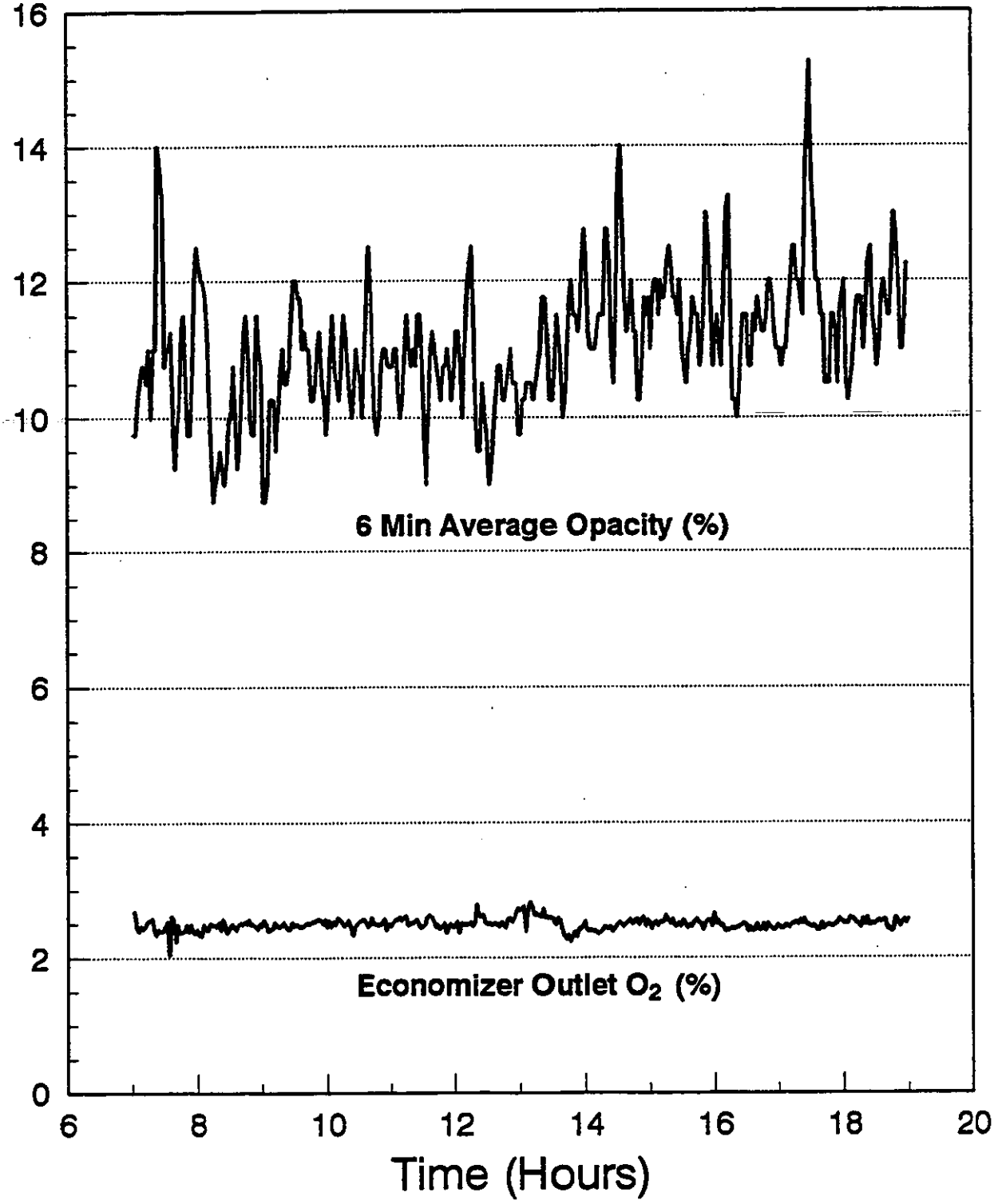
3/12/92



Unit 1

Opacity and Economizer Outlet O_2

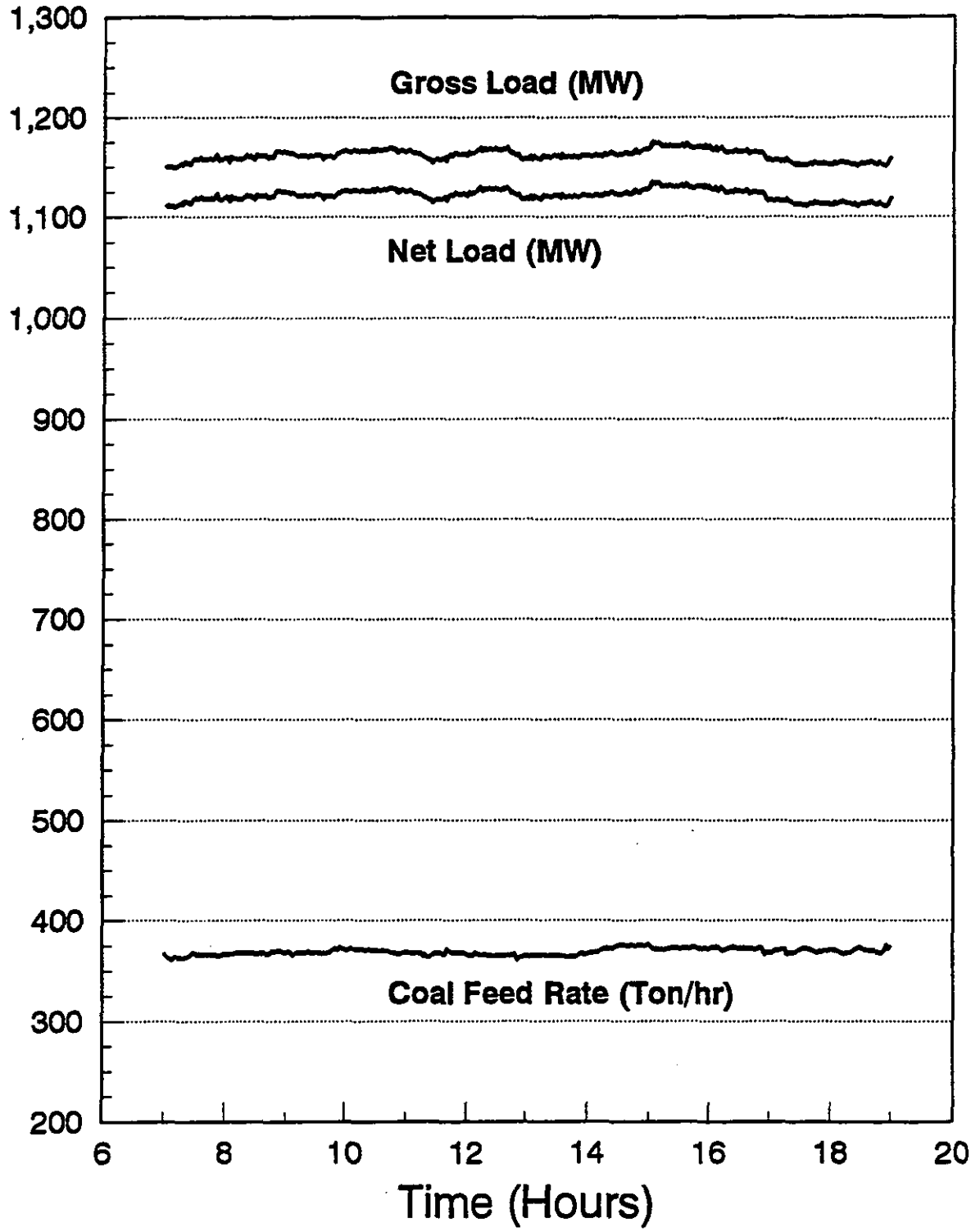
3/12/92



Unit 1

Power Generation and Coal Feed

3/13/92



Unit 1

Opacity and Economizer Outlet O_2

3/13/92