FOSSIL

DOE/PC/93253--T1
(DE94016053)

A STUDY OF TOXIC EMISSIONS FROM A COAL-FIRED POWER PLANT UTILIZING AN ESP WHILE DEMONSTRATING THE ICCT CT-121 FGD PROJECT

Final Report

June 1994

Work Performed Under Contract No. AC22-93PC93253

For
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

By
Radian Corporation
Austin, Texas

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A Study of Toxic Emissions from a Coal-Fired Power Plant Utilizing an ESP While Demonstrating the ICCT CT-121 FGD Project

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GLOSSARY

acfm	Actual Cubic Foot (Feet) per Minute
AAS	Atomic Absorption Spectrophotometry
ADA	ADA Technologies, Inc.
AP-42	Publication number of the principal emission factor document published by EPA.
APH	Air Preheater
ASTM	American Society for Testing and Materials
B	Data Flag (value has been blank corrected)
Btu	British Thermal Unit
C	Data Flag (with blank correction, value was below detection limit, detection limit reported)
CE	Combustion-Engineering, Inc.
CEM	Continuous Emission Monitor
CEMS	Continuous Emission Monitoring System
Chicago OPC	Chicago Office of Patent Counsel (U.S. DOE)
CI	Confidence Interval
C_p	Pitot Tube Coefficient
CT-121	Chiyoda Thoroughbred-121 (a second-generation flue gas desulfurization process)
CT&E	Commercial Testing & Engineering
CVAA	Cold Vapor Atomic Absorption
CVAFS	Cold Vapor Atomic Fluorescence Spectrometry
DAS	Data Acquisition System
ΔP	"Delta P"; Pressure Drop; Pressure Difference (measured in inches of water column)
DL	Detection Limit

DNPH	Dinitrophenylhydrazine
DQO	Data Quality Objective
dscfm	Dry Standard Cubic Foot (Feet) per Minute
E	Data Flag (analyte concentration exceeded calibration range)
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic Precipitator
FGD	Flue Gas Desulfurization
f/sec	Foot (Feet) per Second
g	Gram(s)
GC/MS	Gas Chromatography/Mass Spectrometry
GDMS	Glow Discharge Mass Spectrometry
g-mole	Gram-Mole (weight of a mole of a substance expressed in grams)
GPC	Georgia Power Company
HAP	Hazardous Air Pollutant
HHV	Higher Heating Value
HPLC	High Performance Liquid Chromatography
IC	Ion Chromatography
ICCT	Innovative Clean Coal Technology (a U.S. DOE program)
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectroscopy
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
INAA	Instrumental Neutron Activation Analysis
J	Data Flag (below the lower detection limit)
JBR	Jet Bubbling Reactor (the absorber design used in the CT-121 process)
kg	Kilogram(s)
L	Liter
m	Meter
mL	Milliliter
MM5	Modified Method 5

μg	Microgram(s)
μL	Microliter
μm	Micrometer; 1 x 10^6 meter
NA	Not Applicable
ND	Not Detected
Nm^3	Normal Cubic Meter(s): $1m^3$ @ 0°C and 1.0 atm (equivalent to 37.44 ft^3 @ 68°F and 1.0 atm)
Orsat	Method of Fixed-Gas (O_2, CO_2, CO) Analysis
PAH	Polycyclic Aromatic Hydrocarbon
PCDD	Polychlorinated Dibenzodioxin
PCDF	Polychlorinated Dibenzofuran
PNR	Probe and Nozzle Rinse
POM	Polycyclic Organic Matter
RPD	Relative Percent Difference
PSD	Particle Size Distribution
RSF	Relative Sensitivity Factor (used in mass spectrometry)
RTI	Research Triangle Institute
scf	Standard Cubic Foot (feet): 1 ft^3 @ 68°F and 1.0 atm (equivalent to 0.02671 m^3 @ 0°C and 1.0 atm)
scfm	Standard Cubic Foot (Feet) per Minute
SCS	Southern Company Services, Inc.
SIE	Specific Ion Electrode
SW-846	Publication number of "Test Methods for Evaluating Solid Waste"
TCLP	Toxicity Characteristic Leaching Procedure
Tenax	An organic resin used for sample collection
UV-Vis	Ultraviolet-Visible
VOC	Volatile Organic Compound; Volatile Organic Chemical
VOST	Volatile Organic Sampling Train

EXECUTIVE SUMMARY

The U.S. Department of Energy is performing comprehensive assessments of toxic emissions from eight selected coal-fired electric utility units. This program responds to the Clean Air Act Amendments of 1990, which require the U.S. Environmental Protection Agency (EPA) to evaluate emissions of hazardous air pollutants (HAPs) from electric utility power plants for potential health risks. The resulting data will be furnished to EPA for emissions factor and health risk determinations.

The assessment of emissions involves the collection and analysis of samples from the major input, process, and output streams of each of the eight power plants for selected hazardous pollutants identified in Title III of the Clean Air Act. Additional goals are to determine the removal efficiencies of pollution control subsystems for these selected pollutants and the concentrations associated with the particulate fraction of the flue gas stream as a function of particle size. Material balances are being performed for selected pollutants around the entire power plant and several subsystems to identify the fate of hazardous substances in each utility system.

Radian Corporation was selected to perform a toxics assessment at a plant demonstrating an Innovative Clean Coal Technology (ICCT) Project. The site selected is Plant Yates Unit No. 1 of Georgia Power Company, which includes a Chiyoda Thoroughbred-121 demonstration project.

Site Description

Plant Yates Unit No. 1 is a bituminous coal-fired steam electricity-generating unit with a net generating capacity of 100 megawatts. Located in Newnan, Georgia, the station is owned and operated by Georgia Power Company. The station uses a tangentially fired CE boiler that burns a 2.5%-sulfur blend of Illinois No. 5 and Illinois No. 6 bituminous coals. It uses an electrostatic precipitator to control particulate matter, and the Chiyoda Thoroughbred-121 process controls sulfur dioxide emissions from the entire flue gas stream.

Process Description

The Chiyoda Thoroughbred-121 is a second-generation FGD process employing a unique absorber design, called a jet bubbling reactor, to combine conventional SO_2 absorption, neutralization, sulfite oxidation, and gypsum crystallization in one reaction vessel. The process is designed to operate in a pH range of 3 to 5, where the driving force for limestone dissolution is high, resulting in nearly complete reagent utilization. Oxidation of sulfite to sulfate is also promoted at the lower pH because of the increased solubility of innate oxidation catalysts such as iron. Because all the absorbed SO_2 is oxidized, there is sufficient surface area for gypsum crystal growth to prevent the slurry from becoming significantly supersaturated with respect to calcium sulfate. This significantly reduces the potential for gypsum scaling.

Sampling Locations

Three flue gas stream locations were identified for testing: the ESP inlet, the ESP outlet (FGD inlet), and the stack. The solid streams sampled were raw coal, pulverized feed coal, pulverizer rejects, individual ESP hopper ash, and raw limestone. Samples collected as slurried or sluiced streams include the bottom ash, the combined ESP hopper ash, limestone, and FGD slurry solids. The following liquid streams were sampled: ash pond water, gypsum pond water, ash sluice water (from the bottom ash and fly ash), FGD slurry blowdown filtrate, limestone slurry filtrate, coal pile run-off, and cooling water at the condenser inlet.

Sample Collection

Radian's approach to meeting the test objectives utilized established sampling methods (where possible) and a sampling strategy consistent with that of the EPRI-sponsored Field Chemical Emissions Monitoring (FCEM) program.[1] Samples were collected with the boiler operating within 10% of full load, at steady-state conditions, and in triplicate over two periods of three days each: June 21-23 and June 25-27, 1993.

Detection Limits

Detection limits for the gaseous phase target metals of interest are presented in Table ES-1. These numbers were derived from instrument method detection limits, the volume of gas sampled, and the amount of solid sample that was analyzed. Data are presented for detection limits derived from gas samples collected from the stack. This location was chosen to illustrate typical detection limits, as it represents the highest level of particulate detection limits, due to the low particulate loading at this location. Loading at the stack averaged 0.0145 g/Nm^3, and the numbers presented in the table represent the analysis of approximately 35 mg of particulate collected from a nominal 3 m^3 sample size.

Quality Assurance and Quality Control

During sample collection, quality assurance audits were conducted by Radian's internal QA auditor and by Research Triangle Institute, under contract with EPA. Radian's auditor also conducted a performance evaluation audit by submitting "double-blind" (identity and composition unknown) samples to the analytical laboratories. Quality control procedures involved the evaluation of results for field and laboratory blank samples, duplicate field samples, matrix-spiked and surrogate-spiked samples, and laboratory control samples.

Overall, QA/QC data associated with this program indicate that measurement data are acceptable and defensible. The QA/QC data indicate that the quality control mechanisms

Table ES-1
Detection Limits for Gaseous Phase Target Metals

Specie	Method	Detection Limits, µg/Nm³ Vapor	Detection Limits, µg/Nm³ Solids
Antimony	ICP-MS	0.004	0.0008
Arsenic	GF-AAS	0.2	0.04
Barium	ICP-AES	0.16	0.09
Beryllium	ICP-AES	0.17	0.03
Boron	ICP-AES	4.6	NA
Cadmium	GF-AAS	0.07	0.17
Chromium	ICP-AES	0.76	0.44
Cobalt	ICP-AES	1.0	0.59
Copper	ICP-AES	1.2	0.44
Lead	GF-AAS	0.25	0.04
Manganese	ICP-AES	0.12	0.46
Mercury	CV-AAS	0.13	0.01
Molybdenum	ICP-AES	1.4	0.15
Nickel	ICP-AES	3.0	1.0
Selenium	GF-AAS	0.26	0.12
Vanadium	ICP-AES	0.72	0.66

NA = Not analyzed, insufficient sample size.

were effective in ensuring measurement data reliability within the expected limits of sampling and analytical error.

Plant Operating Conditions

During sample collection, operating conditions were continuously monitored using a computerized data acquisition system which logged process information as 15-minute averages. In addition, boiler operating data were logged hourly by control room operators. Overall, all processes were very stable, and the key operating parameters were within the targeted range during the entire test period.

Three continuous emission monitors were operated during the test period, providing data for sulfur dioxide, nitrogen oxides, and carbon monoxide. ESP characteristics were monitored by ADA Technologies, Inc.

Analytical Results

Samples were analyzed for trace elements, minor and major elements, volatile organic compounds, and semivolatile organic compounds. Analytical results have been tabulated in detail with 95% confidence intervals and detection limit ratios.

Procedures were provided by DOE for results below the detection limit, values outside the calibration range, and blanks. In the detailed data tabulations, some data have been flagged; for example, some background contamination was encountered.

Data Analysis: Mass Balances, Removal Efficiencies, and Emission Factors

Emission factors, removal efficiencies, and other results rely on measurement data that are near the limit of detection or below it for many of the substances of interest. For that reason, uncertainty analyses and the calculation of confidence intervals were performed as part of this program.

Following are observations as a result of the data analysis:

- Material balances were calculated for 27 elements. Sixty-percent of these met the target closure objectives of 70-130% for balance around the plant. Eight-five percent met a closure criteria of 50-150 percent.

- Removal efficiencies for non-volatile particulate metals averaged greater than 98% across the ESP. The JBR was also effective in further reducing the emission of several metals, due primarily to its effectiveness as a particulate control device.

- Emission factors have been calculated for the target trace elements and are presented in Table ES-2. Thirteen of these elements have emission rates of less than 10 pounds per billion Btu of coal.

Table ES-2
Emission Factors

	$lb/10^{12}$ Btu	95% CI
Anions		
Chloride	742	647
Fluoride	122	67
Selected Elements [a]		
Antimony	0.06	0.01
Arsenic	1.2	0.2
Barium	2.8	9.9
Beryllium	0.1	0.1
Cadmium	0.6	2.1
Chromium	5.3	49.5
Cobalt	0.7	0.8
Copper	2.0	2.3
Lead	0.6	0.6
Manganese	7.2	48
Mercury	3.0	0.3
Molybdenum	1.5	2.6
Nickel	40.1	435
Selenium	26.5	58
Vanadium	2.1	0.5
Aldehydes		
Acetaldehyde	8.6	9.2
Formaldehyde	24	36
Volatile Organics [b,c]		
Benzene	1.3	0.3
Carbon Disulfide	2.2	1.2
Toluene	2.0	1.0

Table ES-2 (Continued)

	lb/10^{12} Btu	95% CI
Semivolatile Organics[d]		
2-Methylphenol (o-cresol)	2.9	3.8
4-Methylphenol (p-cresol)	0.95	1.9
Acetophenone	3.2	0.7
Benzoic Acid	120	7
Benzyl Alcohol	2.8	12
Naphthalene	1.5	1.0
Phenol	9.2	8.8

[a] Run 1 particulate-phase data were invalidated for all elements included here except arsenic, selenium, and vanadium due to the filter background comprising 20% or greater of the measured concentration.

[b] Only those compounds with an average concentration above the detection limit are included.

[c] Methylene chloride, acetone, and other halogenated hydrocarbons are not included because their presence is strongly suspected to be the result of contamination.

[d] Phthalate esters are not included because their presence is suspected to be the results of contamination.

The method used to determine uncertainties in calculated results is based on "Measurement Uncertainty"[2] and is consistent with the approach to handling data used in the FCEM program.

Comparison of Vapor and Particulate Composition

Most of the substances measured at Plant Yates are distributed between the flue gas (vapor) and the particulate matter associated with bottom ash, collected ESP ash, ash removed in the FGD system, or emitted ash which exits with the flue gas through the stack. (The sampling and analytical techniques used for organic compounds did not quantify distribution between particulate and vapor phases.)

At ESP inlet conditions, more than 99% of most of the substances of interest are in the particulate phase. Exceptions are chloride, fluoride, selenium, and mercury. With these same exceptions, the particulate phase is the predominant phase at the ESP outlet and stack.

Distribution of HAPs as a Function of Particle Size in the Flue Gas and the Particle Size Distribution of the ESP

Most of the metals are removed across the ESP at a rate that is approximately the same as that of the total particulate. Exceptions are arsenic, cadmium, phosphorus, and selenium. Arsenic, cadmium, and phosphorus penetration could be due to low concentrations or to association with particles in the range of 0.5 to 2 μm. The selenium penetration is thought to be due to sampling or analytical error.

Mercury Methods Comparison and Speciation Determinations

Two different methods were used to measure mercury concentrations in the flue gas. The Bloom mercury speciation train[3] was used to measure the concentrations of individual vapor-phase mercury species: ionic mercury, elemental mercury, and methyl mercury. Total mercury, particulate and vapor phases, was measured using a multi-metals train.[4]

Ionic mercury appears to be the predominant species in the ESP inlet and ESP outlet gas streams, but ionic mercury is more efficiently removed by the scrubber. Methyl mercury concentrations also appear to decrease across the scrubber.

Hexavalent Chromium Determinations

Hexavalent chromium as well as total chromium were nondetectable in the samples collected after appropriate blank correction had been applied. Although samples were collected as specified by the published method,[5] it should be noted that the collection procedure for obtaining Cr^{6+} samples from a flue gas matrix containing SO_2 has not been validated.

Determinations of Toxics on Particle Surfaces

Because of the health and environmental importance of toxic substances that are found on the surfaces of particles and because these substances are more available to biological and ecological systems, a comparison between bulk composition and surface leachability was performed. Results have been tabulated, and some conclusions can be drawn for individual elements, but no overall trends are clearly evident.

Recommendations and Considerations

Some technical issues have been identified during this study that may warrant further consideration. Among these are the following sampling, analytical and/or process related issues:

- Selenium sampling and analysis;
- Mercury partitioning and speciation; and
- Fly ash penetration of the FGD process.

Selenium

Selenium could not be accurately quantified throughout the process. Apparent problems were associated with both the collection and the analysis of selenium. Further directed study of selenium is recommended. Problems associated with the quantification of selenium are discussed in Section 8.

Mercury

Mercury was collected and analyzed by both Method 29[6] and by the Bloom method[7] which uses charcoal tubes for the absorption and speciation of mercury. Results obtained from these two methods are presented in Section 9. One of the phenomena observed is an apparent increase in the elemental mercury concentration across the FGD system. Another anomaly is the apparent enrichment in fly ash particles of mercury when collected from the flue gas via filtration. These two items warrant further study and investigation.

Fly Ash Penetration of FGD System

The link between particle size, surface orientation of trace elements, and the penetration of fine particles cannot be demonstrated by comparing the extractable and total metal concentrations of the particulate emissions from the FGD system. Fly ash penetration, the mass contribution from sulfuric acid mist and scrubber mist soluble salts (gypsum) add additional variables to the assessment of air toxic emissions as a function of surface orientation. The following penetration mechanisms can potentially impact the analysis of the particulate emissions from wet scrubbers:

- Direct penetration of the fly ash;
- Capture of the ash particles in the scrubber liquor and re-entrainment during recycle;
- Entrainment of scrubber-generated solids;
- Evaporation and penetration of scrubber mist as soluble salts; and
- Condensation and recovery of sulfuric acid mist as particulate.

Controlled condensation test methods should be used in future test efforts for measuring sulfuric acid emissions apart from gypsum, and SO_2 artifacts. The analysis of tracer elements associated only with the coal ash may be warranted to determine ash penetration and dilution from scrubber solids. Analysis of size-fractionated particulate emissions could potentially identify the predominant size ranges associated with individual components.

Test efforts to quantify the relative contribution of each phenomenon to particulate emissions may be of interest to those considering wet scrubbers for the control of air toxics as well as SO_2. This data would provide a basis of comparison between the surface extractability of the dry ash entering an FGD system and the particulate emissions downstream.

References

1. Electric Power Research Institute. *Field Chemical Emissions Monitoring (FCEM) Generic Sampling and Analytical Plan.* Draft Report. Palo Alto, CA (May 1994).

2. American Society of Mechanical Engineers. *Measurement Uncertainty: Instruments and Apparatus.* PTC 19.1-1985 (reaffirmed 1990), pp 1-65. United Engineering Center, New York, NY. Published by the American National Standards Institute.

3. Nicolas S. Bloom, Eric M. Prestbo, and Vesna L. Miklavicic, "Fluegas Mercury Emissions and Speciations from Fossil Fuel Combustion." Published in the proceedings of the Second International Conference on Managing Hazardous Air Pollutants (sponsored by the Electric Power Research Institute) Washington, D.C. (July 1993).

4. 40 CFR 266, Subpart H, "Method 29: Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Processes: Proposed Method."

5. 40 CFR 266, Appendix IX: *Methods Manual for Compliance with the BIF Regulations.* "Determination of Hexavalent Chromium Emissions from Stationary Sources (Method Cr^{+6})."

6. 40 CFR 266, Subpart H, "Method 29: Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Processes: Proposed Method."

7. Nicolas S. Bloom, Eric M. Prestbo, and Vesna L. Miklavicic, "Fluegas Mercury Emissions and Speciations from Fossil Fuel Combustion." Published in the proceedings of the Second International Conference on Managing Hazardous Air Pollutants (sponsored by the Electric Power Research Institute) Washington, D.C. (July 1993).

1

INTRODUCTION

Background

The U.S. Department of Energy is performing comprehensive assessments of toxic emissions from eight selected coal-fired electric utility units. These data are being collected in response to the Clean Air Act Amendments of 1990, which require that EPA conduct a study of the emissions of hazardous air pollutants (HAPs) from electric utility power plants, and these emissions be evaluated for potential health risks. The data will be compiled and combined with similar data that are being collected as part of the Field Chemical Emissions Monitoring program[1] sponsored by the Electric Power Research Institute (EPRI) and will then be furnished to the U.S. Environmental Protection Agency for emissions factor and health risk determinations.

The assessments of emissions involve the collection and analysis of samples from the major input and output streams of each of the eight power plants for selected hazardous pollutants contained in Title III of the Clean Air Act. Additional goals of these assessments are to collect data from the selected plants that may be helpful in characterizing removal efficiencies of pollution control subsystems for these selected pollutants and to determine the concentrations associated with the particulate fraction of the flue gas stream as a function of particle size. Material balances will be performed for selected pollutants around the entire power plant and various subsystems to determine the fate of hazardous substances in each utility system.

Radian Corporation was selected to perform one toxics assessment at a plant demonstrating an Innovative Clean Coal Technology (ICCT) Project. The selected site is the Plant Yates Unit No. 1 of Georgia Power Company, which includes the ICCT CT-121 demonstration project.

Objectives

The specific objectives of this project are:

- To collect and subsequently analyze representative solid, liquid, and gas samples of all specified input and output streams of the Plant Yates, Unit No. 1, including the CT-121 flue gas desulfurization system, for selected hazardous air pollutants that are contained in Title III of the 1990 Clean Air Act Amendments and to assess the potential level of release (concentration) of these pollutants;

- To determine the removal efficiencies of specified pollution control subsystems for selected pollutants at Plant Yates Unit No. 1;
- To determine material balances for selected pollutants in specified subsystems of the power plant and an overall material balance for the power plant;
- To determine the concentration as a function of particle size of the respective pollutants associated with the particulate fraction of the flue gas stream of Plant Yates Unit No. 1;
- To determine the concentration of the respective pollutants associated with the particulate and vapor-phase fractions of the specified flue gas streams of Plant Yates Unit No. 1;
- To determine the concentrations of toxic substances on the surfaces of fly ash particles;
- To provide data for EPA for use in risk assessments and in updating publication AP-42[2];
- To determine hexavalent chromium stack emissions; and
- To compare Method 29[3] vapor-phase mercury results with those obtained via charcoal absorption.

Table 1-1 lists the chemical substances analyzed during this project.

Emission factors, removal efficiencies, and other results rely on measurement data that vary and/or may be near the limit of detection or below it for many of the substances of interest. This report includes uncertainty analysis and confidence intervals in order to assess the quality of the data.

Auditing

During the field sampling program conducted at Plant Yates in June 1993, quality assurance audits were conducted by Radian Corporation's internal QA auditor as well as by Research Triangle Institute, under contract with the U.S. Environmental Protection Agency.

Radian's audit was conducted with the purpose of providing an objective, independent assessment of the sampling effort, ensuring that the sampling procedures, data generating, data gathering, and measurement activities produce reliable and useful results. The audit provided a review of calibration documentation, documentation of QC data, completeness of data forms and notebooks, data review/validation procedures, sample logging procedures, and others.

Table 1-1
Target Analytes

Trace Elements

Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Chromium, total
Cobalt
Copper
Lead
Manganese
Mercury
Molybdenum
Nickel
Selenium
Vanadium

Radionuclides

Hexavalent Chromium

Mercury Speciation/Comparison

Anions

Chloride (HCl)
Fluoride (HF)
Sulfates
Phosphates

Reduced Species

Ammonia
Cyanide

Organics

Formaldehyde
Dioxins
Furans

Volatile Organics

Benzene
Bromoform
Carbon Disulfide
Carbon Tetrachloride
Chlorobenzene
Chloroform
1,4-Dichlorobenzene
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
Ethyl Benzene
Ethyl Chloride (Chloroethane)
Ethylene Dichloride (1,2-Dichloroethane)
Ethylidene Dichloride (1,1-Dichloroethane)
Methyl Bromide (Bromomethane)
Methyl Chloride (Chloromethane)
Methyl Chloroform (1,1,1-Trichloroethane)
Methyl Ethyl Ketone (2-Butanone)
Methylene Chloride (Dichloromethane)
Propylene Dichloride (1,2-Dichloropropane)
Styrene
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,1,2-Trichloroethane
Trichloroethene
Vinyl Acetate
Vinyl Chloride
Vinylidene Chloride (1,1-Dichloroethene)
m,p-Xylene
o-Xylene

Table 1-1 (Continued)

Semivolatile Organics

Acenaphthene
Acenaphthylene
Acetophenone
4-Aminobiphenyl
Aniline
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Benzoic Acid
Benzyl Alcohol
4-Bromophenyl Phenyl Ether
Butylbenzylphthalate
4-Chloro-3-Methylphenol
p-Chloraniline
bis(2-Chloroethoxy)methane
bis(2-Chloroethyl)ether
bis(2-Chloroisopropyl)ether
1-Chloronaphthalene
2-Chloronaphthalene
2-Chlorophenol
4-Chlorophenyl Phenyl Ether
Chrysene
bis(2-Ethylhexyl)phthalate
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Isophorone
Methyl Methanesulfonate
3-Methylchlolanthrene
2-Methylnaphthalene
2-Methylphenol (o-cresol)
4-Methylphenol (p-cresol)
N-Nitroso-di-n-butylamine
N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosopropylamine
N-Nitrosopiperidine
Naphthalene
1-Naphthylamine
2-Naphthylamine
2-Nitroaniline
3-Nitroaniline
4-Nitroaniline
Nitrobenzene
Di-n-octylphthalate
Dibenz(a,h)anthracene
Dibenz(a,j)acridine
Dibenzofuran
Dibutylphthalate
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
2,4-Dichlorophenol
2,6-Dichlorophenol
2,6-Dichlorophenol
Diethylphthalate
p-Dimethylaminoazobenzene
7,12-Dimethylbenz(a)anthracene
Dimethylphenethylamine
2,4-Dimethylphenol
Dimethylphthalate
4,6-Dinitro-2-methylphenol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Diphenylamine
1,2-Diphenylhydrazine
Ethyl Methanesulfonate
2-Nitrophenol
4-Nitrophenol
Pentachlorobenzene
Pentachloronitrobenzene
Pentachlorophenol
Phenacetin
Phenanthrene
Phenol
2-Picoline
Pronamide
Pyrene
Pyridine
1,2,4,5-Tetrachlorobenzene
2,3,4,6-Tetrachlorophenol
1,2,24-Trichlorobenzene
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
2-Fluorobiphenyl
2-Fluorophenol
Nitrobenzene-d5
Phenol-d5
Terphenyl-d14
2,4,6-Tribromophenol

Additional Elements

Aluminum
Calcium
Iron
Magnesium
Potassium
Sodium
Silicon
Strontium
Titanium
Zinc
Uranium (coal only)
Thorium (coal only)

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 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 Appendix D.

RTI was on site during the field sampling program to conduct a systems audit and a performance audit. These audits addressed the Radian sampling program. Results of the RTI audit are presented in Appendix A.

Project Organization

Figure 1-1 shows the organization of this project.

Report Organization

Table 1-2 lists the contents of the major sections and appendices of this final report.

References

1. Electric Power Research Institute. *Field Chemical Emissions Monitoring (FCEM) Generic Sampling and Analytical Plan.* Draft Report. Palo Alto, CA (May 1994).

2. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards. *Compilation of Air Pollutant Emission Factors, Vol. 1: Stationary Point and Area Sources.* AP 42, 4th ed., Research Triangle Park, NC (September 1985 with periodic updates).

3. 40 CFR 266, Subpart H, "Method 29: Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Processes: Proposed Method."

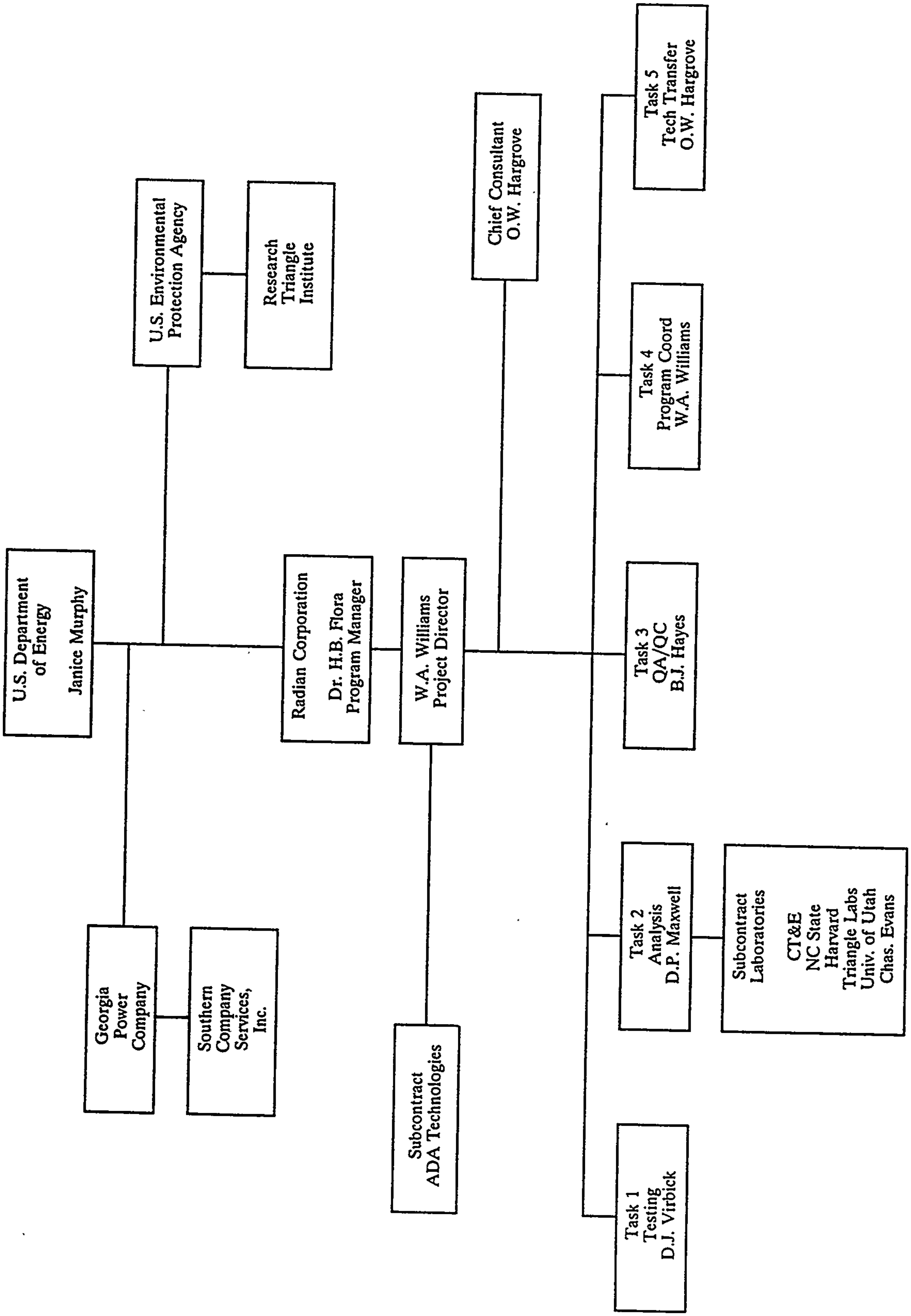


Figure 1-1
Project Organization

Table 1-2
Report Organization

Section	Contents
Glossary	Acronyms, abbreviations, and definitions.
Executive Summary	Stand-alone summary of the document.
Introduction (p. 1-1)	Background, objectives, auditing, contractor organization, and report organization.
Auditing (p. A-1, App. A)	Information on audits conducted by RTI.
Site Description (p. 2-1)	Power plant configuration, process description, sampling locations, and plant operating conditions.
Sample Collection (p. 3-1)	Sampling schedule, test matrix, samples collected, sample handling, sample presentation, sample compositing.
Sampling Protocol (p. B-1, App. B)	Method descriptions, sample train disassembly, sample preparation for transportation, and storage.
Sample Preparation and Analysis Methods (p. 4-1)	Preparation procedures and chemical analysis methods for gases, liquids, and solids.
Analytical Protocol (p. E-1, App. E)	Method descriptions, deviations, and modifications.
Analytical Results (p. 5-1)	Tabulated analytical information for gases, liquids, and solids.
Sampling Data Sheets (p. C-1, App. C)	Data for gas samples, including calculations for samples at the stack outlet.
Data Analysis and Interpretation (p. 6-1)	An evaluation of the overall quality of the data, material balances, trace species removal efficiencies, and emission factor determinations.
Quality Assurance/Quality Control (p. D-1, App. D)	Radian systems and performance audits: precision, accuracy, and completeness in the areas of sample collection, analysis, and DQOs. Detailed QA/QC results in tabular form.

Table 1-2 (Continued)

Section	Contents
Uncertainty Analysis (p. F-1, App. F)	Description of how the error propagation analysis was performed on calculated results.
Treatment of Non-Detects, Values Outside of the Calibration Range, and Blanks (P. G-1, App. G)	Information provided by DOE.

2

SITE DESCRIPTION

Power Plant Configuration

The Plant Yates Unit No. 1 is a bituminous coal-fired steam electricity-generating unit with a net generating capacity of 100 megawatts. Located in Newnan, Georgia, the station is owned and operated by Georgia Power Company. Unit 1 includes a tangentially fired CE boiler that burns a 2.5% sulfur blend of Illinois No. 5 and Illinois No. 6 bituminous coals, an electrostatic precipitator for particulate control, and the CT-121 flue gas desulfurization system for sulfur dioxide (SO_2) emissions control during the ICCT demonstration.[1]

A process flow diagram of the Plant Yates facility that includes sampling locations is presented in Figure 2-1. Flue gas flows through a single duct into the ESP, which is four chambers wide and three rows of chambers deep; however, only the first two rows of chambers are energized. The ESP has a separate row of hoppers to collect the fly ash from each field, i.e., one row of hoppers per field. After the ESP, the flue gas flows through a single ID fan and then to the CT-121 system. The flue gas exiting the CT-121 unit is vented to the atmosphere through a 250-foot exhaust stack. No other units at the station use this stack.

Process Description: Major Process Streams

CT-121 Wet FGD System

The CT-121 is a second-generation FGD process which employs a unique absorber design, called a jet bubbling reactor (JBR), to combine conventional SO_2 absorption, neutralization, sulfite oxidation, and gypsum crystallization in one reaction vessel. The process is designed to operate in a pH range (3 to 5) where the driving force for limestone dissolution is high, resulting in nearly complete reagent utilization. Oxidation of sulfite to sulfate is also promoted at the lower pH because of the increased solubility of innate oxidation catalysts such as iron (Fe). Because all of the absorbed SO_2 is oxidized, there is sufficient surface area for gypsum crystal growth to prevent the slurry from becoming significantly supersaturated with respect to calcium sulfate. This significantly reduces the potential for gypsum scaling, a problem that frequently occurs in natural-oxidation FGD systems. Since much of the crystal attrition and secondary nucleation associated with the large centrifugal pumps in conventional FGD systems is also eliminated in the CT-121 design, large, easily dewatered gypsum crystals can be produced.

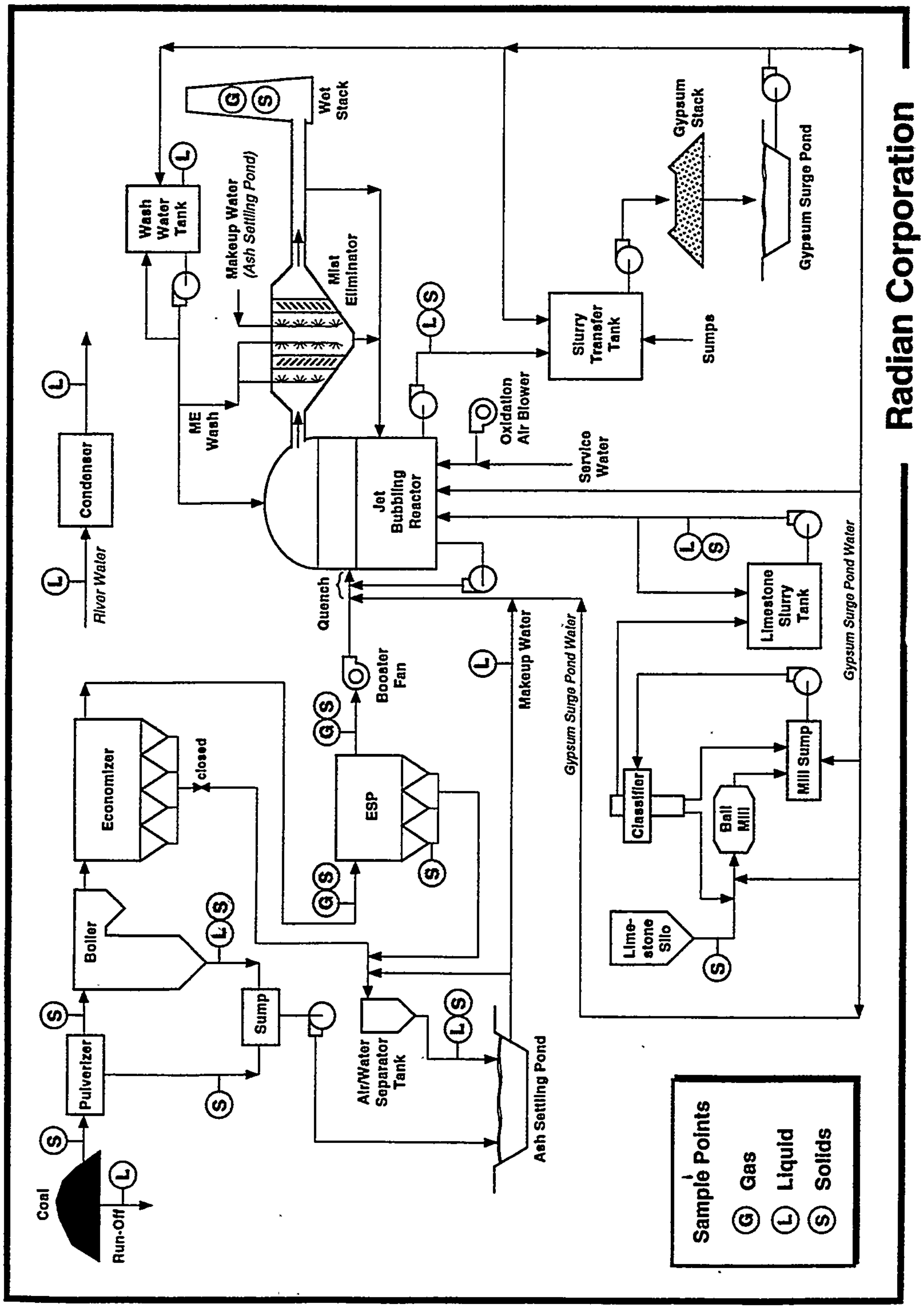


Figure 2-1
Simplified Process Flow Diagram Illustrating Sampling Locations and Flue Gas Flow

Gas Cooling Section. Flue gas from the boiler passes through the ESP and is pressurized by the Unit 1 I.D. fan. From the fan, the flue gas enters the gas cooling section. Here the flue gas is cooled and saturated with a mixture of JBR slurry, makeup water, and pond water. The quench slurry is sprayed into the gas at a liquid-to-gas ratio of about 10 gal/1000 acf at full boiler load using two centrifugal gas cooling pumps. The suction for the gas cooling pumps is located near the bottom of the JBR.

JBR. From the gas cooling section, the flue gas enters the JBR. The JBR is the central feature of the CT-121 process. The gas enters an enclosed plenum chamber formed by an upper deck plate and a lower deck plate. Sparger tube openings in the lower deck plate force the gas into the slurry contained in the jet bubbling (froth) zone of the JBR vessel. After bubbling through the slurry, the gas flows upward through gas risers which pass through both the lower and upper deck plates. Entrained liquor in the gas disengages in a second plenum above the upper deck plate, and the cleaned gas passes to the mist eliminator.

The slurry in the JBR can be divided into two zones: the jet bubbling or froth zone and the reaction zone. SO_2 absorption occurs in the froth zone, while neutralization, sulfite oxidation, and crystal growth occur in both the froth and reaction zones.

The froth zone is formed when the untreated gas is accelerated through the sparger tubes in the lower deck and bubbled beneath the surface of the slurry at a depth of 6 to 16 inches. The froth zone provides the gas-liquid interfacial area for SO_2 mass transfer to the slurry. The bubbles in the froth zone are continually collapsing and reforming to generate new and fresh interfacial areas and to transport reaction products away from the froth zone to the reaction zone. The amount of interfacial area can be varied by changing the level in the JBR, and consequently, the injection depth of flue gas. The deeper the gas is injected into the slurry, the greater the interfacial area for mass transfer and the greater the SO_2 removal. In addition, at deeper sparger depths, there is an increase in the gas-phase residence time. SO_2 removal can also be increased by increasing the pH of the slurry in the froth zone, since a higher pH results in higher slurry alkalinity. The pH is controlled by the amount of limestone fed to the reaction zone of the JBR.

The solids concentration in the JBR is maintained at a constant level by removing a slurry stream from the bottom of the reaction zone and pumping this stream to a holding tank (gypsum slurry transfer tank), where it is diluted with pond water before being pumped to the gypsum stack. This is done to keep the velocity high over a range of operating conditions.

The oxygen which reacts with absorbed SO_2 to produce sulfate is provided to some extent by oxygen diffusion from the flue gas, but the predominant source is air bubbled into the reaction zone of the JBR. The oxidation air lines enter through the very top of the JBR vessel, penetrate the upper and lower deck plates, and introduce the air near the bottom of the JBR. Oxygen diffuses from the air into the slurry as the bubbles rise to the froth zone of the JBR. Excess air mixes with the flue gas and exits the JBR to the mist eliminator. Before the oxidation air enters the JBR, it is saturated with service water to prevent a wet-dry interface at the discharge of the oxidation air lines.

Ash and Cooling System

Plant Yates uses an ash settling and storage area consisting of one ash-settling pond. Bottom ash from the boiler and pyrites from the pulverizers are sluiced together and are disposed of in the ash-settling pond. The ESP ash, economizer ash, and air preheater ash are also sluiced together and disposed of in the same ash-settling pond. Water from the Chattahoochee River is used for cooling water in a once-through type steam condenser.

ESP Design

The ESP is a conventional weighted wire configuration typical of many of the older ESPs found on coal-fired utility boilers in the Midwest and Eastern parts of the United States. Details of the ESP are provided in Table 2-1. The specific collection area (SCA) is 210 ft^2/kacfm at full load. This size is representative of the ESPs built during the 1970s to provide collection efficiencies of 95 to 99 percent. The plate-to-plate spacing is 9 inches, which is typical for this vintage ESP. Current ESP design standards use 12- to 16-inch spacing to reduce the impact of plate or wire misalignment which can cause sparking at lower voltages. The velocity is somewhat lower than many of the older ESPs which often operate at velocities of 6 or 7 ft/sec. The average ESP velocity of 4.4 ft/sec is more characteristic of modern design practices.

Figure 2-2 shows a schematic layout of the ESP. The ESP is configured with three mechanical sections and four electrical sections. As shown in the schematic, the arrangement is somewhat unusual in that the mechanical sections are not aligned with the electrical sections. This provided some minor difficulties in modeling the performance of the ESP, as described in Section 8.

Figure 2-2 also identifies the rapping components. The Plant Yates ESP uses a Forry Rapper Control System programmed to operate vibrators on the high voltage wire frames and electromechanical rappers on the collector plate assemblies. Table 2-2 presents a detailed breakdown of the rapping frequencies. The high-voltage wire frame vibrators are on a 12 minute repeat cycle and have 2 second on-times. The collector plate rappers have a 30 minute repeat cycle and are energized to lift the 20-pound solenoids nominally four inches before releasing them. The rapping cycles are offset so that only one section of the plates is rapped at any single period of time. This rapping procedure results in smaller but more frequent spikes in opacity.

Process Description: Sampling Locations

Samples were collected from streams representing three types of matrices: gases, solids, and liquids. Gaseous samples were collected from the inlet and outlet of the ESP and from the stack. Solids were collected of the coal feed, bottom and fly ashes, limestone,

Table 2-1
Summary of Design Data on the Yates Unit #1 ESP

Manufacturer	Buell
Housing	1 ESP Box
Mechanical Sections	3
Electrical Sections	4
Gas Flow Passages	82
Collector Electrodes	
Plate Spacing	9 inches
Plate Height	30 ft
Total Plate Length	21 ft
Length of Sections	9 ft Section 1, 6 ft for Sections 2 & 3
Total Plate Area	103,320 ft^2
Total Cross Section Area	1845 ft^2
Gas Conditions	
Gas Flow at Full Load	491,000 acfm
Gas Velocity at Full Load	4.4 ft/second
Residence Time at Full Load	4.7 seconds
SCA at Full Load	210 ft^2/kacfm
Emitter Design	
Design	Weighted Wire
Diameter	0.110 inches
Spacing	8 inches
Number	2,296
Total Wire Length	68,880 ft

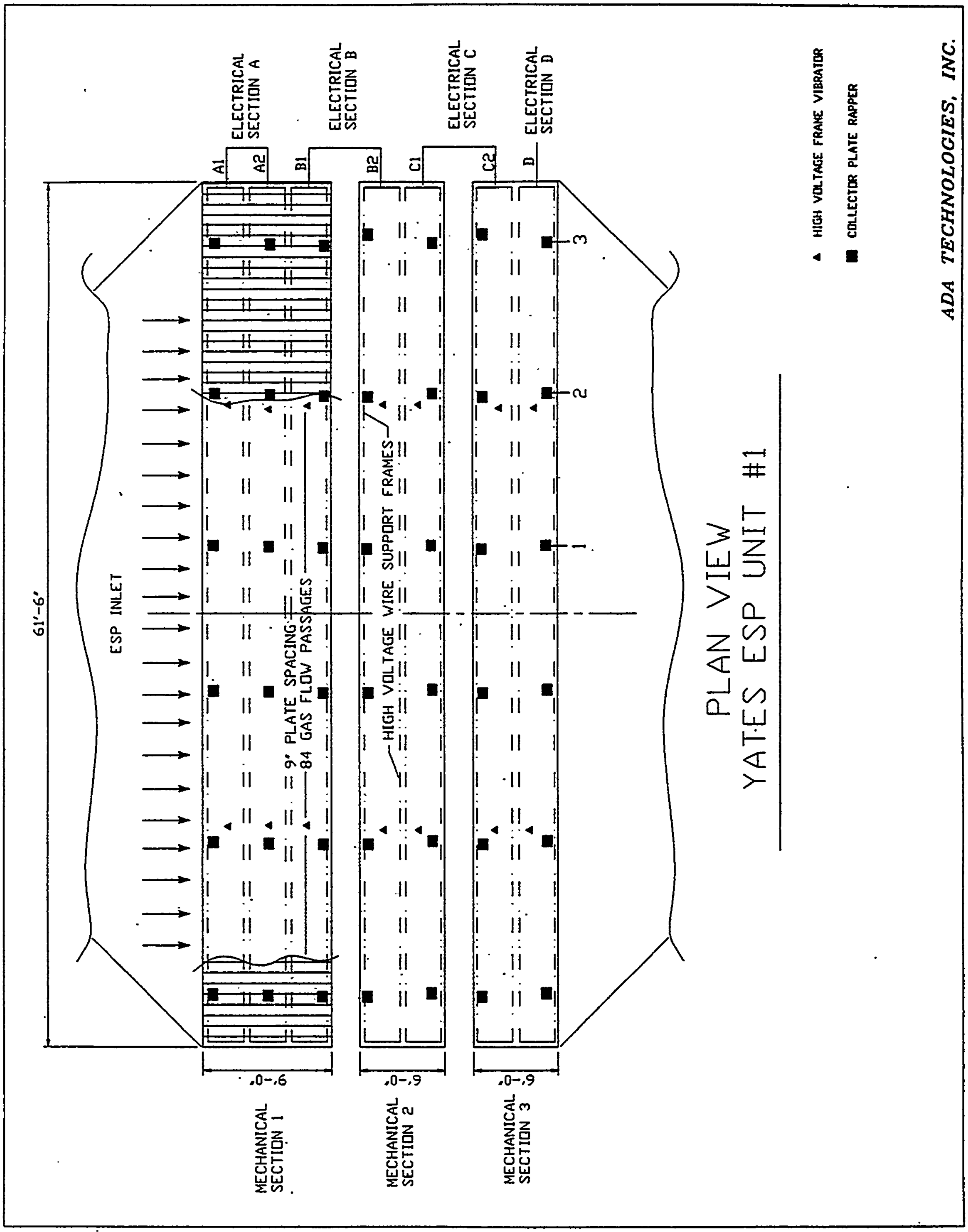


Figure 2-2
Plan View Plant Yates ESP Unit #1

Table 2-2
ESP Rapping Schedule
Plant Yates Unit #1

Mechanical Section	Rapper Type	Cycle Repeat Time	Rapper Identification	Activated (minutes into cycle)
1	HV Vibrator (1 vibrator per frame)	12 minutes	HV: A1	4
			HV: A2	8
			HV: B1	12
2	HV Vibrator	12 minutes	HV: B2	5
			HV: C1	10
3	HV Vibrator	12 minutes	HV: C2	6
			HV: D	12
1	Plate Rapper (1 rapper per plate support)	30 minutes	Plate: A1-1	4
			Plate: A1-2	8
			Plate: A1-3	12
1	Plate Rapper	30 minutes	Plate: A2-1	5
			Plate: A2-2	10
			Plate: A2-3	15
1	Plate Rapper	30 minutes	Plate: B1-1	6
			Plate: B1-1	12
			Plate: B1-3	18
2	Plate Rapper	30 minutes	Plate: B2-1	7
			Plate: B2-2	14
			Plate: B2-3	21
2	Plate Rapper	30 minutes	Plate: C1-1	8
			Plate: C1-2	16
			Plate: C1-3	24
3	Plate Rapper	30 minutes	Plate: C2-1	9
			Plate: C2-2	18
			Plate: C2-3	27
3	Plate Rapper	30 minutes	Plate: D-1	10
			Plate: D-2	20
			Plate: D-3	30

Note: Rapping frequency and cycles are duplicated for each side of the ESP.

and FGD slurry. Liquids included the makeup waters, sluice waters associated with the ash steams, and filtrate from the limestone and FGD slurry streams, cooling water, and coal pile runoff. Figure 2-1 illustrates the sampling locations which are described in detail in the following sections.

Flue Gas Sample Streams

Three flue gas stream locations were identified for testing:

- ESP inlet;
- ESP outlet (FGD inlet); and
- Stack.

The ESP inlet sampling location is located at ground level. Sixteen four-inch ports are located horizontally just downstream of where two ducts which exit the air preheater are combined.

The ESP outlet location is located approximately 60 feet above ground level. Six four-inch ports are located vertically across the duct.

The stack sampling location is approximately 120 feet above ground level and has four four-inch ports, equally spaced at 90 degrees.

Solid Sample Streams

Solid streams sampled were the following:

- Raw coal;
- Pulverized feed coal;
- Pulverizer rejects;
- Bottom ash;
- ESP fly ash;
- Raw limestone;
- Limestone slurry solids; and
- FGD slurry solids.

Solid samples were collected concurrent with the gas stream testing and are considered to be representative of process operation.

Coal Samples. The sample locations for collecting coal samples are located around each of the four coal pulverizers serving Unit 1. Samples of raw coal were collected from each pulverizer feed chute after the weigh belt. Feed coal samples were collected at the exit of each pulverizer, just prior to the boiler feed, and the pulverizer rejects were collected at the inlet to each reject hopper.

Ash Samples. Bottom ash samples were collected wet at the bottom ash sluice water sump upstream of the bottom ash sluice pumps. Bottom ash was separated from the sluice water by allowing the solids to settle and siphoning off the sluice water. ESP fly ash was collected dry from the clean-out ports of the two energized banks of ESP hoppers, and sluiced ESP fly ash was also collected at the sluice water discharge to the ash pond.

Limestone. Limestone samples were collected from two sampling locations. Raw limestone was collected off the weigh belt feed to the grinding mill, and limestone slurry was collected from a sample tap on the recirculating limestone slurry feed line to the JBR. Slurry samples were filtered to obtain the solids.

FGD Solids. FGD solids were sampled from a sample tap at the discharge of the JBR underflow slurry pumps. The solids were filtered through a filter press to separate the solid and liquid phases at the time of collection.

Liquid Sample Streams

The following liquid streams were sampled:

- Ash pond water;
- Gypsum pond water;
- Ash sluice water (bottom ash and fly ash);
- FGD slurry blowdown filtrate;
- Limestone slurry filtrate;
- Coal pile run-off; and
- Cooling water at the condenser inlet.

Liquid samples were collected concurrent with the gas-phase testing and are considered to be representative of process operation during that time period.

Pond Waters**.** Ash and gypsum pond water were sampled from sample taps. The ash pond water sample tap is located near the limestone slurry tank containment area where ash pond water is used in limestone slurry preparation. Gypsum pond water was collected from a sample tap located on the mist eliminator wash water tank.

Ash Sluice Water**.** Bottom ash and ESP fly ash sluice water samples were obtained by siphoning the aqueous phase of the ash/water sluice mixture from the solid phase after allowing approximately 2 hours for the solids to settle. The collection points for the ash sluice samples are described in the section on solid sample streams.

Limestone and FGD Filtrates**.** The aqueous phases of the limestone slurry and JBR underflow slurry were obtained from filtration of the collected solids samples described earlier. Limestone slurry and all FGD filtrates for organic compound analyses were sampled from a filter press at the point of collection to avoid loss of organics and to prevent further reactions in the FGD slurry matrix.

Coal Pile Run-off**.** Coal pile run-off collection was performed after a rain storm. Samples were collected from shallow trenches leading from the coal pile to the run-off collection pond.

Condenser Water Samples**.** Cooling water samples at the inlet of the turbine steam condenser were collected from a sample tap located at the discharge of the cooling water pumps.

Plant Operating Conditions

Operating conditions were continuously monitored via a computerized data acquisition system (DAS) which logged process information as 15 minute averages. In addition, boiler operating data were logged hourly by the control room operators. Of the total amount of data collected, key parameters have been summarized and are presented in Table 2-3. These data reflect the general stability of the process. Unit load and furnace gas oxygen concentrations are shown graphically in Figures 2-3 and 2-4. The dashed lines represent the bounds of what is considered normal operation. Also, the grey shaded areas represent the periods during which testing was being performed. Key operating parameters for the CT-121 process are shown in Figures 2-5 and 2-6. Overall, all processes were very stable and the key operating parameters were within the targeted range during the entire test period.

Three continuous emission monitors were operated during the test period. Sulfur dioxide and nitrogen oxides were monitored continuously by existing Plant Yates instrumentation. Carbon monoxide was monitored using an instrument supplied by Radian. The results of the CEM monitoring are presented in Figures 2-7, 2-8, and 2-9.

Table 2-3
Summary of Process Monitoring Data[a]

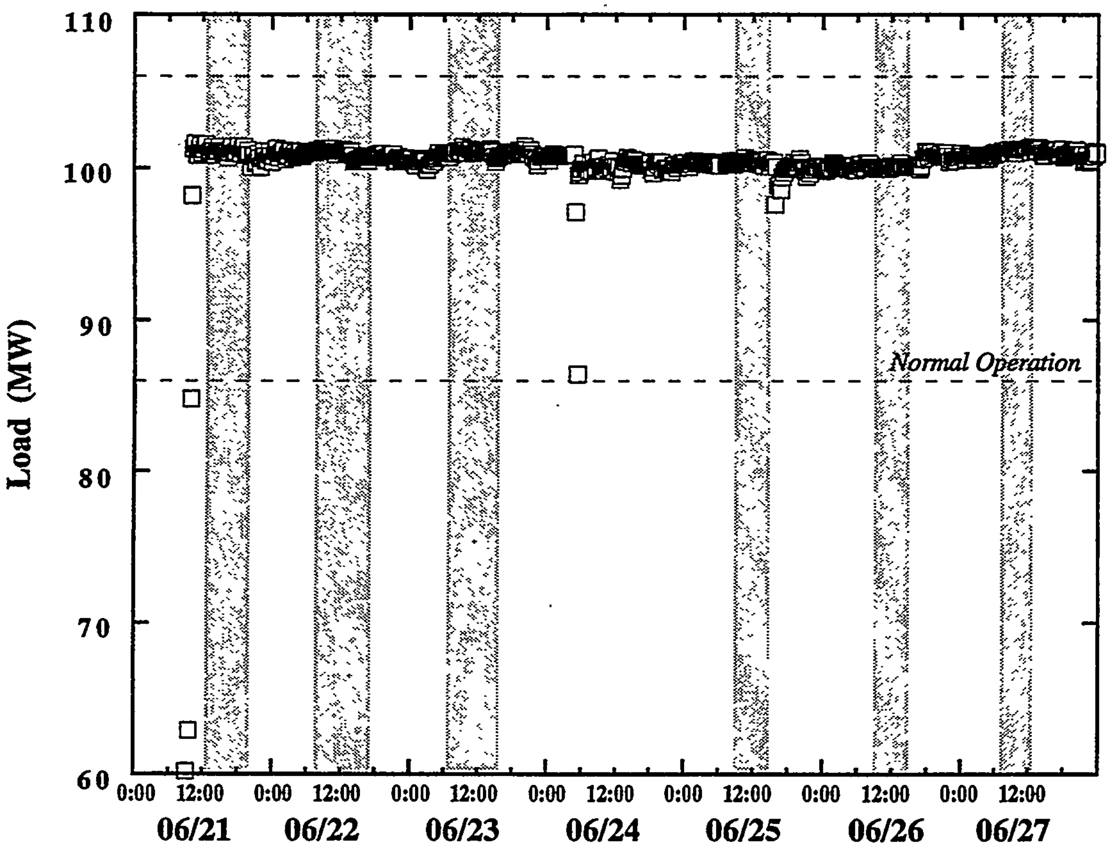
Parameter	6/21	6/22	6/23	6/25	6/26	6/27
Boiler:						
Load (MW)	101	101	101	100	100	101
Coal Flow (1,000 lb/hr, wet)	89	88	89	90	91	92
Furnace O_2 (%)	3.5	3.6	3.5	3.3	3.3	3.4
Burners in Service	16	16	16	16	16	16
ESP:						
Opacity (%)	15.0	14.4	16.0	17.1	17.7	18.6
JBR:						
SO_2 removal[b] (%)	93.0	91.6	90.7	88.8	--[c]	--[c]
Scrubber pH	4.6	4.5	4.5	4.5	4.5	4.5
JBR ΔP (Inches H_2O)	14.1	14.1	14.1	14.1	14.1	14.1
Stack:						
O_2 (%, dry)	8.2	8.0	7.9	7.7	7.7	7.6
SO_2 (ppmv, dry)	160	181	202	236	182	186
NO_x (ppmv, dry)	430	490	470	430	420	320
CO (ppmv, dry)	3.5	--[d]	2.6	2.6	2.0	5.7

[a] Daily averages.

[b] Based upon SO_2 corrected to 3% O_2.

[c] Inlet O_2 monitor not functioning properly.

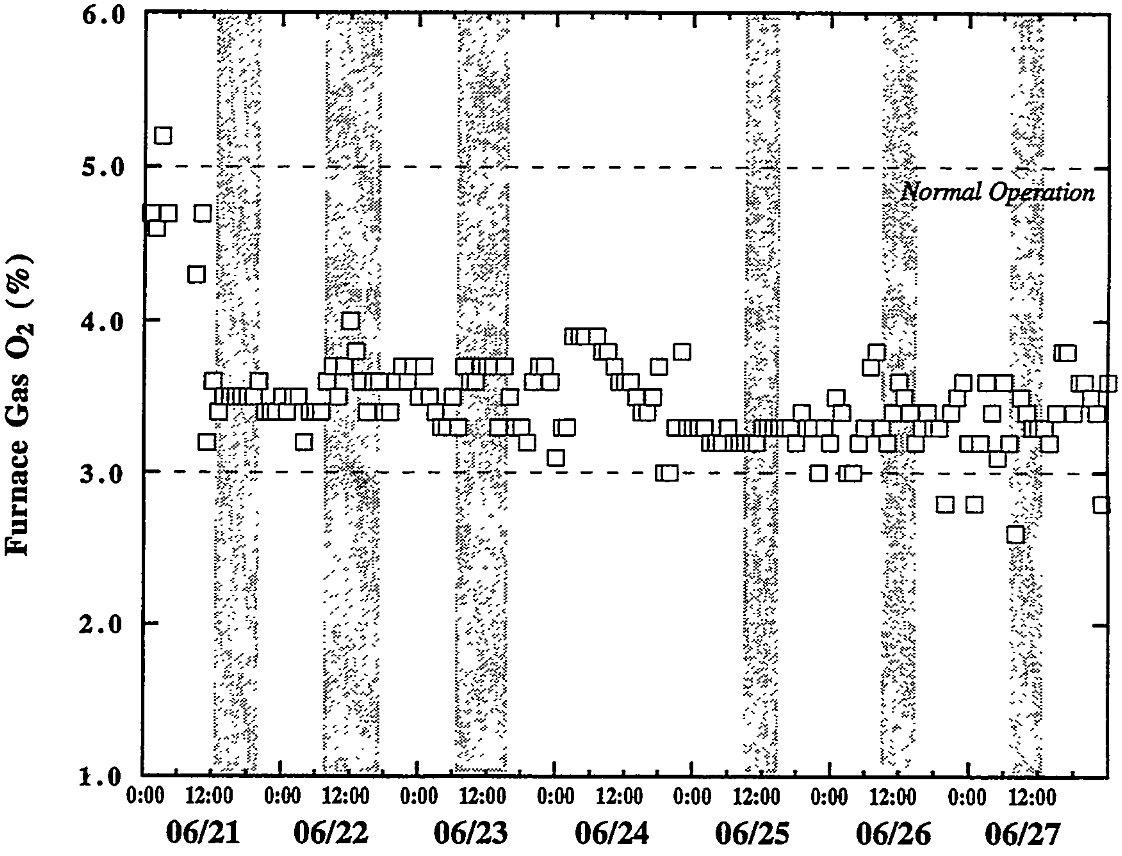
[d] CO monitor not functioning properly.



Load
Data points are 15-minute average values.

▨ **Test Periods**

Figure 2-3
Unit 1 Load



Furnace Gas O_2
Data points are hourly values.

▨ **Test Periods**

Figure 2-4
Furnace Gas Oxygen

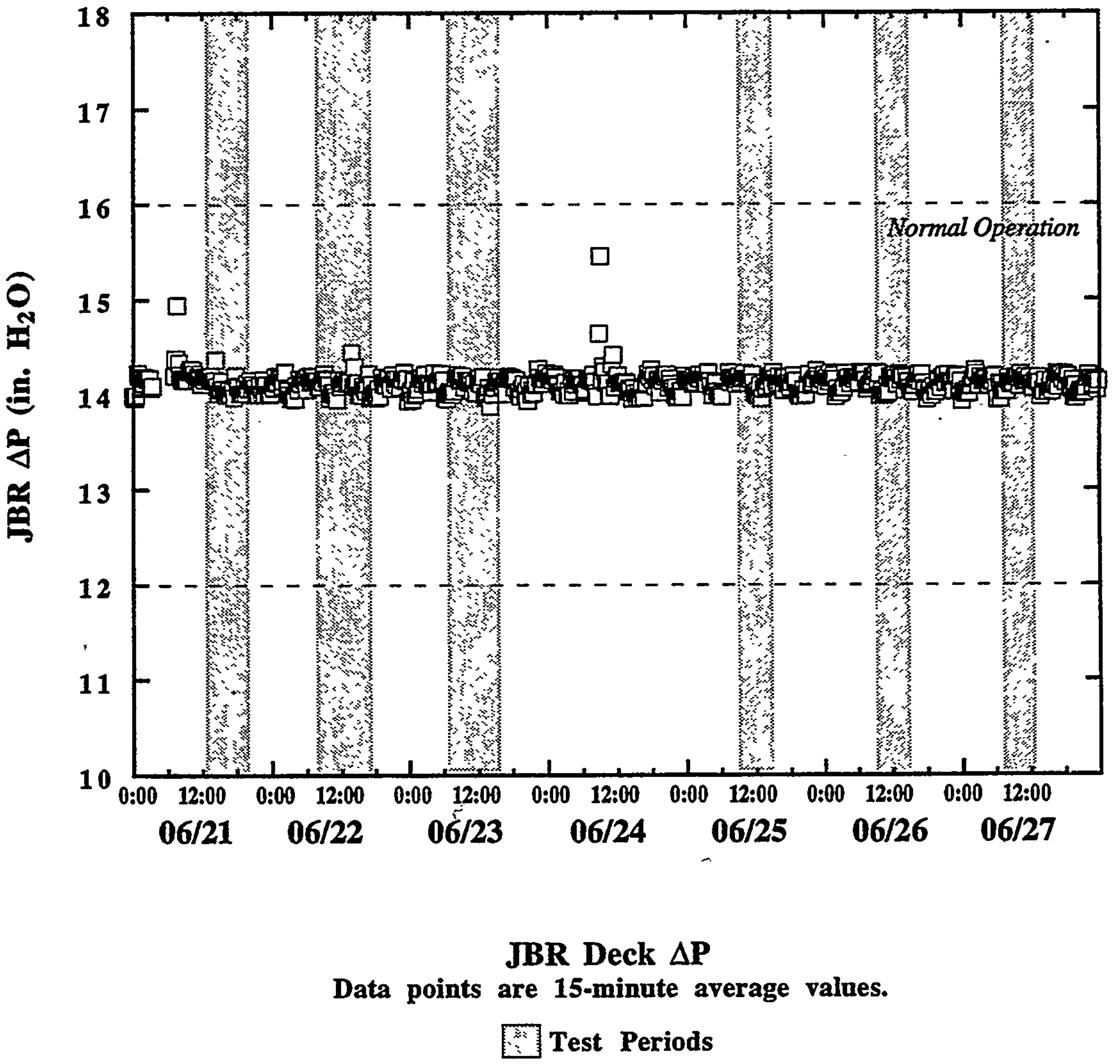


Figure 2-5
JBR Pressure Drop

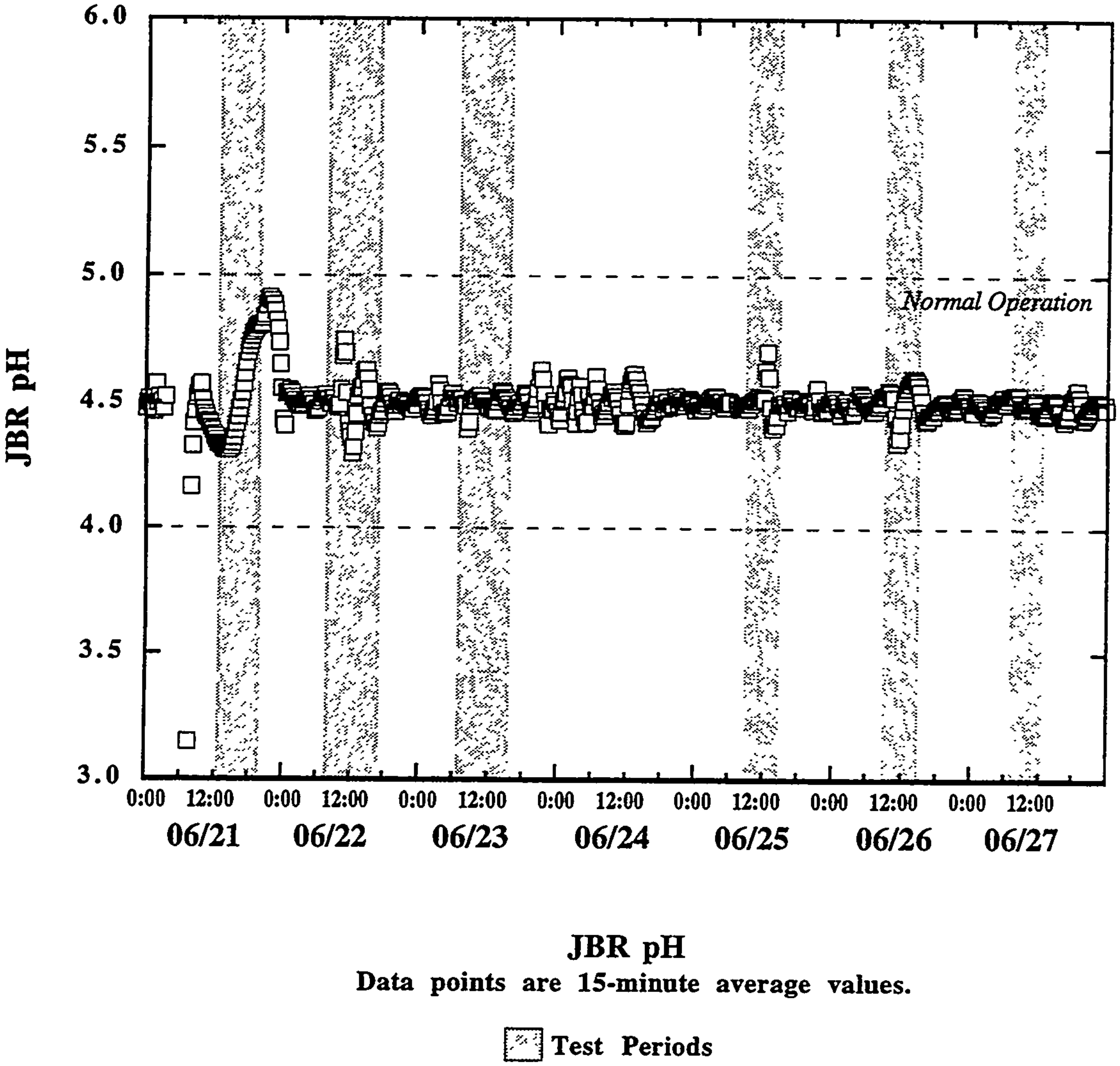
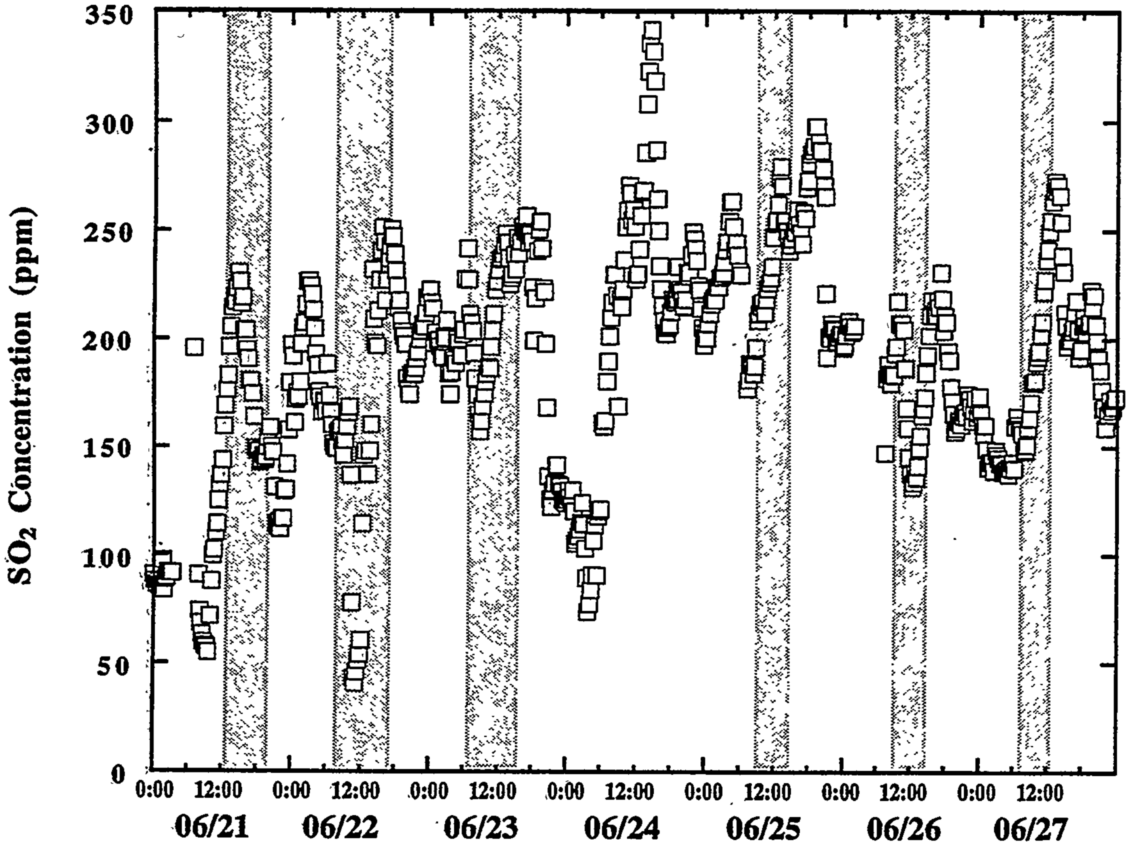


Figure 2-6
JBR pH



Stack SO$_2$ Concentration @ 3% O$_2$

Data points are 15-minute average values.

▨ **Test Periods**

Figure 2-7
Stack SO$_2$

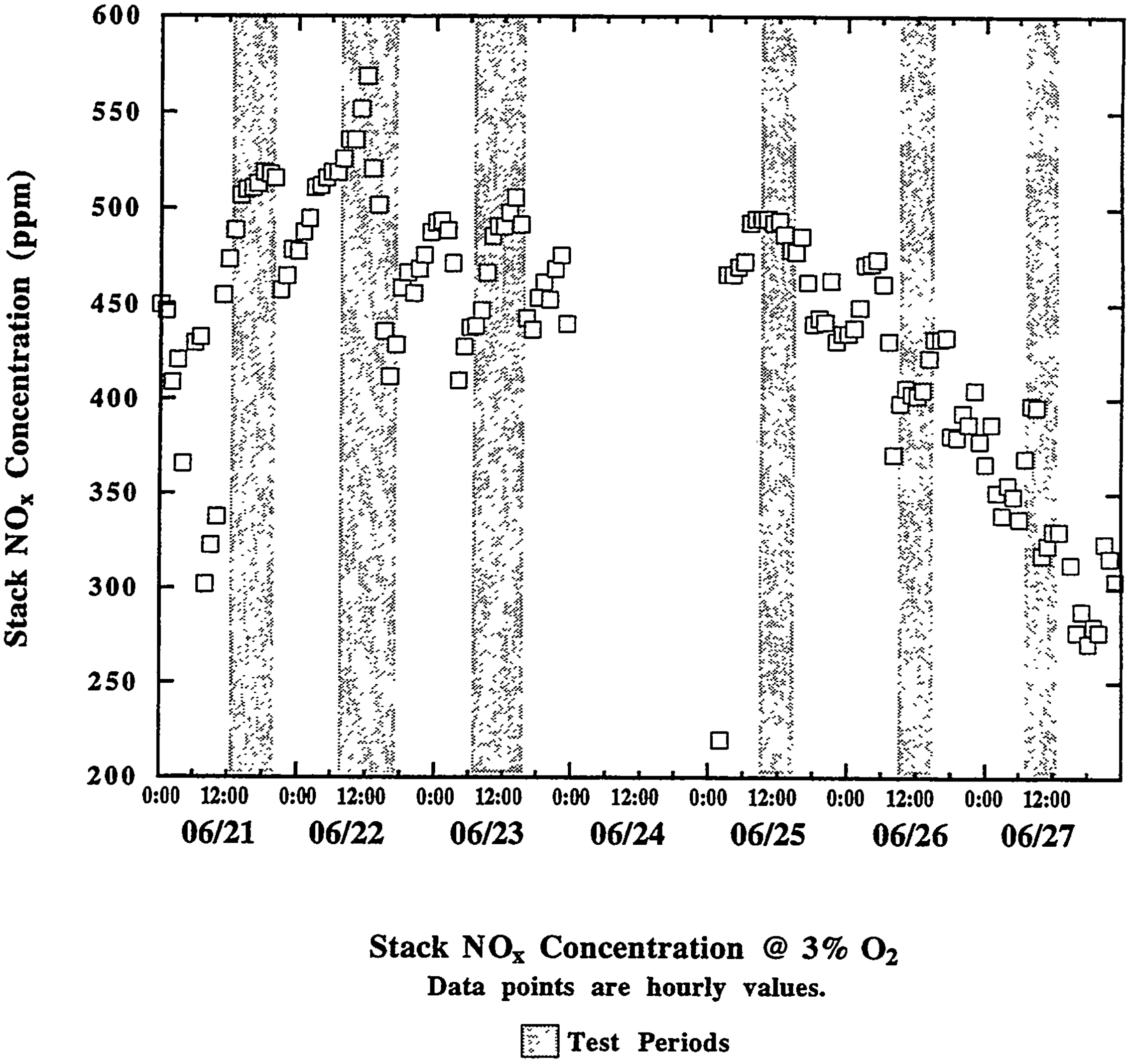


Figure 2-8
Stack NO_x

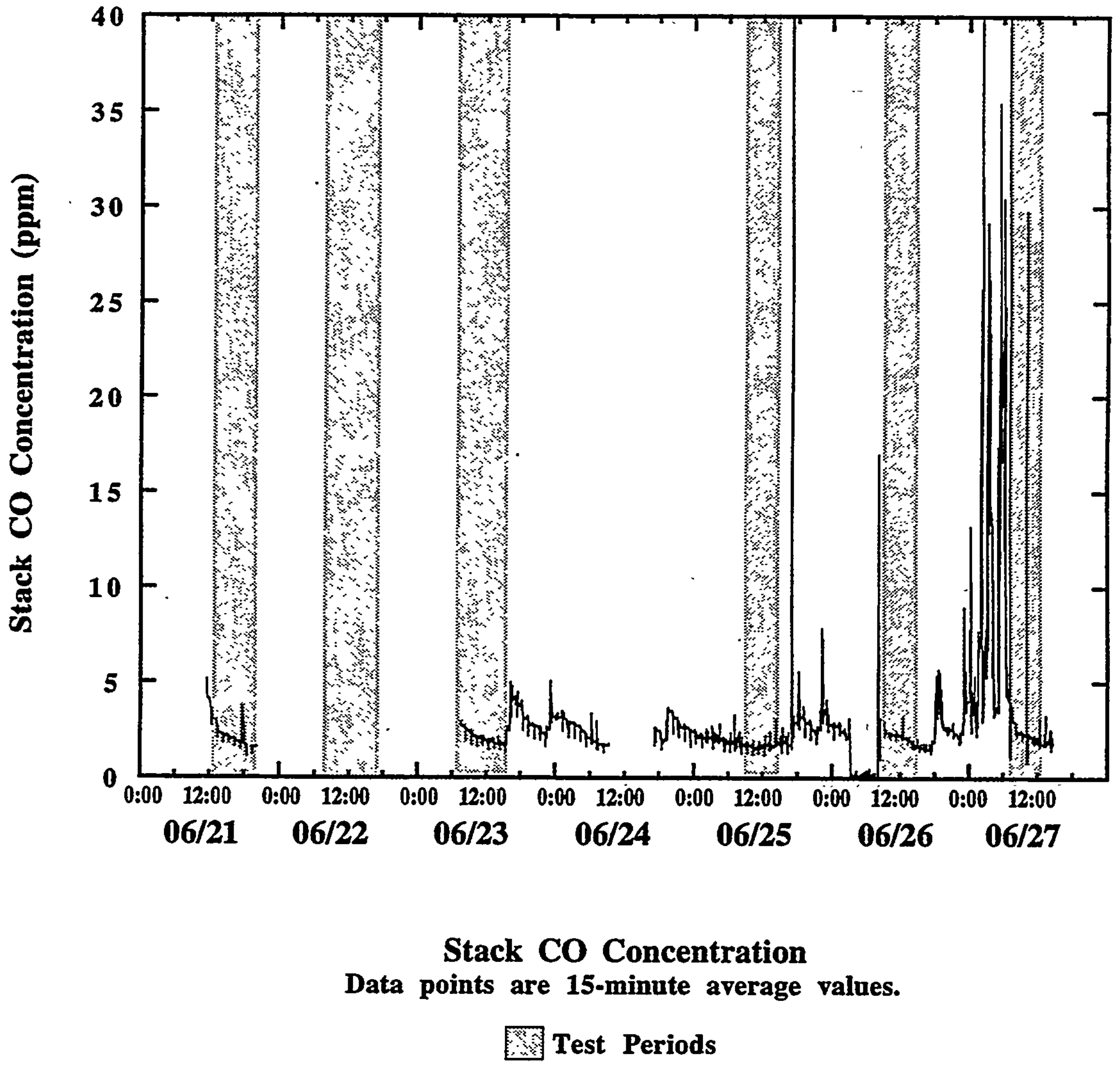


Figure 2-9
Stack CO

Problems

Only slight operational problems were encountered during the test effort. On the first day of testing, a steam leak was detected and, although the leak was minor, plant personnel opted to bring the plant down to fix the leak, rather than run the risk of having a major problem occur while the testing was in progress. Repairing the leak resulted in a six-hour delay in the start of the testing activities on day one.

The average JBR SO_2 removal efficiency dropped below 90% on June 25. A change in the JBR piping is believed to have resulted in a high bias in the pH indicators. For this reason, SO_2 removal was generally lower than expected. However, with respect to the range of SO_2 removal achieved over the previous four days, the 88.8% removal is within normal operating limits and had no effect on the test results.

Deviations from Sampling Plan

The sampling approach was defined with soot blowing confined to the evening shifts and no testing was to be performed during soot blowing events (with the exception of round-the-clock sample collection for PSD at the stack and bulk particulate collection at the stack and ESP Outlet). However, during the second day of the material balance period a high pressure drop was encountered across the air pre-heater (APH). Sampling was delayed for two hours while the APH soot-blowers were activated. A full pressure drop reduction could not be achieved and the decision was made to continue testing with the APH soot blowers activated continuously. Testing on the third day was also done with the APH soot blowers activated. This approach provided consistent process operation for the testing. Soot blowing at all other boiler locations was not performed until after the testing was completed each day. A post-test inspection of boiler operator logs indicated that APH soot-blowing was probably done continuously during the first day of the material balance period also. Although boiler control room instructions were for "no soot blowing," the post-test inspection revealed a steadily decreasing pressure drop across the APH on Day 1 of the material balance period. Typically, this only happens if the APH soot blowers are on. There was, however, no way to confirm this after the fact. The impact of the APH soot blowing is currently judged not to have an impact on the data quality or the overall test results.

References

1. David P. Burford, Oliver W. Hargrove, and Harry J. Ritz, "Demonstration of Innovative Applications of Technology for the CT-121 FGD Process." Published in the proceedings of the First Annual Clean Coal Technology Conference (sponsored by the U.S. Department of Energy), Cleveland, OH (September 1992).

3

SAMPLE COLLECTION

Radian used established sampling methods (where possible) and a sampling strategy consistent with that of the EPRI-sponsored Field Chemical Emissions Monitoring (FCEM) program[1] to accomplish the project goals. Samples were collected with Plant Yates operating within 10% of full load, at steady-state conditions, and in triplicate over two three-day periods.

Sampling Schedule

Radian performed the test program at the Yates facility in two discrete three-day sampling periods. During the first three-day period (Phase I), samples were collected for the characterization of organic species and particle size distribution, and ADA Technologies performed an assessment of the ESP operating characteristics. The second three-day sampling period (Phase II) was a "material balance period," during which samples were collected for analysis of inorganic components.

Figures 3-1 and 3-2 illustrate the sampling periods for each sample stream. Field blank samples were collected June 20, 1993 for the organic-phase test parameters and field blank samples were collected for the "material balance" parameters on June 24, 1993.

Samples Collected

All sampling was performed according to the procedures detailed in the Management Plan for the Plant Yates CT-121 FGD Project.

Only two deviations were noted from the specifications provided in the Management Plan. The first involves the collection of dry ash from the ESP ash hoppers. The management plan specified for the collection of samples from three rows of hoppers; however, after arrival on site, it was discovered that only the first two rows were energized. The sampling approach was modified to limit the sampling to just the first two rows of hoppers. These first two rows (four hoppers per row) of hoppers were to be sampled individually; however, only seven of the eight hoppers could be sampled. A valve stuck open on hopper number 7, and the system could not be isolated from the sluice system.

The second deviation concerned the collection of condenser water. No condenser outlet samples could be collected, as the two valves located at the condenser outlet were not operational.

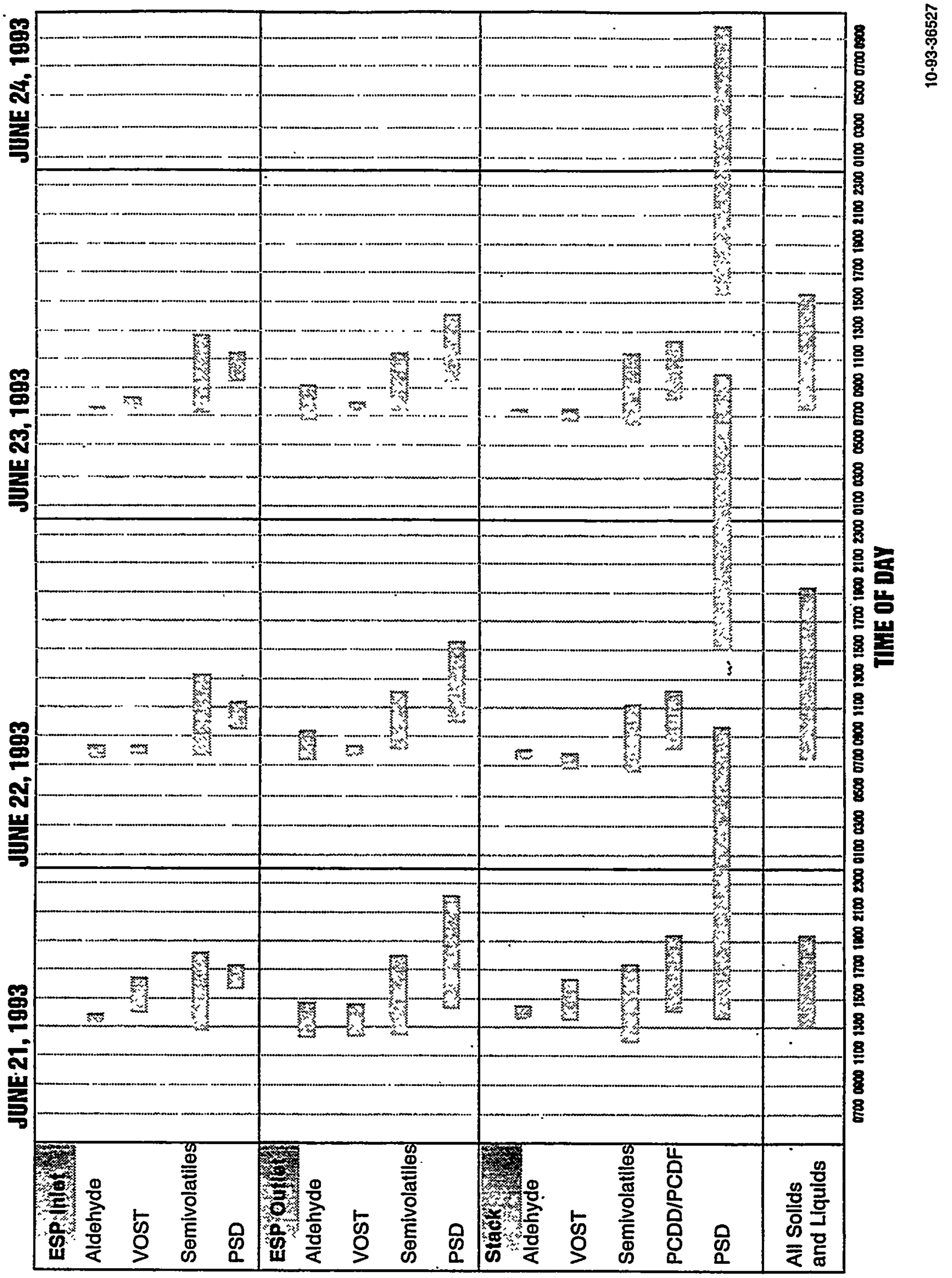


Figure 3-1
Sample Collection Schedule for June 21-24, 1993

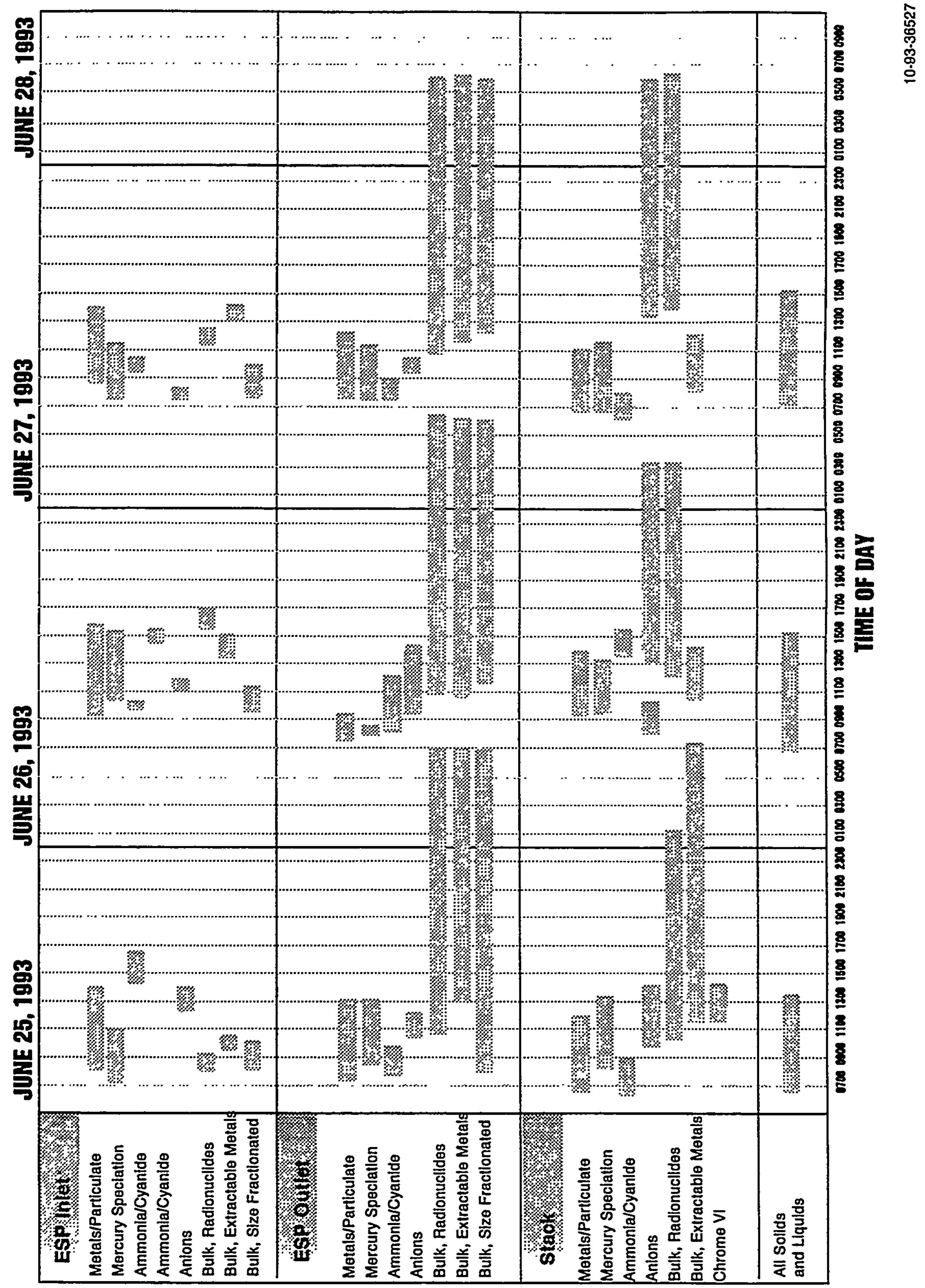


Figure 3-2
Sample Collection Schedule for June 25-28, 1993

Gas Samples

Samples were collected from three separate gas locations during the toxics emission study, namely the ESP inlet, the ESP outlet, and the stack. Sampling was performed concurrently at each location with specific run times varying due to effluent conditions.

A summary of the samples collected from the gaseous locations is presented in Table 3-1. The summary identifies the sample type, collection method, the number of samples collected and analyzed from each location, and the sample preservation techniques. Samples collected as part of the QA/QC program for gaseous samples are identified in Table 3-2.

Gas sampling data sheets are available in Appendix C. Data presented in Appendix C include the sample run times and sample volumes. In addition to the summarized field data, the calculations used for data reduction are also presented.

Liquid Samples

Liquid samples were collected concurrently with the gaseous sampling. The primary liquid collection technique was grab sampling. Table 3-3 identifies each of the streams sampled as well as the collection method, number of samples collected and analyzed, and the sample preservation techniques. Table 3-4 lists the liquid samples which were collected and/or analyzed as part of the QA/QC program.

Liquid samples were composited daily during each test run with the exception of the aldehydes and volatile organic compound (VOC) samples which were collected as single grab samples. The sluices and slurry filtrates were also collected as composite samples during each test run and the solids removed either by settling and decantation, or direct filtration from the process sample point. Detailed descriptions of the sampling techniques are presented in Appendix B.

Solid Samples

Solid samples were collected concurrently with the gaseous and liquid sampling. Sampling was performed by compositing grab samples that were collected at regular intervals during the gas sampling period. In addition to the grab sampling, solids were also collected during sluicing operations of the bottom ash and ESP ash. These samples were collected by grab sampling techniques through the duration of the sluicing and composited into one sample per test run.

Detailed descriptions of the solids sampling techniques are presented in Appendix B. Table 3-5 summarizes the solid sampling effort during this program. The table identifies the sample location or sample type, the collection method, the number of samples collected and analyzed, and the sample preservation techniques. Samples collected or submitted to support the QA/QC program for the solids are listed in Table 3-6.

Table 3-1
Gaseous Sampling Summary

Test Parameter	Collection Method[a]	ESP Inlet		ESP Outlet		Stack		Sample Handling and Preservation
		Samples Collected	Samples Analyzed	Samples Collected	Samples Analyzed	Samples Collected	Samples Analyzed	
Aldehyde	EPA Method 0011	3	3	3	3	3	3	Cooled to <4 °C prior to analysis
Volatile Organics	VOST	9	9	9	9	10	9	Cooled to <4 °C prior to analysis
Semivolatile Organics	Modified Method 5	3	3	3	3	3	3	Cooled to <4 °C prior to analysis
PCDD/PCDF	Method 23	-	-	-	-	3	3	Cooled to <4 °C prior to analysis
Particle Size Distribution	Method 17	3	3	3	3	3	3	No special handling
Particulate Loading and Metals	Method 5/Method 29	3	3	3	3	3	3	No special handling
Mercury Speciation	Nick Bloom Method	3	3	3	3	3	3	No special handling
Anions	Method 5 (Modified)	3	3	3	3	3	3	No special handling
Ammonia/Cyanide	Method 5 (Modified)	4	3	3	3	3	3	Cooled to <4 °C prior to analysis
Radionuclides	Method 5/17	3	3	3	3	3	3	No special handling
Extractable Metals	Method 5/17	3	3	3	3	3	3	No special handling
Size Fractionated Particulate - Metals	Method 17	3	3	3	3	-	-	No special handling
Chromium VI	Method Cr^{+6}	-	-	-	-	3	3	Analyzed on-site

[a] Detailed references are shown in Appendix B.

Table 3-2
Number and Type of Gas Sample Analyses Plant Yates

Parameter	Field Samples	Matrix Spike	Audit Samples	Field Blanks	Trip Blanks	Total Samples
Moisture	9	–	–	–	–	9
Particulate Loading	9	–	–	3	1	13
Particle Size Distribution	9	–	–	–	–	9
Chloride (Particulate)	9	1	–	1	–	11
Fluoride (Particulate)	9	1	–	1	–	11
Sulfate (Particulate)	9	1	–	1	–	11
ICP Screen (Particulate)	9	1	1	3	1	15
GFAAS Metals[a] (Particulate)	9	1	1	3	1	15
Mercury (Particulate)	9	1	1	3	1	15
Semivolatiles (Particulate & Flue Gas)	9	2	–	3	1	15
PCDD/PCFD (Particulate)	3	–	–	1	1	5
Radioactivity (Particulate)	9	–	–	1	–	12
Ammonia (Flue gas)	9	1	1	1	–	12
Cyanide (Flue gas)	9	1	1	1	–	12
Chloride (Flue gas)	9	1	1	1	–	12
Fluoride (Flue gas)	9	1	1	1	–	12
Sulfate (Flue gas)	9	1	1	1	–	12
ICP Screen (Flue gas)	9	1	1	3	1	15
GFAAS Metals[a] (Flue gas)	9	1	1	3	1	15
Mercury (Flue gas)	9	1	1	3	1	15
Aldehydes (Flue gas)	9	2	–	3	2	16
Volatile Organics (Flue gas)	27	–	–	9	1	37
PCDD/PCDF (Flue gas)	3	–	–	1	1	5

[a] GFAAS metals include As, Cd, Pb, and Se.

Table 3-3
Liquids Sampling Summary

Test Parameter	Collection Method	Ash Pond		Gypsum Pond Water		Ash Sluice Filtrates		JBR Slurry		Limestone Slurry Filtrate		Coal Pile Run-Off		Condenser Inlet	
		Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed
Formaldehyde	Grab	3	3	3	3	6	6	3	3	3	3	2	2	3	3
Volatile Organics	Grab	3	3	3	2	6	6	3	3	3	3	2	1	3	3
Semivolatile Organics	Grab	3	3	3	2	8	6	4	3	4	3	2	1	4	3
Metals, Soluble	Grab	3	3	3	3	6	6	3	3	3	3	-	-	3	3
Metals, Total	Grab	3	3	3	3	-	-	-	-	-	-	-	-	3	3
Anions	Grab	3	3	3	3	6	6	3	3	3	3	-	-	3	3
Ammonia	Grab	3	3	3	3	6	6	3	3	3	3	-	-	3	3
Cyanide	Grab	3	3	3	3	6	6	3	3	3	3	-	-	3	3

Table 3-4
Liquid Stream QA/QC Samples

Parameter	Field Samples	Field Dups	Matrix Spike	Audit Samples	Trip Blanks	Total Samples
Chloride	21	7	3	1	--	32
Fluoride	21	7	3	1	--	32
Phosphate	21	7	3	1	--	32
Sulfate	21	7	3	1	--	32
Sulfite	3	1	--	--	--	4
Ammonia	21	7	3	1	--	32
Cyanide	21	7	3	1	--	32
ICP Screen (Soluble)	30	10	4	2	--	46
Arsenic	30	10	4	2	--	46
Cadmium	30	10	4	2	--	46
Lead	30	10	4	2	--	46
Mercury	30	10	4	2	--	46
Selenium	30	10	4	2	--	46
Aldehydes	23	7	6	--	--	36
Semivolatile Organics	22	7	6	--	--	35
Volatile Organics	22	7	--	--	1	30

Table 3-5
Solids Sampling Summary

Test Parameter	Collection Method	Raw Coal		Pulverizer Rejects		Feed Coal		Raw Limestone		Limestone Slurry Solids		Bottom Ash		ESP Fly Ash		FGD Slurry Solids	
		Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed	Collected	Analyzed
Formaldehyde	Grab	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3
Semivolatile Organics	Grab	-	-	-	-	-	-	-	-	-	-	3	3	6	6	3	3
Particle Size Distribution	Grab	-	-	-	-	-	-	-	-	-	-	-	-	6	6	-	-
Metals, Total	Grab	3	3	3	3	3	3	3	3	3	3	3	3	6	6	3	3
Anions	Grab	3	3	3	3	3	3	3	3	3	3	3	3	6	6	3	3
Radionuclides	Grab	-	-	-	-	3	3	3	3	-	-	3	3	6	6	3	3
Moisture,	Grab	3	3	3	3	3	3	3	3	-	-	3	3	6	6	-	-
Ultimate/ Proximate	Grab	3	3	3	3	3	3										
Heating Value	Grab	3	3	-	-	3	3										

Table 3-6
Solid Stream QA/QC Samples

Parameter	Field Samples	Field Dups	Matrix Spike	Audit Samples	Total Samples
Moisture	12	4	--	--	16
Particle Size Distribution	6	2	--	--	8
Ultimate/Proximate	9	3	--	1	13
Carbon	12	4	--	--	16
Sulfur	9	3	--	--	12
Heating Value	6	2	--	1	9
Chloride	30	10	4	2	46
Fluoride	30	10	4	2	46
Phosphate (Phosphorus)	30	10	4	2	46
Sulfate/Sulfite	3	1	1	--	5
ICP Screen	30	10	4	2	46
Metals	9	3	--	1	13
Arsenic	30	10	4	2	46
Cadmium	30	10	4	2	46
Lead	30	10	4	2	46
Mercury	30	10	4	2	46
Selenium	30	10	4	2	46
Aldehydes	3	1	2	--	6
Semivolatile Organics	12	4	4	--	20
Radioactivity	15	4	--	--	19

Process Stream Flow Rates

Table 3-7 presents average process stream flow rates for Phase II of the testing. The methods used to measure and equations used to calculate these flow rates are described in Table 3-8. These flow rates were used in the material balance calculations, described in Section 6.2. Those flow rates measured directly are presented on a run-by-run basis. Others are presented as Phase II test period averages, since they are calculated from averaged data; i.e., the dry feed coal flow rate is calculated from the average wet raw coal flow rate and average water content. Gaseous flow rates were measured at three different locations at the site: ESP inlet, outlet, and the stack. The actual measurements from these locations averaged 293,000 dscfm $\pm <3\%$, well within the expected limits of the measurement technique. However, given the various physical properties of the three locations, engineering judgment would indicate that the measurements from the stack were the most accurate of the three and, since the stack measurements also reflect ultimate emissions, the measurements from this location should be the reference point for consistency in the treatment of data and determination of internal mass flow rates. An average of 4,000 scfm of oxidation air was added to the flue gas as it passes through the JBR. Therefore, the rate of gas that enters and exits the ESP is that amount measured at the stack minus (-) the oxidation air added at the JBR. The stack flow rate was 288,000 dscfm - 4,000 dscfm (oxidation air) = 284,000 dscfm as the flow rate for the INLET AND OUTLET of the ESP. The ESP operates at negative pressure; therefore, these numbers represent maximum rates, since any inleakage of gas would be measured at the stack.

Coal flow rates were determined from data obtained from the boiler control room. Raw coal is loaded into buckets which hold nominally 500 pounds of coal and a counter records each time a bucket is dumped. These readings, obtained over a 24-hour period, provide the basis for the coal feed rate. The dry feed coal rate was determined from the raw coal rate (corrected for moisture) less the pulverizer rejects. This method yields an average feed coal rate for the material balance period of 80,200 lb/hr. As a consistency check, the full-load unit heat rate was used to calculate a coal feed rate of 86,000 lb/hr, approximately 7% higher than measured. The calculated coal feed rate falls within the 95% confidence interval of the measured coal rate shown in Table 3-7. The bottom ash flow rate was determined by subtracting the ash flow rate measured at the ESP inlet from the ash contained in the feed coal.

Other flow rates used in mass balance calculations were measured by process instrumentation and are discussed in Section 6. Uncertainties for these calculated flow rates, expressed as 95% confidence intervals, were calculated using the method detailed in Appendix F.

References

1. Electric Power Research Institute. *Field Chemical Emissions Monitoring (FCEM) Generic Sampling and Analytical Plan.* Draft Report. Palo Alto, CA (May 1994).

Table 3-7
Process Flow Rates During Phase II of Testing

	Run 1 6/25/93	Run 2 6/26/93	Run 3 6/27/93	Mean	Std. Dev.
Raw Coal Moisture (%)	12.7	11.2	11.2	11.7	0.9
Feed Coal Ash (%, dry)	10.5	11.3	11.6	11.1	0.6
Measured Flow Rates and Grain Loadings:					
Raw Coal (lb/hr, wet)	90,200	90,700	92,000	91,000	3,200[a]
Coal Pulverizer Rejects (lb/hr)	110	130	110	120	15[b]
ESP Inlet Loading (gr/dscf)	3.38	3.67	3.88	3.64	0.25
ESP Outlet Loading, (gr/dscf)	0.0598	0.0489	0.0644	0.0577	0.0080
Stack Gas (dscfm)	290,000	287,000	285,000	288,000	2,500
Stack Loading (gr/dscf)	0.0078	0.0048	0.0051	0.0059	0.0017
Calculated Flow Rates:					<u>95% CI</u>
Feed Coal (lb/hr, dry)	--	--	--	80,200	8,200
ESP Inlet Gas (dscfm)[c]	--	--	--	284,000	6,200
ESP Outlet Gas (dscfm)[c]	--	--	--	284,000	6,200
ESP Inlet Ash, (lb/hr)[d]	--	--	--	8,870	1,500
ESP Outlet Ash, (lb/hr)	--	--	--	140	49
ESP Collected Ash (lb/hr)	--	--	--	8,730	2,500
Bottom Ash (lb/hr)[e]	--	--	--	440	1,100
Particulate Emissions:					
Emissions (lb/hr)	--	--	--	14.6	10.4
Emissions (lb/10^6 Btu)	--	--	--	0.014	0.009

[a] Standard deviation calculated from 71 hourly values measured over the three days of testing.

[b] Standard deviation calculated from 9 values measured over the three days of testing.

[c] The stack gas flow rate was considered to be the most accurate measurement of the gas flow rate; the ESP inlet and outlet flow rates were assumed equal to the stack gas less the JBR oxidation air (4,100 scfm).

[d] Includes 4.5% unburned carbon.

[e] Includes 2.3% unburned carbon.

Table 3-8
Flow Rate Calculations

Raw Coal:

Counting of 500 lb (nominal) buckets

Pulverizer Rejects:

Measured by bucket-and-stopwatch method

Stack Gas:

Measured by Pitot tube traverse

Feed Coal, dry basis:

91,000 lb/hr Raw Coal - 91,000 lb/hr * 0.117 lb Water/lb coal - 120 lb/hr Rejects = 80,200 lb/hr

ESP Inlet and ESP Outlet Flue Gas:

288,000 dscfm Stack Gas - 4,100 scfm Oxidation Air = 284,000 dscfm

ESP Inlet Ash:

284,000 dscfm * 3.64 gr/dscf * 0.000143 lb/gr * 60 m/hr = 8,870 lb/hr

ESP Outlet Ash:

284,000 dscfm * 0.0577 gr/dscf * 0.000143 lb/gr * 60 m/hr = 140 lb/hr

ESP Collected Ash:

8,870 lb/hr ESP Inlet Ash - 140 lb/hr ESP Outlet Ash = 8,730 lb/hr

Bottom Ash:

[80,200 lb/hr Dry Feed Coal * 0.111 lb ash/lb coal - (8,870 lb/hr ESP Inlet Ash- 8,870 lb/hr *0.045 lb Carbon/lb Ash]/(1-0.023) lb Carbon-Free Bottom Ash/lb Bottom Ash = 440 lb/hr

Stack Emissions:

288,000 dscfm Stack Gas * 0.0059 gr/dscf * 0.000143 lb/gr * 60 m/hr = 14.6 lb/hr

Stack Emission Factor:

14.6 lb/hr/(80,200 lb/hr Feed coal * 12,700 Btu/lb) * 1,000,000 = 0.014 lb/10^6 Btu

4

SAMPLE PREPARATION AND ANALYSIS METHODS

Preparation procedures and chemical analysis methods for gases are shown in Figures 4-1 through 4-12.

Procedures for liquid sample preparation and analysis are shown in Figure 4-13. Procedures for coal are shown in Figure 4-14 and Table 4-1. Procedures for ash are in Figure 4-15. Procedures for limestone and FGD solids are shown in Figure 4-16.

Appendix E of this technical note contains descriptions of and references for the methods used for this project.

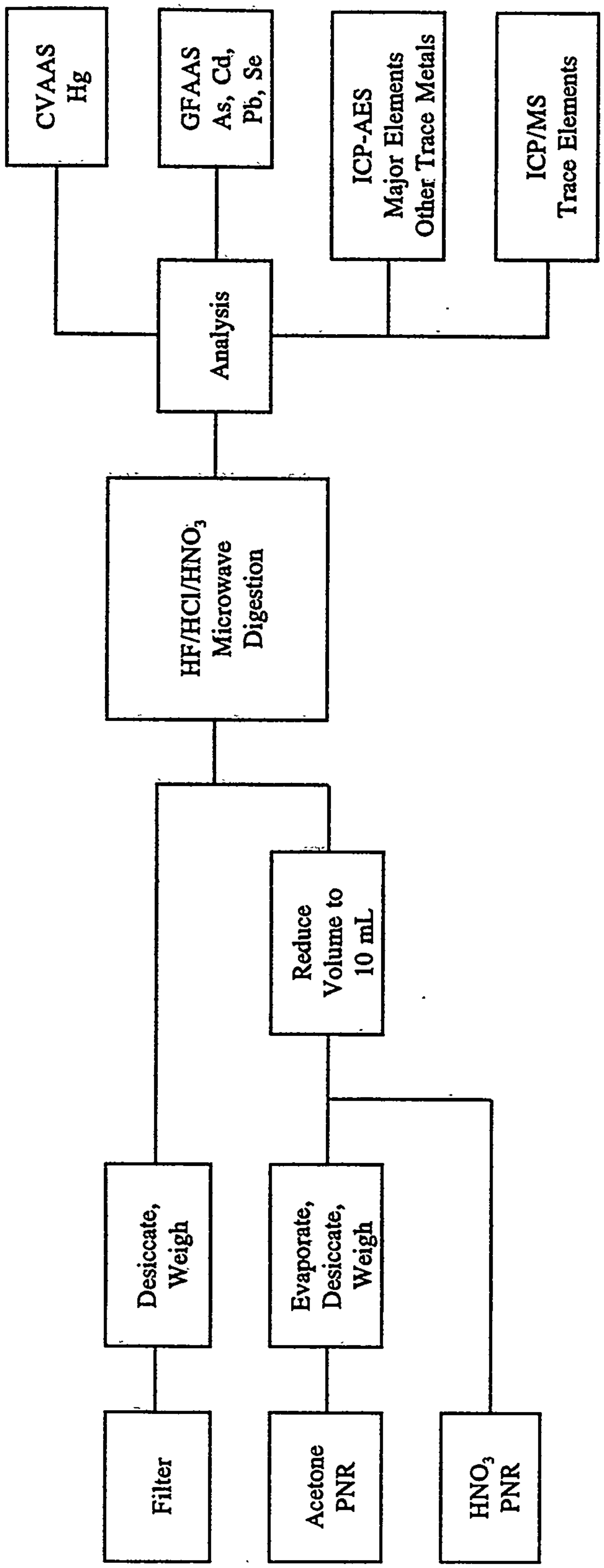


Figure 4-1
Gas Particulate Sample Preparation and Analysis Plan for Metals

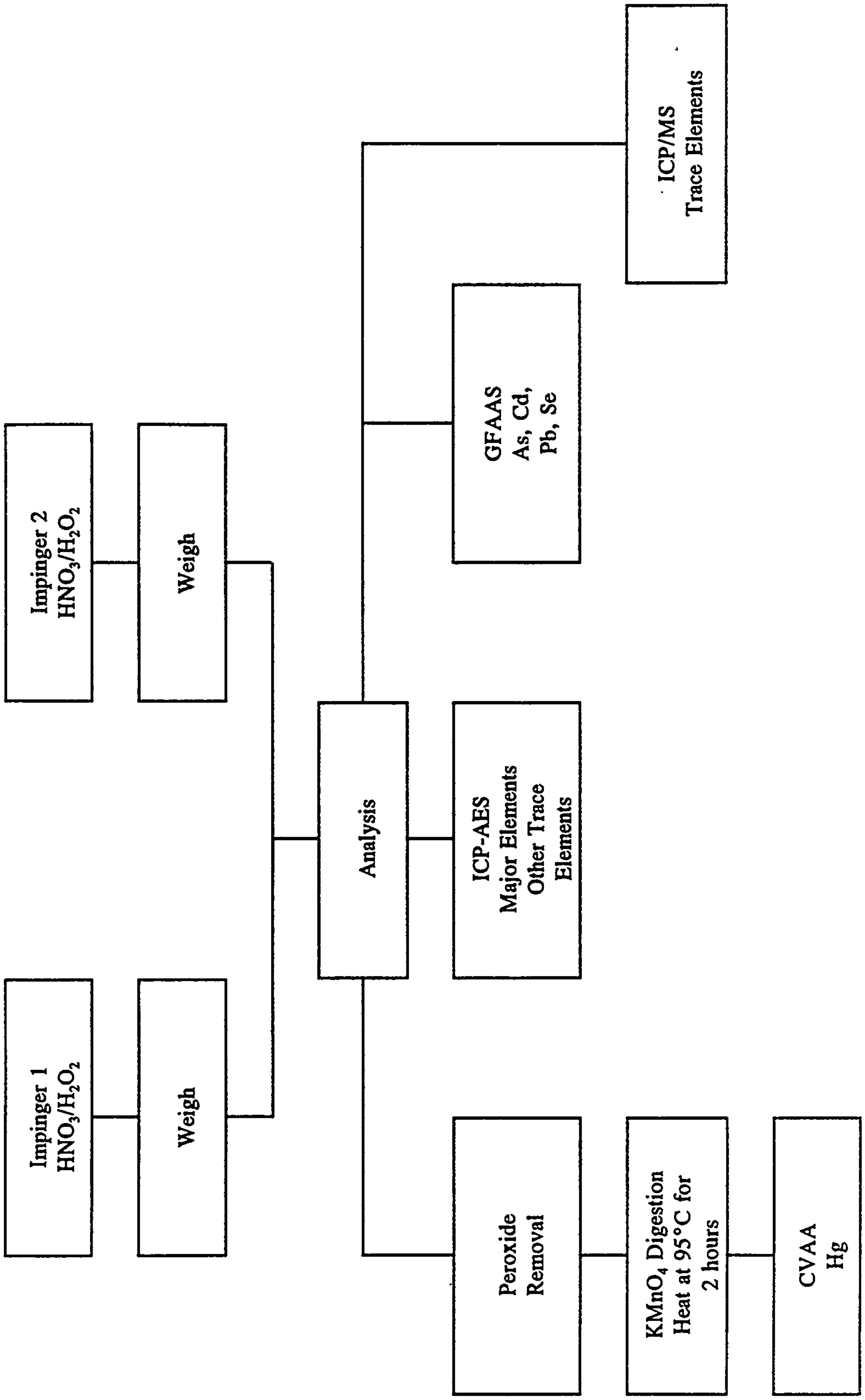


Figure 4-2
Flue Gas Impinger Sample Preparation and Analysis Plan for Metals

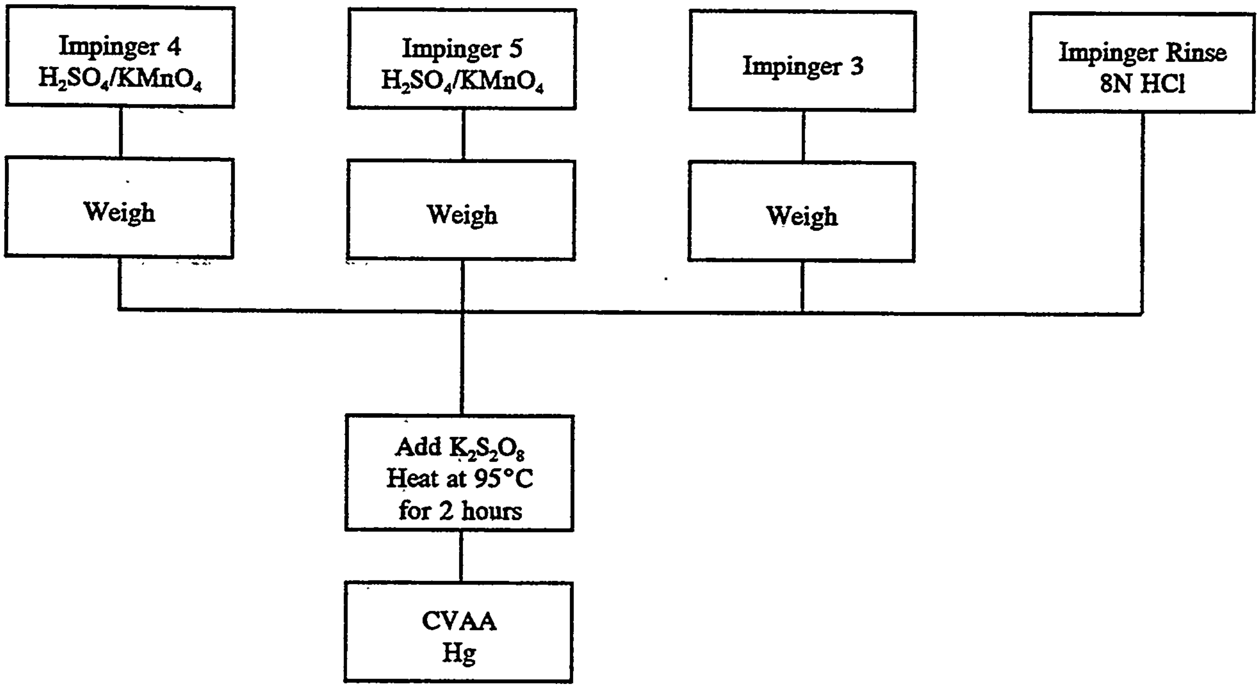


Figure 4-3
Flue Gas Impinger Sample Preparation and Analysis Plan for Mercury

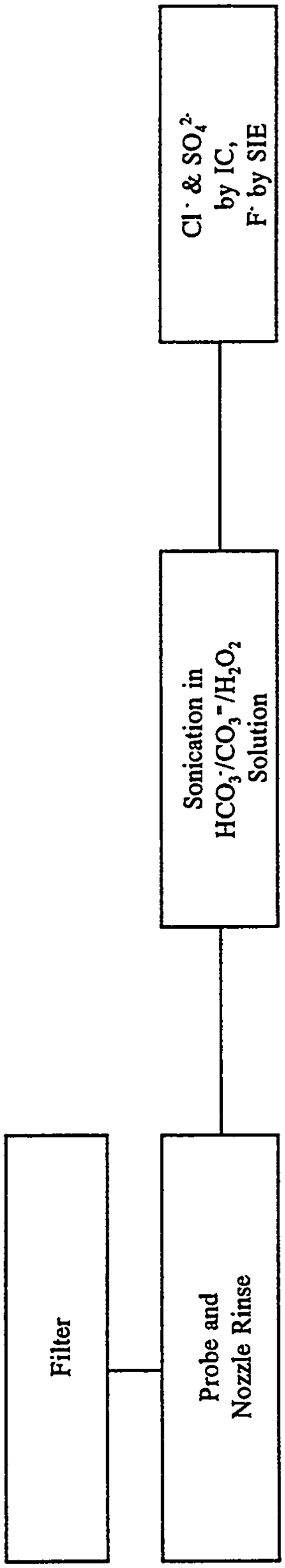


Figure 4-4
Gas Particulate Sample Preparation and Analysis Plan for Anions

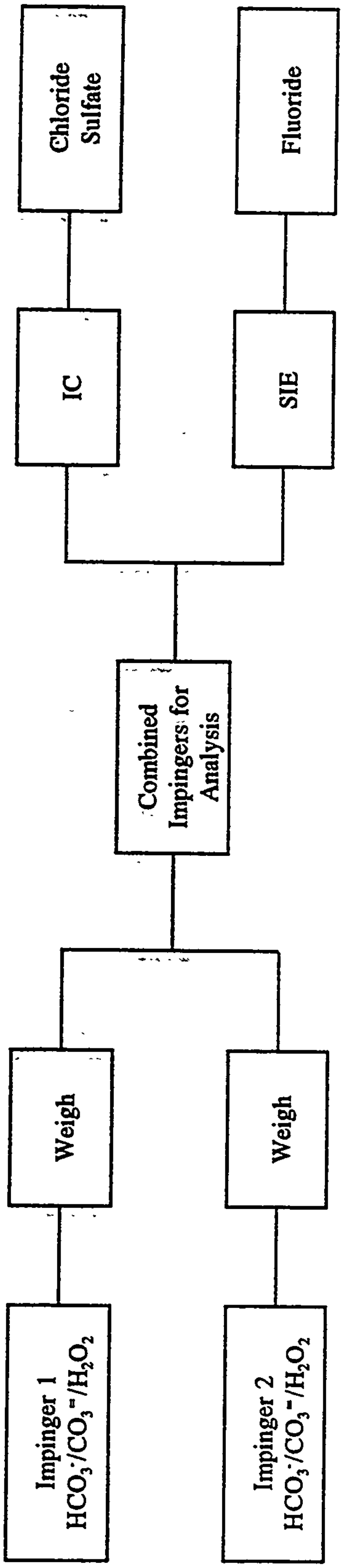


Figure 4-5
Flue Gas Impinger Sample Preparation and Analysis Plan for Anions

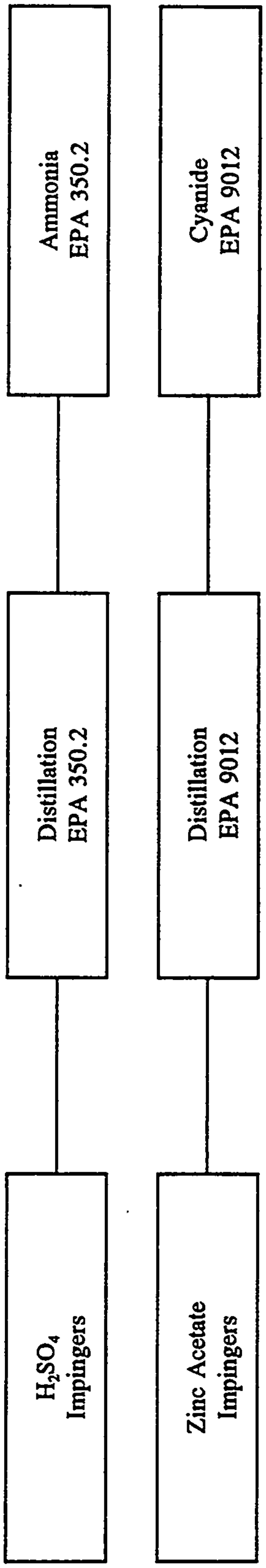


Figure 4-6
Flue Gas Impinger Sample Preparation and Analysis Plan for Ammonia and Cyanide

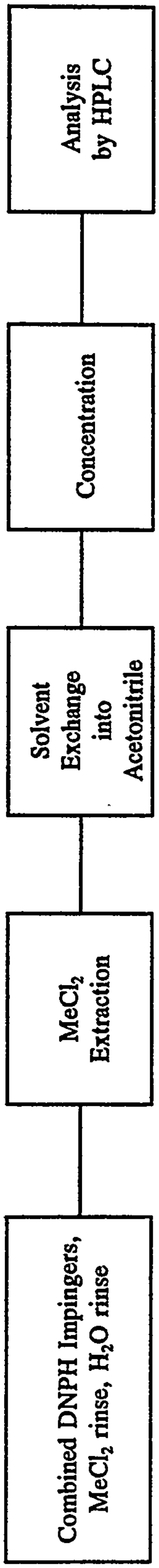


Figure 4-7
Flue Gas Impinger Sample Preparation and Analysis Plan for Formaldehyde

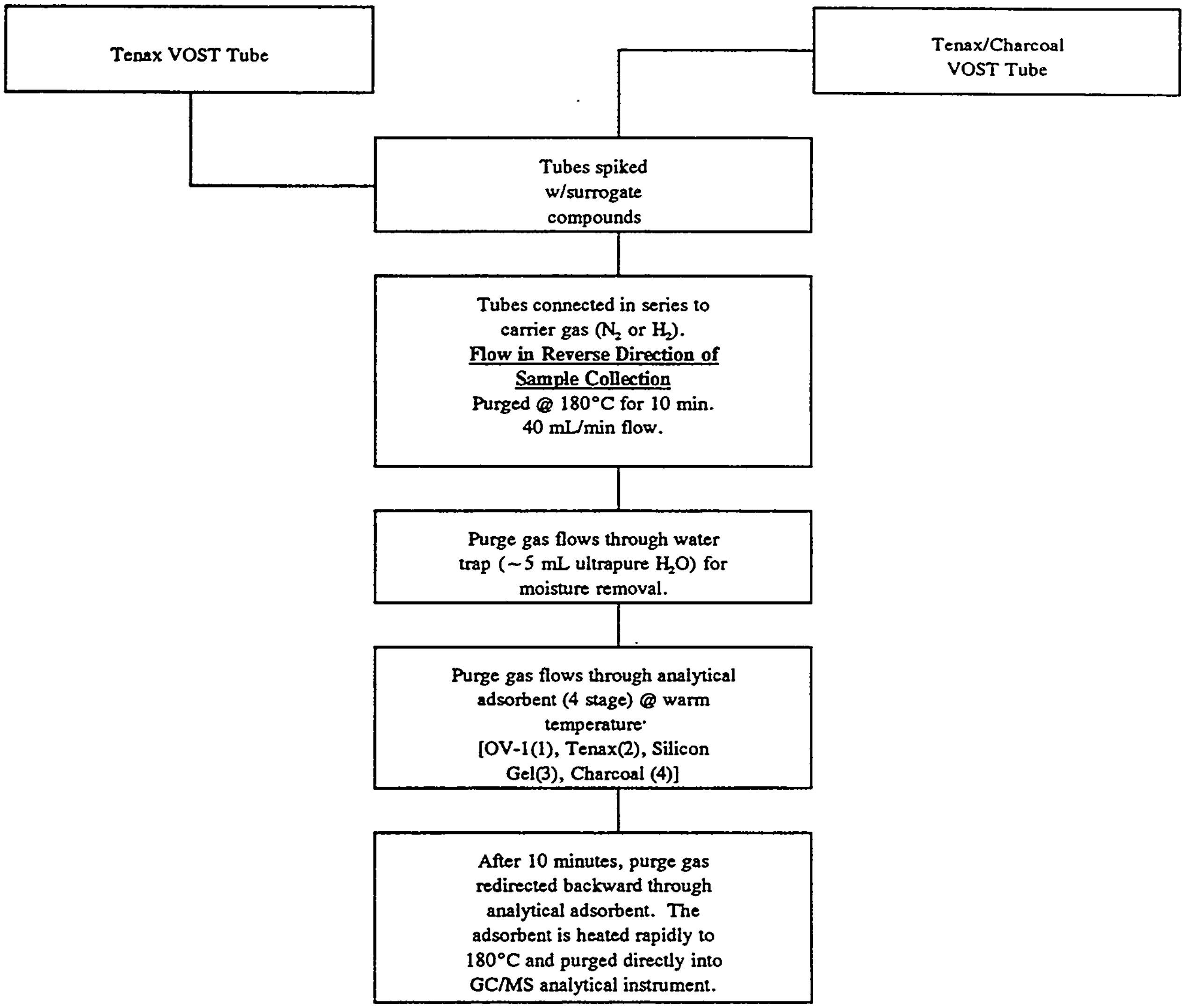


Figure 4-8
VOST Sorbent Sample Preparation and Analysis Plan for Volatile Organic Compounds

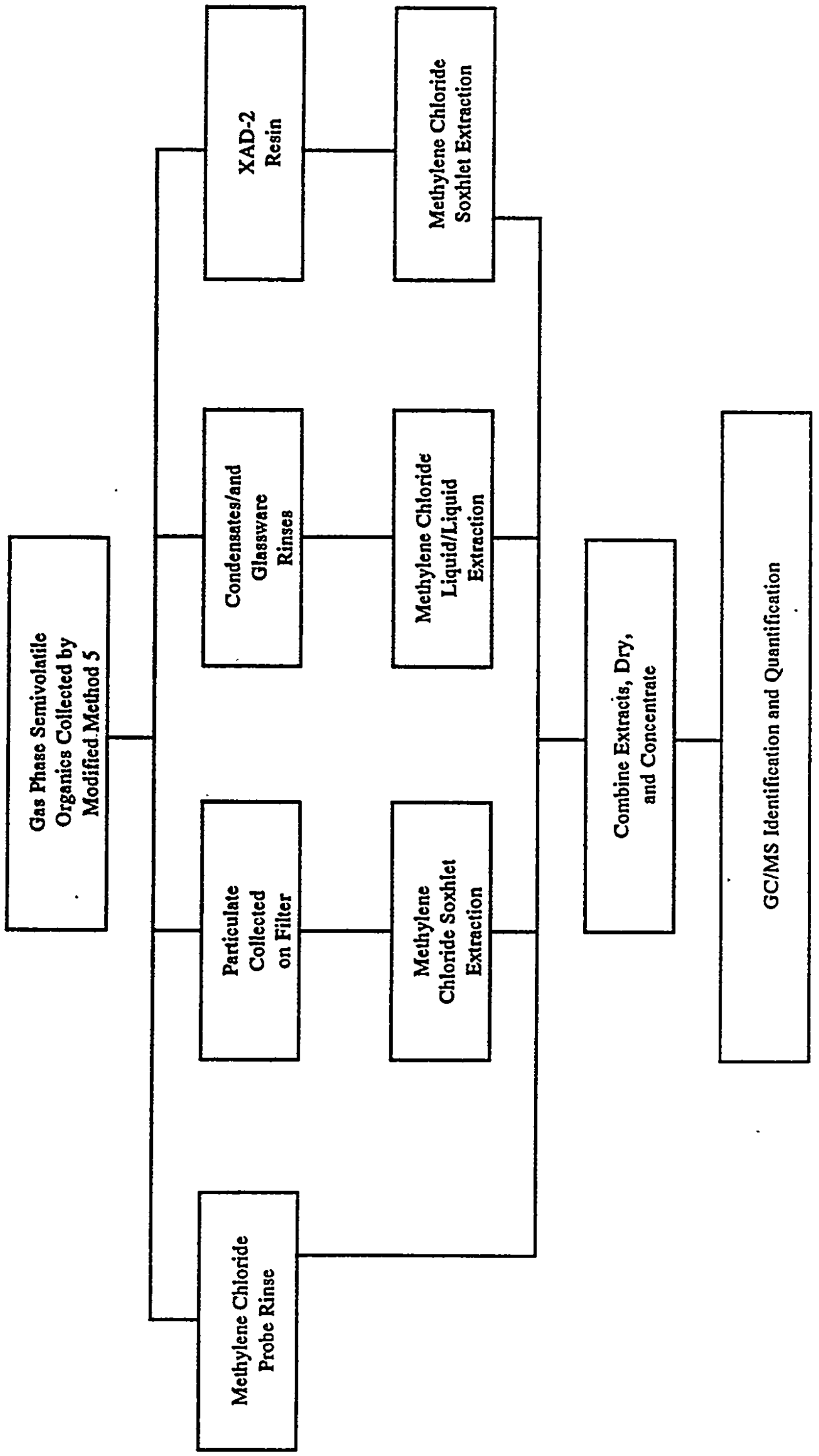


Figure 4-9
Flue Gas Sample Preparation and Analysis Plan for Semivolatile Organic Compounds

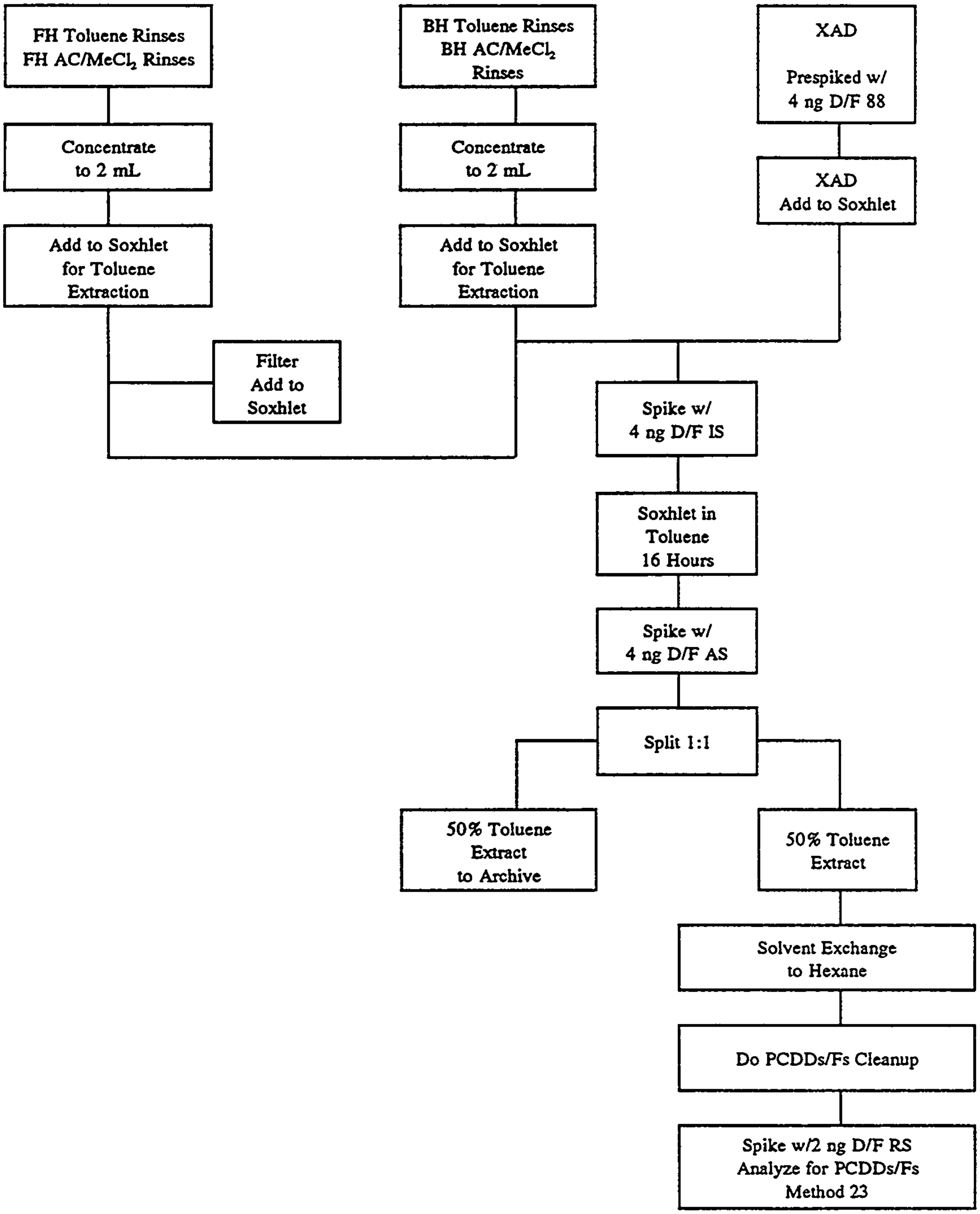


Figure 4-10
Flue Gas Sample Preparation and Analysis Plan for Dioxins and Furans

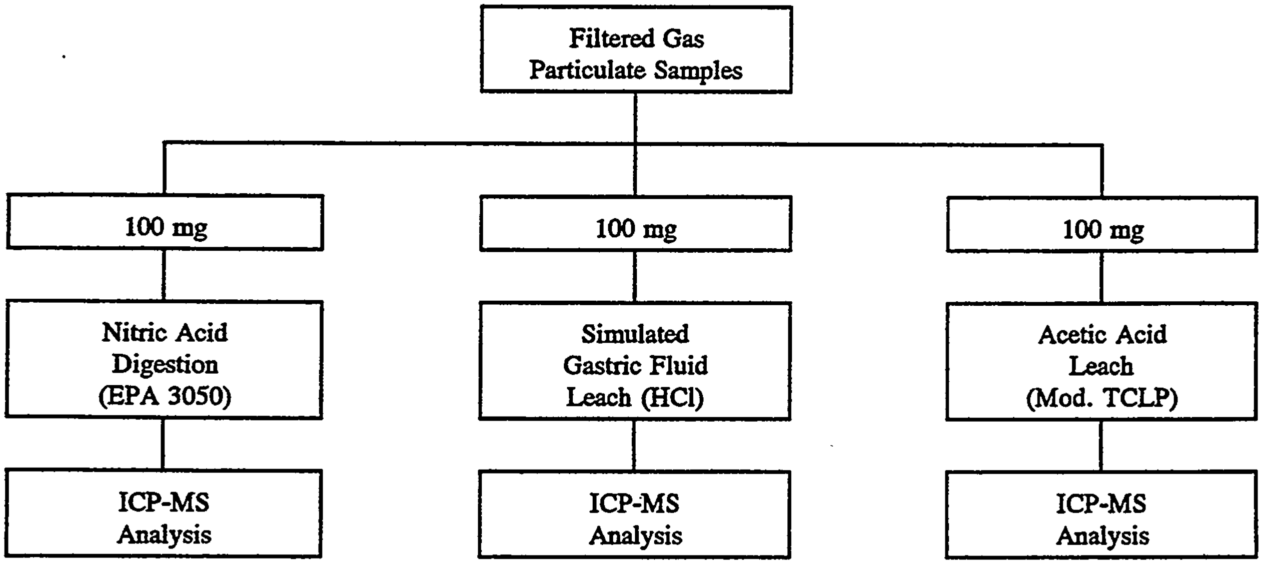


Figure 4-11
Gas Particulate Sample Preparation and Analysis Plan for Extractable Metals

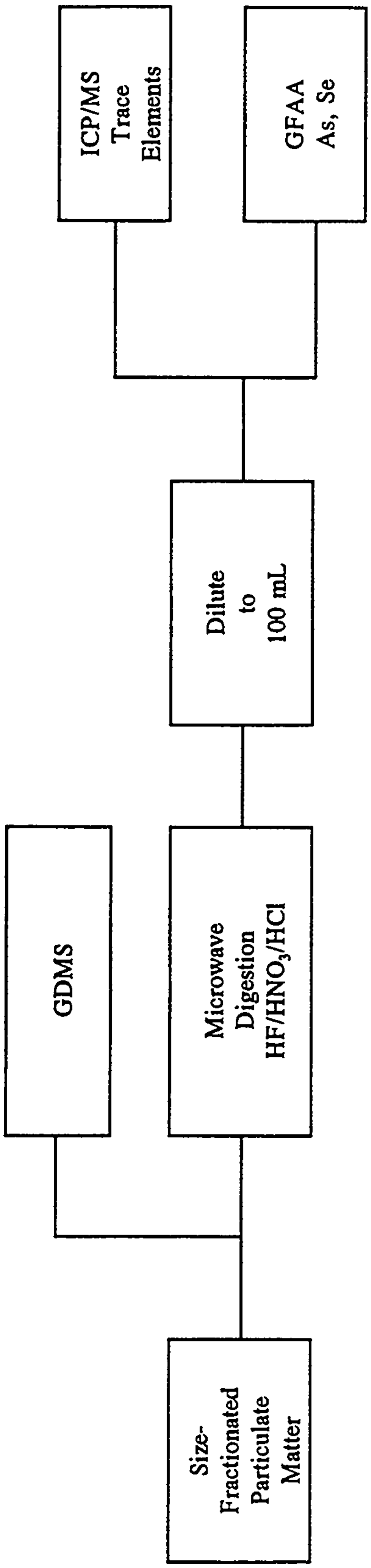


Figure 4-12
Size-Fractionated Particulate Sample Preparation and Analysis Plan for Metals

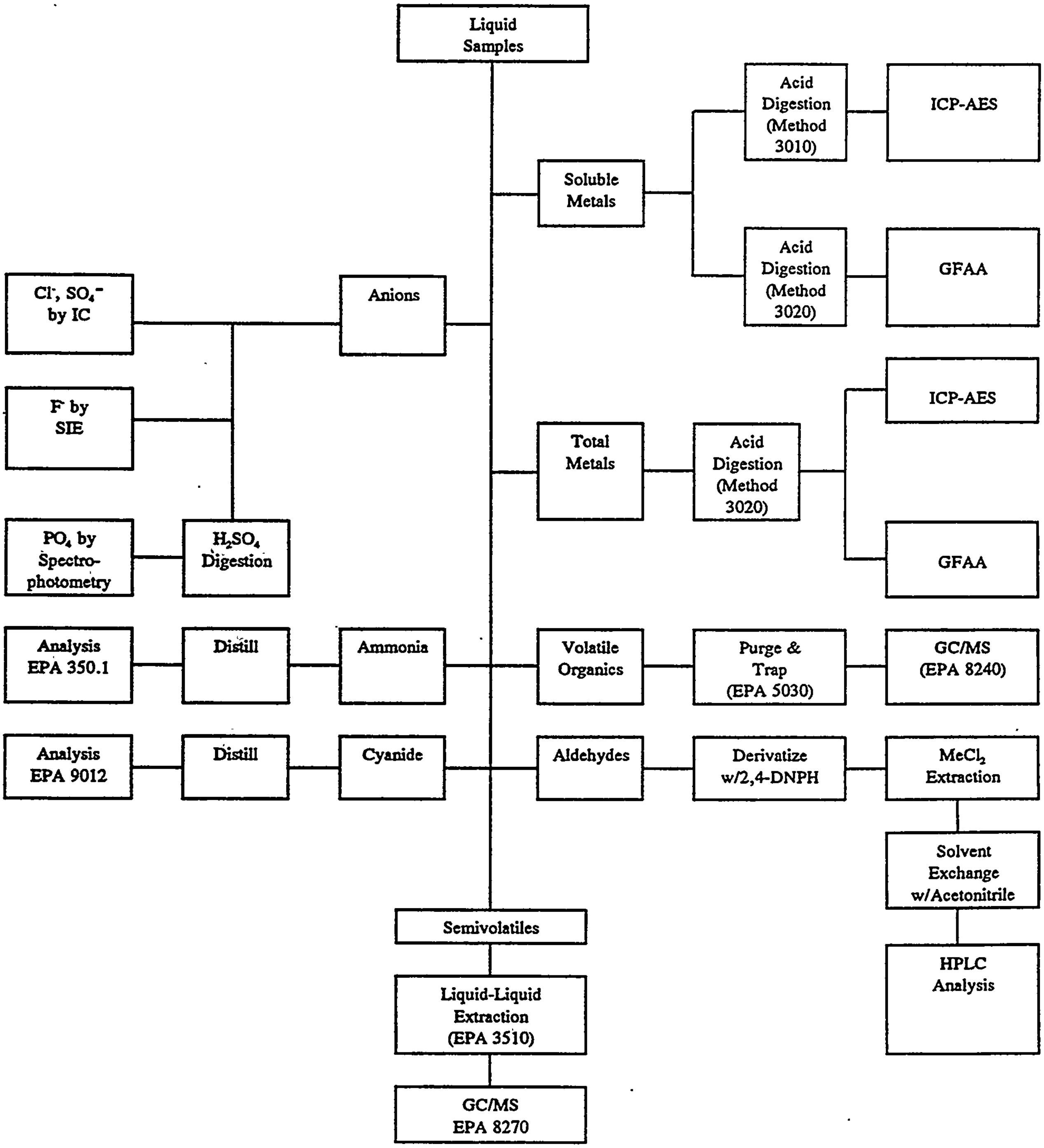


Figure 4-13
Liquid Sample Preparation and Analysis Plan

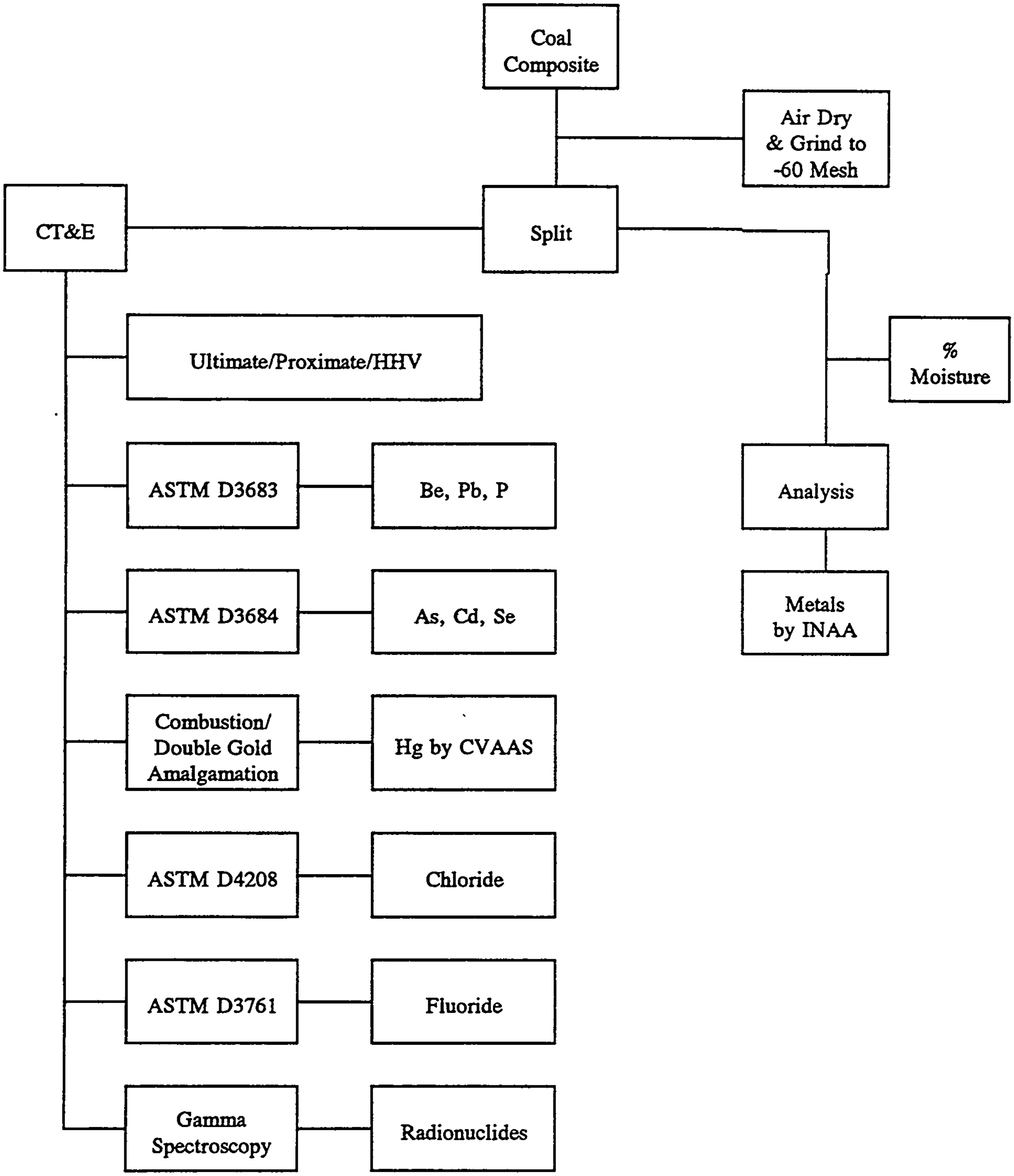


Figure 4-14
Coal Sample Preparation and Analysis Plan

Table 4-1
Summary of Coal Analytical Methods

Chemical Substance	Analytical Method
Ultimate/Proximate/Higher Heating Value	
Moisture	ASTM D3173
Ash	ASTM D3174
Carbon, Hydrogen, Nitrogen	ASTM D5373
Sulfur	ASTM D4239
Volatile Matter	ASTM D3175
Heating Value	ASTM D2015
Chlorine in Coal	ASTM D4208
Fluorine in Coal	ASTM D3761
Radionuclides	Gamma Emission Spectroscopy

ASTM = American Society for Testing and Materials.

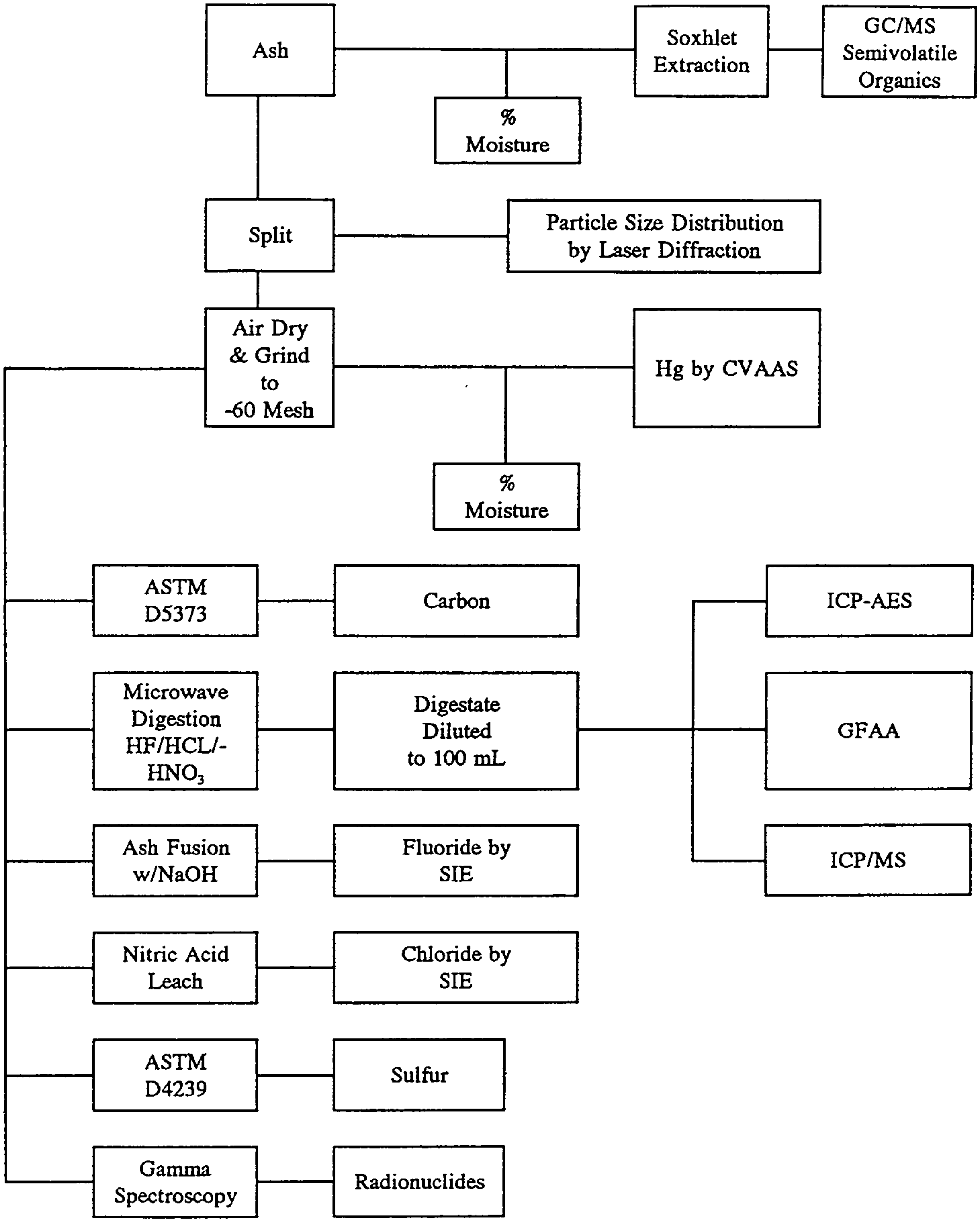


Figure 4-15
Ash Sample Preparation and Analysis Plan

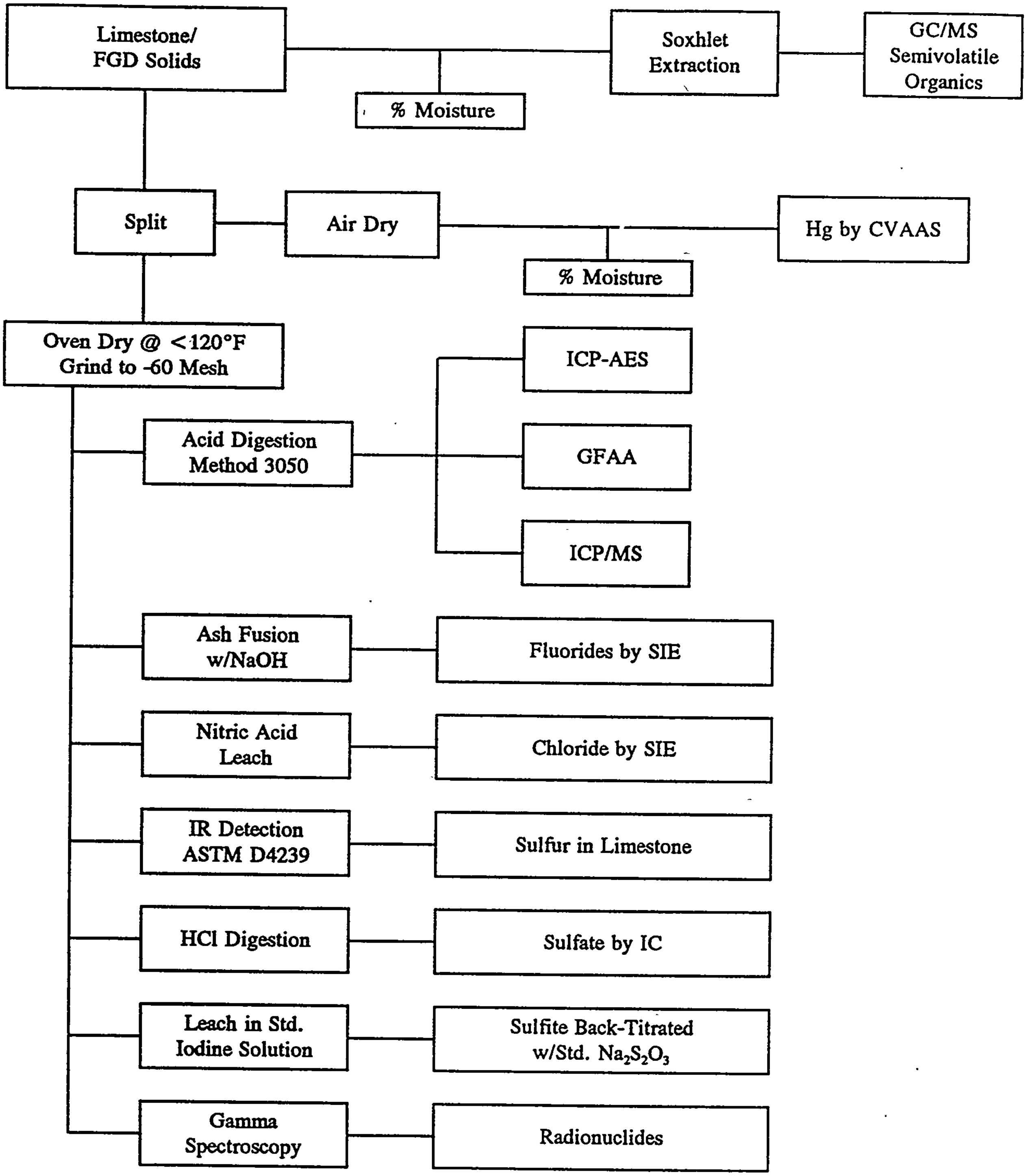


Figure 4-16
Limestone and FGD Solids Sample Preparation and Analysis Plan

5

Analytical Results

The results of the analyses performed on samples collected during the emissions test program are presented in this section. The results are reported by stream matrix, i.e., gaseous, solid, or liquid, and are presented as averages for individual process streams along with the 95% confidence interval (CI) and the detection limit (DL) ratio. The detection limit ratio represents the percentage of the average value that is contributed by data which were below the detection limit. The analytical results for organic species reported in the following tables have been limited to only those compounds which were detected in any of the three test runs. Complete details of the analytical results may be found in Appendix H. Appendix H contains results on a per run basis, the analytical method used for each analysis, appropriate data flags for each value, additional analytical results for compounds which were not part of the scope of work but which information was obtained by virtue of the particular analytical method used, along with the averages of Runs 1-3, 95% CI, and DL ratios. Treatment of values that were less than the method detection limit are explained in Appendix G. Confidence intervals and error propagation are described in Appendix F.

Some data in Appendix H have been flagged. These data (which have been shaded) are suspect due to extremely high background contamination and have been excluded from the mean and CI calculations. High background contamination was encountered in gaseous particulate samples obtained from three of the multi-metals runs performed at the ESP outlet and the stack. This problem arose from the misidentification (during the field prep phase) of three glass fiber filter substrates. These glass fiber substrates were prepped, labelled and treated as quartz filters. The error was discovered during analysis when very high levels of barium and zinc were identified. The glass fiber substrates were used in Runs 1 and 3 at the ESP outlet and in Run 1 at the stack. Table 5-1 shows results for a blank analysis of a quartz and glass fiber filter. Background results are similar for Sb, As, Se, and V. All other species (except Mo) are substantially higher in the glass fiber matrix. Again, shaded data have been invalidated and are not included in the reported mean values.

Gases

The particulate loading and analytical results for the ESP inlet, ESP outlet and the stack are presented in Table 5-2. Concentration of trace elements as a function of particle size is given for three approximate size ranges; less than 3 μm, 3-10 μm, and greater than 10 μm on an aerodynamic basis. The analysis of boron and silicon in the fly ash samples filtered from the flue gas streams was not performed due to the limited quantity of sample and the limitations of the sampling and sample preparation techniques. For gas particulate samples, the filtered solids are prepared for analysis by digesting the entire filter with a mixed acid solution containing hydrochloric, nitric, and hydrofluoric acids.

Table 5-1
Filter Substrate Data Comparison

Specie	Quartz (μg)	Glass Fiber (μg)
Aluminum	122	36,500
Antimony	<9	<9
Arsenic	0.14	<0.12
Barium	8.6	57,600
Beryllium	0.08	6
Cadmium	<0.13	4
Calcium	101	15,500
Chromium	1.4	21
Cobalt	0.25	22
Copper	0.57	4
Iron	15	312
Lead	<0.13	35
Magnesium	14	2,700
Manganese	0.60	15
Mercury	0.07	0.1
Molybdenum	19	2
Nickel	2.6	8
Phosphorus	<7.5	144
Potassium	<205	30,000
Selenium	0.06	<0.09
Sodium	224	88,800
Strontium	0.80	664
Titanium	8.2	78
Vanadium	0.65	0.15
Zinc	6.3	39,900

Table 5-2
Gas Process Stream Data Summary

Analyte Group/ Specie	Units	ESP Inlet			ESP Outlet			Stack		
		Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Particulate Loading	g/Nm^3	8.95	1.5	--	0.142	0.05	--	0.0145	0.010	--
Reduced Species										
Ammonia as N	µg/Nm^3	29.0	7.4	--	27	16	--	11	17	--
Hydrogen Cyanide	µg/Nm^3	0.15	0.24	--	0.90	1.7	--	28	94	--
Anions-Vapor										
Chloride	µg/Nm^3	112,000	34,300	--	136,000	67,000	--	540	820	--
Fluoride	µg/Nm^3	8,300	1,400	--	7,900	3,200	--	124	66	--
Sulfate	µg/Nm^3	7,460,000	432,000	--	6,900,000	1,500,000	--	680,000	160,000	--
Anions-Particulate										
Chloride	µg/Nm^3	6,100	9,100	--	45	94	--	210	310	--
Fluoride	µg/Nm^3	1.3	2.4	--	0.12	0.21	--	0.051	0.041	--
Sulfate	µg/Nm^3	79,000	98,000	--	4,200	760	--	5,900	8,700	--
Anions-Total										
Chloride	µg/Nm^3	118,000	31,000	--	136,000	67,000	--	750	800	--
Fluoride	µg/Nm^3	8,300	1,400	--	7,900	3,200	--	124	66	--
Sulfate	µg/Nm^3	7,500,000	417,000	--	6,900,000	1,500,000	--	690,000	170,000	--
Radionuclides										
Actinium-228 @ 338 KeV	pCi/g	25	36	11%						
Actinium-228 @ 911 KeV	pCi/g	20	15	--						
Actinium-228 @ 968 KeV	pCi/g	29	41	13%						
Bismuth-212 @ 727 KeV	pCi/g	<39	--	100%						
Bismuth-214 @ 1120.4 KeV	pCi/g	<24	--	100%						
Bismuth-214 @ 1764.7 KeV	pCi/g	49	71	12%						
Bismuth-214 @ 609.4 KeV	pCi/g	28	17	--						
K-40 @ 1460 KeV	pCi/g	230	317	--	73	31	--	<56	--	48%
Lead-210 @ 46 KeV	pCi/g	79	33	--						
Lead-212 @ 238 KeV	pCi/g	19	19	--						
Lead-214 @ 295.2 KeV	pCi/g	24	20	--						
Lead-214 @ 352.0 KeV	pCi/g	25	8.0	--						
Radium-226 @ 186.0 KeV	pCi/g	130	50	--						
Thallium-208 @ 583 KeV	pCi/g	17	11	--						
Thallium-208 @ 860 KeV	pCi/g	<67	--	100%						
Thorium-234 @ 1001 KeV	pCi/g	79	35	--						
Thorium-234 @ 63.3 KeV	pCi/g	69	43	--						
Uranium-235 @ 143 KeV	pCi/g	69	43	--						
Part Metals by Wt.										
Aluminum	µg/g	97,000	11,000	--	101,000	--	--	13,800	7,300	--
Antimony	µg/g	3.6	2.4	--	2.7	0.65	--	3.8	5.7	--
Arsenic	µg/g	45	12	--	117	48	--	81	71	--
Barium	µg/g	490	106	--	620	--	--	210	1,100	--
Beryllium	µg/g	10	0.57	--	14	--	--	2.9	2.1	--
Cadmium	µg/g	2.70	1.4	--	8.9	--	--	41	79	--
Calcium	µg/g	18,100	3,900	--	14,800	--	--	18,600	31,000	--
Chromium	µg/g	320	500	--	190	--	--	330	3,000	--
Cobalt	µg/g	31	0.83	--	37	--	--	<150	--	52%

Table 5-2 (Continued)

Analyte Group/ Specie	Units	ESP Inlet Average	ESP Inlet 95% CI	ESP Inlet DL Ratio	ESP Outlet Average	ESP Outlet 95% CI	ESP Outlet DL Ratio	Stack Average	Stack 95% CI	Stack DL Ratio
Copper	µg/g	86	2.6	–	116	35	–	56	49	–
Iron	µg/g	91,000	27,000	–	61,000	14,000	–	11,700	22,000	–
Lead	µg/g	79	19	–	153	–	–	36	20	–
Magnesium	µg/g	4,690	480	–	5,500	–	–	2,800	10,700	–
Manganese	µg/g	237	32	–	243	68	–	490	2,600	–
Mercury	µg/g	0.79	0.59	–	0.90	0.3	–	0.57	5.2	14%
Molybdenum	µg/g	35	39	–	58	31	–	73	120	–
Nickel	µg/g	230	250	–	157	25	–	2,500	27,000	–
Phosphorus	µg/g	230	150	–	830	–	–	<220	–	100%
Potassium	µg/g	17,500	1,900	–	17,900	–	–	2,900	1,600	–
Selenium	µg/g	15	7.0	–	570	860	–	1,700	3,500	–
Sodium	µg/g	5,120	190	–	6,700	–	–	4,200	1,900	–
Strontium	µg/g	324	12	–	360	–	–	106	53	–
Titanium	µg/g	6,140	790	–	5,400	1,600	–	910	1,700	–
Vanadium	µg/g	308	5.7	–	381	93	–	112	46	–
Part Metals by Vol										
Aluminum	µg/Nm^3	870,000	240,000	–	12,100	–	–	190	260	–
Antimony	µg/Nm^3	33	26	–	0.39	0.11	–	0.052	0.019	–
Arsenic	µg/Nm^3	400	170	–	16	6.6	–	1.1	0.24	–
Barium	µg/Nm^3	4,400	1,700	–	74	–	–	2.8	10	–
Beryllium	µg/Nm^3	93	16	–	1.7	–	–	0.041	0.047	–
Cadmium	µg/Nm^3	24	15	–	1.1	–	–	0.59	2.2	–
Calcium	µg/Nm^3	161,300	7,200	–	1,800	–	–	270	920	–
Chromium	µg/Nm^3	2,900	4,600	–	23	–	–	5.1	50	–
Cobalt	µg/Nm^3	275	48	–	4.5	–	–	<0.6	–	59%
Copper	µg/Nm^3	770	130	–	16	1.2	–	0.77	0.76	–
Iron	µg/Nm^3	808,000	99,000	–	8,500	1,100	–	170	600	–
Lead	µg/Nm^3	710	290	–	18	–	–	0.50	0.64	–
Magnesium	µg/Nm^3	42,000	11,000	–	660	–	–	41	220	–
Manganese	µg/Nm^3	2,120	120	–	34	3.7	–	7.2	49	–
Mercury	µg/Nm^3	7.1	5.6	–	0.126	0.037	–	0.0071	0.057	18%
Molybdenum	µg/Nm^3	320	390	–	8.1	1.3	–	1.4	2.6	–
Nickel	µg/Nm^3	2,000	2,300	–	22	5.7	–	39	440	–
Phosphorus	µg/Nm^3	2,100	1,600	–	100	–	–	<2.6	–	100%
Potassium	µg/Nm^3	157,000	43,000	–	2,150	–	–	40	53	–
Selenium	µg/Nm^3	133	73	–	82	130	–	26	58	–
Sodium	µg/Nm^3	45,800	6,200	–	800	–	–	59	140	–
Strontium	µg/Nm^3	2,910	570	–	43	–	–	1.5	3.5	–
Titanium	µg/Nm^3	55,000	16,000	–	760	230	–	12.5	0.59	–
Vanadium	µg/Nm^3	2,760	430	–	54	11	–	1.6	0.47	–
Metals, Vapor										
Aluminum	µg/Nm^3	150	940	–	58	48	–	<8.7	–	50%
Antimony	µg/Nm^3	0.56	6.5	–	0.021	0.0096	–	0.012	0.0019	–
Arsenic	µg/Nm^3	<0.17	–	100%	<0.18	–	100%	<0.18	–	100%
Barium	µg/Nm^3	1.5	7.9	–	1.0	1.1	–	<0.14	–	54%
Beryllium	µg/Nm^3	0.06	0.25	–	<0.16	–	57%	<0.17	–	82%

Table 5-2 (Continued)

Analyte Group/ Specie	Units	ESP Inlet			ESP Outlet			Stack		
		Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Boron	$\mu g/Nm^3$	6,400	12,000	--	6,900	1,200	--	440	70	--
Cadmium	$\mu g/Nm^3$	0.11	0.93	16%	0.10	0.31	21%	<0.064	--	100%
Calcium	$\mu g/Nm^3$	300	110	--	184	87	--	<40	--	52%
Chromium	$\mu g/Nm^3$	11	140	--	<0.73	--	42%	<0.67	--	100%
Cobalt	$\mu g/Nm^3$	<0.74	--	55%	<1.0	--	31%	0.39	0.77	--
Copper	$\mu g/Nm^3$	1.1	1.6	--	1.1	1.2	16%	1.2	2.4	14%
Iron	$\mu g/Nm^3$	140	120	--	50	78	--	<1.8	--	50%
Lead	$\mu g/Nm^3$	<0.21	--	100%	0.40	1.1	20%	<0.22	--	100%
Magnesium	$\mu g/Nm^3$	20	18	--	12	6.4	--	<7.0	--	24%
Manganese	$\mu g/Nm^3$	<0.10	--	100%	<0.11	--	100%	<0.11	--	100%
Mercury	$\mu g/Nm^3$	5.5	5.6	--	5.6	1.1	--	3.0	0.27	--
Molybdenum	$\mu g/Nm^3$	<1.4	--	52%	<1.4	--	37%	0.12	0.048	--
Nickel	$\mu g/Nm^3$	7	7%	8%	<2.9	--	59%	<2.6	--	46%
Phosphorus	$\mu g/Nm^3$	<16	--	100%	<17	--	100%	<16	--	100%
Potassium	$\mu g/Nm^3$	10	130	2%	20	100	1%	37	96	0.4%
Selenium	$\mu g/Nm^3$	<0.22	--	100%	<0.23	--	100%	0.80	1.6	--
Sodium	$\mu g/Nm^3$	240	360	--	290	280	--	<11	--	100%
Strontium	$\mu g/Nm^3$	2	4	--	1.4	0.28	--	<0.045	--	100%
Titanium	$\mu g/Nm^3$	9	71	--	2.5	3.4	--	<0.27	--	58%
Vanadium	$\mu g/Nm^3$	1.2	3	--	1.0	1.3	12%	0.55	0.57	--
Total Metals										
Aluminum	$\mu g/Nm^3$	870,000	240,000	--	12,200	--	--	200	250	--
Antimony	$\mu g/Nm^3$	33	25	--	0.41	0.12	--	0.065	0.026	--
Arsenic	$\mu g/Nm^3$	410	170	--	17	6.6	--	1.2	0.24	--
Barium	$\mu g/Nm^3$	4,400	1,700	--	75	--	--	2.9	10	--
Beryllium	$\mu g/Nm^3$	93	16	--	1.7	--	--	0.099	0.29	--
Boron (vapor only)	$\mu g/Nm^3$	6,600	2,500	--	6,900	1,200	--	440	70	--
Cadmium	$\mu g/Nm^3$	24	15	--	1.3	--	--	0.63	2.2	--
Calcium	$\mu g/Nm^3$	163,300	6,200	--	1,900	--	--	290	830	--
Chromium	$\mu g/Nm^3$	2,900	4,700	--	23	--	--	5.4	50	--
Cobalt	$\mu g/Nm^3$	276	48	--	5	--	--	0.74	4	--
Copper	$\mu g/Nm^3$	770	130	--	17	1.9	--	2.0	1.8	--
Iron	$\mu g/Nm^3$	809,000	98,000	--	8,600	1,100	--	170	600	--
Lead	$\mu g/Nm^3$	710	290	--	19	--	--	0.61	0.54	--
Magnesium	$\mu g/Nm^3$	42,000	11,200	--	670	--	--	45	230	--
Manganese	$\mu g/Nm^3$	2,120	130	--	34	3.7	--	7.3	49	--
Mercury	$\mu g/Nm^3$	13	5.6	--	5.7	1.1	--	3.1	0.44	--
Molybdenum	$\mu g/Nm^3$	320	390	--	8.7	1.4	--	1.5	2.4	--
Nickel	$\mu g/Nm^3$	2,100	2,300	--	24	6.3	--	41	430	--
Phosphorus	$\mu g/Nm^3$	2,100	1,600	--	110	--	--	<10	--	100%
Potassium	$\mu g/Nm^3$	157,000	43,000	--	2,200	--	--	79	540	--
Selenium	$\mu g/Nm^3$	133	73	--	80	130	--	27	57	--
Sodium	$\mu g/Nm^3$	46,100	6,200	--	1,000	--	--	65	130	--
Strontium	$\mu g/Nm^3$	2,920	580	--	45	--	--	1.5	3.5	--

Table 5-2 (Continued)

		ESP Inlet			ESP Outlet			Stack		
Analyte Group/ Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Titanium	μg/Nm³	55,000	16,000	--	760	230	--	13	0.26	--
Vanadium	μg/Nm³	2,770	440	--	55	10	--	2.2	1	--
Hg Vapor, Bloom										
Mercury, Elemental	μg/Nm³	2.0	1.8	--	2.5	0.28	--	2.8	1.1	--
Mercury II	μg/Nm³	4.1	1.4	--	4.2	2	--	0.47	0.33	--
Mercury, Methyl	μg/Nm³	0.31	0.59	--	0.63	0.45	--	0.044	0.041	--
Mercury, Total	μg/Nm³	6.4	1.1	--	7.3	2.4	--	3.3	0.88	--
Hexavalent Chromium										
Chromium VI	μg/Nm³							<0.190	--	100%
Total Chromium	μg/Nm³							<0.560	--	100%
Extract Metals, Nitric										
Antimony	μg/g	2.7	1	--	3.2	3.4	--	5.8	--	--
Arsenic	μg/g	43	45	--	98	40	--	160	--	--
Barium	μg/g	220	145	--	318	8.4	--	350	--	--
Beryllium	μg/g	4.1	2.3	--	5.4	5.8	--	10	--	--
Boron	μg/g	1,520	857	--	1,900	1,200	--	<15	--	100%
Cadmium	μg/g	2.2	5	5%	10	18	--	67	--	--
Chromium	μg/g	29	30	--	64	61	--	44	--	--
Cobalt	μg/g	5.0	10	--	17	3.8	--	<0.90	--	100%
Copper	μg/g	32	36	--	98	32	--	120	--	--
Lead	μg/g	39	52	--	116	31	--	91	--	--
Manganese	μg/g	120	87	--	1000	3,500	--	330	--	--
Mercury	μg/g	80	230	0.4%	4.0	11	8.1%	<7.0	--	100%
Molybdenum	μg/g	43	59	--	72	21	--	51	--	--
Nickel	μg/g	45	30	--	84	46	--	390	--	--
Selenium	μg/g	<23	--	100%	<23	--	100%	<87	--	100%
Vanadium	μg/g	150	160	--	270	260	--	390	--	--
Extract Metals, Gastric										
Antimony	μg/g	0.71	0.095	--	1.0	0.4	--	3.4	--	--
Arsenic	μg/g	<0.68	--	100%	<0.66	--	100%	<2.5	--	100%
Barium	μg/g	103	55	--	125	22	--	210	--	--
Beryllium	μg/g	1.1	0.61	--	2.7	0.66	--	4.2	--	--
Boron	μg/g	698	4.6	--	822	88	--	150	--	--
Cadmium	μg/g	1.8	3.0	--	5.9	3.2	--	12	--	--
Chromium	μg/g	27	13	--	54	18	--	85	--	--
Cobalt	μg/g	1.8	1.4	--	5.5	2	--	11	--	--
Copper	μg/g	10	5.3	--	33	9.3	--	51	--	--
Lead	μg/g	9.4	9.6	--	33	7.1	--	66	--	--
Manganese	μg/g	60	65	--	46	11	--	350	--	--
Mercury	μg/g	1.9	3.0	--	0.38	0.22	--	<0.15	--	100%
Molybdenum	μg/g	29	22	--	61	12	--	49	--	--
Nickel	μg/g	10	21	--	38	22	--	170	--	--
Selenium	μg/g	<0.88	--	100%	18	6.8	--	140	--	--
Vanadium	μg/g	<0.36	--	100%	122	79	--	<1.3	--	100%

Table 5-2 (Continued)

		ESP Inlet			ESP Outlet			Stack		
Analyte Group/ Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Extract Metals, Acetic										
Antimony	µg/g	0.80	1.1	--	0.88	0.38	--	<0.03	--	100%
Arsenic	µg/g	1.0	0.63	--	3.4	3.9	--	<0.5	--	100%
Barium	µg/g	48	30	--	44	13	--	17	--	--
Beryllium	µg/g	0.32	0.54	--	0.98	0.53	--	2.9	--	--
Boron	µg/g	1,010	240	--	910	280	--	<0.82	--	100%
Cadmium	µg/g	1.6	2.9	--	10	27	--	5.9	--	--
Chromium	µg/g	7.4	1	--	19	7.2	--	36	--	--
Cobalt	µg/g	1.5	0.87	--	6.0	7.4	--	7.5	--	--
Copper	µg/g	11	14	--	18	4.9	--	64	--	--
Lead	µg/g	0.21	0.35	--	1.5	0.98	--	20	--	--
Manganese	µg/g	51	52	--	39	8.5	--	470	--	--
Mercury	µg/g	0.70	1.9	--	0.13	0.38	--	<0.38	--	100%
Molybdenum	µg/g	1.5	5.3	--	4.0	12	--	3.5	--	--
Nickel	µg/g	8.6	5.6	--	23	1.0	--	66	--	--
Selenium	µg/g	<0.54	--	41%	4.1	3.3	--	61	--	--
Vanadium	µg/g	1.5	1.0	--	5.0	10	--	<0.19	--	100%
Metals by Size, >10 µm										
Percent of Total Mass	%	57			16					
Aluminum	µg/g	109,000	35,000	--	72,000	16,000	--			
Antimony	µg/g	2.0	1.1	--	3.2	1.0	--			
Arsenic	µg/g	26	8.4	--	49	21	--			
Barium	µg/g	520	130	--	390	100	--			
Beryllium	µg/g	10	5.6	--	10	18	--			
Cadmium	µg/g	1.7	0.88	--	3.6	1.8	--			
Calcium	µg/g	22,100	10,000	--	14,000	3,900	--			
Chromium	µg/g	184	4.3	--	213	35	--			
Cobalt	µg/g	32	4.4	--	32	18	--			
Copper	µg/g	87	23	--	102	33	--			
Iron	µg/g	102,000	2,500	--	160,000	140,000	--			
Lead	µg/g	51	19	--	72	31	--			
Magnesium	µg/g	5,400	2,000	--	3,700	1,600	--			
Manganese	µg/g	238	17	--	700	1,100	--			
Mercury	µg/g	0.50	0.47	--	0.55	0.21	--			
Molybdenum	µg/g	16	20	--	43	13	--			
Nickel	µg/g	121	34	--	129	96	--			
Phosphorus	µg/g	<72	--	100%	<71	--	100%			
Potassium	µg/g	18,500	2,700	--	14,600	2,900	--			
Selenium	µg/g	11	1	--	160	210	--			
Silicon	µg/g	218,000	20,000	--	175,000	77,000	--			
Sodium	µg/g	4,600	1,900	--	5,500	4,000	--			
Strontium	µg/g	357	97	--	294	58	--			
Titanium	µg/g	6,150	560	--	5,300	2,000	--			
Vanadium	µg/g	293	45	--	290	120	--			

Table 5-2 (Continued)

Analyte Group/ Specie	Units	ESP Inlet			ESP Outlet			Stack		
		Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Metals by Size, 3-10 μm										
Percent of Total Mass	%	27			44					
Aluminum	μg/g	118,000	23,000	--	105,000	63,000	--			
Antimony	μg/g	4.8	2.7	--	8.6	1.1	--			
Arsenic	μg/g	71	31	--	127	11	--			
Barium	μg/g	630	250	--	629	85	--			
Beryllium	μg/g	13	8.1	--	18	15	--			
Cadmium	μg/g	5.8	3.6	--	11	2.4	--			
Calcium	μg/g	19,000	17,000	--	14,000	1,600	--			
Chromium	μg/g	218	16	--	275	65	--			
Cobalt	μg/g	43	5.6	--	51	10	--			
Copper	μg/g	142	22	--	170	39	--			
Iron	μg/g	64,000	19,000	--	63,000	14,000	--			
Lead	μg/g	119	82	--	191	5.2	--			
Magnesium	μg/g	6,350	520	--	5,000	4,200	--			
Manganese	μg/g	226	34	--	280	110	--			
Mercury	μg/g	0.47	0.54	--	<0.48	--	18%			
Molybdenum	μg/g	46	34	--	80	25	--			
Nickel	μg/g	152	69	--	211	73	--			
Phosphorus	μg/g	<73	--	100%	228	100	--			
Potassium	μg/g	21,800	3,300	--	21,300	7,200	--			
Selenium	μg/g	3.1	7.3	6%	45	33	--			
Silicon	μg/g	231,000	14,000	--	218,000	20,000	--			
Sodium	μg/g	6,700	2,600	--	7,900	1,500	--			
Strontium	μg/g	384	11	--	370	120	--			
Titanium	μg/g	6,830	960	--	6,860	850	--			
Vanadium	μg/g	390	190	--	509	91	--			
Metals by Size, <3 μm										
Percent of Total Mass	%	16			40					
Aluminum	μg/g	135,000	18,000	--	122,000	10,000	--			
Antimony	μg/g	10	5.7	--	13	0.94	--			
Arsenic	μg/g	160	110	--	202	54	--			
Barium	μg/g	780	400	--	758	85	--			
Beryllium	μg/g	17	9.8	--	15	5.0	--			
Cadmium	μg/g	15	12	--	21	8.0	--			
Calcium	μg/g	19,000	13,000	--	16,200	2,100	--			
Chromium	μg/g	246	65	--	290	84	--			
Cobalt	μg/g	63	28	--	64	15	--			
Copper	μg/g	195	52	--	250	180	--			
Iron	μg/g	58,600	4,700	--	67,900	5,100	--			
Lead	μg/g	180	120	--	220	230	--			
Magnesium	μg/g	7,500	1,500	--	6,700	3,500	--			
Manganese	μg/g	267	79	--	319	29	--			
Mercury	μg/g	0.63	0.25	--	0.39	0.15	--			
Molybdenum	μg/g	103	72	--	118	49	--			
Nickel	μg/g	202	49	--	235	52	--			

Table 5-2 (Continued)

Analyte Group/ Specie	Units	ESP Inlet Average	ESP Inlet 95% CI	ESP Inlet DL Ratio	ESP Outlet Average	ESP Outlet 95% CI	ESP Outlet DL Ratio	Stack Average	Stack 95% CI	Stack DL Ratio
Phosphorus	µg/g	<499	--	35%	820	790	--			
Potassium	µg/g	24,500	2,600	--	22,700	5,700	--			
Selenium	µg/g	<8.0	--	36%	60	43	--			
Silicon	µg/g	223,000	38,000	--	207,000	18,000	--			
Sodium	µg/g	8,000	2,300	--	8,300	2,800	--			
Strontium	µg/g	430	120	--	429	91	--			
Titanium	µg/g	6,970	480	--	6,890	170	--			
Vanadium	µg/g	2,700	9,100	--	770	230	--			
Organics, Aldehydes										
Acetaldehyde	µg/Nm³	130	170	--	1.2	2.8	--	8.7	9.2	
Formaldehyde	µg/Nm³	61	56	--	0.50	1.1	--	24	35	
Organics, Semivolatile										
2-Methylphenol(o-cresol)	ng/Nm³	1,500	4,500	1%	5,000	11,000	--	3,000	3,700	--
4-Methylphenol(p-cresol)	ng/Nm³	1,100	2,700	3%	1,730	780	--	960	2,000	3%
Acetophenone	ng/Nm³	2,400	5,000	1%	3,260	750	--	3,300	710	--
Benzoic acid	ng/Nm³	140,000	100,000	--	130,000	70,000	--	119,000	5,000	--
Benzyl alcohol	ng/Nm³	2,300	9,100	4%	4,000	18,000	2%	2,800	1,100	3%
Butylbenzylphthalate	ng/Nm³	<230	--	39%	340	170	--	300	130	--
Dibutylphthalate	ng/Nm³	2,600	10,000	--	<160	--	39%	170	260	--
Diethylphthalate	ng/Nm³	260	360	12%	190	530	24%	240	140	--
Dimethylphthalate	ng/Nm³	<110	--	100%	<96	--	100%	180	560	18%
Naphthalene	ng/Nm³	900	460	--	1,100	1,000	--	1,500	980	--
Phenol	ng/Nm³	8,000	11,000	--	9,000	15,000	--	9,300	8,700	--
bis(2-Ethylhexyl)phthalate	ng/Nm³	1,400	1,700	--	15,000	41,000	--	1,400	1,400	--
Organics, Volatile										
1,1,1-Trichloroethane	ng/Nm³	700	270	--	690	190	--	640	810	14%
Acetone	ng/Nm³	16,000	63,000	6%	<2,600	--	100%	3,600	6,300	13%
Benzene	ng/Nm³	1,100	680	--	1,470	240	--	1,310	360	--
Carbon Disulfide	ng/Nm³	7,000	25,000		3,400	7,700		2,300	1,200	
Chloromethane	ng/Nm³	<460	--	100%	<530	--	100%	6,000	13,000	1%
Methylene Chloride	ng/Nm³	170,000	540,000	--	33,000	37,000	--	130,000	280,000	--
Tetrachloroethene	ng/Nm³	1,000	800	--	820	470	--	1,500	2,300	--
Toluene	ng/Nm³	1,200	2,000	--	1,200	1,100	--	2,000	1,000	--
Trichlorofluoromethane	ng/Nm³	9,000	27,000	--	<540	--	44%	1,100	1,700	--
m,p-Xylene	ng/Nm³				<540	--	40%			
Dioxins/Furans										
Total TCDD	ng/Nm³							0.0067	0.008	16%

Boric acid is added to dissolve the insoluble metal fluorides that are produced during digestion. This addition of boric acid makes the quantification of boron in the sample impossible. Silicon in the gas particulate sample cannot be isolated due to the overwhelming contribution of silicon from the filter media.

The results presented in the data tables in this section of the report have been corrected for significant figures and may vary slightly from the detailed data summary presented in Appendix H. The number of significant figures reported is directly related to the order of magnitude of the 95% CI. Therefore, numbers with a small degree of variability will contain more significant figures than those whose CI is extremely broad.

Detection limit ratios are presented where the mean value is derived in some part from results that are below the method detection limit. If all values used in determining the mean value were above the detection limit, then no DL ratio was calculated and is represented by "--."

Flue Gas Particle Size Distribution Results

Flue gas particle size distributions were measured in three runs at the ESP inlet, ESP outlet, and the stack. All of these measurements were performed with inertial sizing devices. The Andersen High Capacity Source Sampler was used at the ESP inlet. This device has two impaction stages, a cyclone, and a final filter. The University of Washington Mark V cascade impactor was used at the ESP outlet and at the stack. This impactor was equipped with a right angle pre-cutter, eleven impaction stages, and a final filter. Because the cutpoint of the pre-cutter was close to the cutpoints of the first two stages, the weights of the pre-cutter and first two impaction stages were combined for the size distribution calculations.

Since these particle sizing devices are inertial sizing devices, the particle cutpoints are reported from the field in aerodynamic micrometers. Conversion of aerodynamic diameter to physical diameter will be described and used in Section 8. Table 5-3 gives the average cumulative particle size distributions for the ESP inlet, ESP outlet, and stack in terms of aerodynamic particle size for the three runs. As an example of how to read the tables, Table 5-3 shows that at the ESP outlet, 15.5% of the particulate mass was found in particles with aerodynamic diameters less than 2.1 aero μm.

ESP Hopper Particle Size Distribution Results

The particle size distributions of ESP hopper catches were also measured. ESP hopper catches were collected once during Runs 1 and 2 and twice during Run 3. Field 1 and Field 2 hopper catch composites were made and analyzed by Microtracs laser diffraction. This method measures particle volumes as a function of physical particle diameter. Table 5-4 shows the average cumulative percent particle volumes as a function of physical particle diameter for the ESP Field 1 composites and the ESP Field 2 composites, respectively. These results are discussed in Section 8.

Table 5-3
Flue Gas Particle Size Distribution

	Aerodynamic Particle Diameter (Aero μm)	Average Mass Percent Less than Indicated Diameter
ESP Inlet	12.0	32.6
	6.5	20.3
	1.8	3.8
ESP Outlet	10.1	66.3
	4.3	35.0
	2.1	15.5
	1.14	7.4
	0.74	4.1
	0.57	3.1
	0.43	2.1
	0.33	1.4
	0.27	0.7
	0.16	0.7
Stack	10.7	60.8
	4.6	52.6
	2.3	43.2
	1.26	30.0
	0.85	17.7
	0.67	11.7
	0.52	7.3
	0.41	3.7
	0.34	0.6
	0.21	0.6

Table 5-4
ESP Fields 1 and 2 Hopper Composite Catches

Hopper 1		Hopper 2	
Physical Particle Diameter (physical μm)	**Average Volume Percent Less than Indicated Diameter**	**Physical Particle Diameter (physical μm)**	**Average Volume Percent Less than Indicated Diameter**
106	100.0	42	100.0
75	90.6	30	93.4
53	76.6	21	83.9
38	67.7	15	72.5
27	57.3	10.6	60.5
19	46.4	7.5	47.9
13	38.4	5.3	34.6
9.4	30.5	3.7	24.5
6.6	21.2	2.6	17.2
4.7	15.0	1.7	11.1
3.3	8.2	1.01	6.0
2.4	3.5	0.66	2.7
1.7	2.1	0.43	0.8
1.0	0.7	0.34	0.3
0.66	0.1	0.24	0.1

FGD System

Analytical results for influent and effluent streams associated with the JBR have been compiled and are presented in Table 5-5. Mean results are presented for the limestone slurry, the JBR underflow slurry and the inlet and outlet gaseous streams. These data are also presented elsewhere in this section with 95% CI and DL ratios.

Solids

Data for the solid streams have been summarized and are presented in Tables 5-6 to 5-9. Table 5-6 contains data representing the coal feed section of the process. Table 5-7 represents the primary ash streams exiting the boiler, Table 5-8 contains ESP hopper ash data and Table 5-9 contains data from the JBR/FGD removal process.

Liquids

Liquid streams data have been summarized and are presented in Tables 5-10 to 5-12. Table 5-10 contains data from the ash sluice system. Table 5-11 presents the FGD process stream data and ancillary streams such as the cooling water and coal pile run-off are in Table 5-12. As with the gaseous results, the only organic results that are presented are for those species which were detected. Detailed results are contained in Appendix H.

Table 5-5
FGD System Summary

	Limestone Slurry		JBR Underflow Slurry		ESP Outlet	Stack
Specie	**Aqueous (μg/mL)**	**Solids (μg/g)**	**Aqueous (μg/mL)**	**Solids (μg/g)**	**Total (μg/Nm^3)**	**Total (μg/Nm^3)**
Aluminum	0.26	760	12.3	1,100	12,200	200
Antimony	<0.24	0.019	<0.19	0.073	0.53	0.41
Arsenic	0.07	<0.33	0.20	<0.41	17	1.9
Barium	4	5.39	3.39	4.02	75	3.2
Beryllium	<0.0055	0.143	0.0069	0.129	2.4	0.43
Boron	1,400	202	1,400	425	6,900	440
Cadmium	0.0067	0.608	0.456	0.247	1.3	1.2
Calcium	7,070	392,000	17,000	255,-	1,900	300
Chromium	0.063	13.4	0.07	000	24	6.4
				11.3		
Cobalt	0.09	1.48	0.304	0.99	6.0	0.74
Copper	0.04	3.71	0.239	2.73	18	2.0
Iron	<0.06	2,510	<0.048	2,190	8,600	170
Lead	0.0017	0.98	0.013	0.84	19	1.3
Magnesium	1,900	1,390	1,800	810	670	47
Manganese	40	429	307	103	35	7.9
Mercury	0.00006	<0.012	0.001	0.178	5.7	3.1
Molybdenum	0.21	0.23	0.064	1.48	9.1	1.5
Nickel	0.8	4.0	1.52	2.8	25	42
Phosphorus	0.16	110	0.720	88	120	<19
Potassium	140	338	123	310	2,200	80
Selenium	0.128	8.4	0.50	25.5	80	27
Silicon	7	370	42.4	447		
Sodium	290	55	244	84.1	1,000	71
Strontium	40	112	32.9	73.8	45	2.1
Titanium	0.5	<0.16	0.82	20.9	760	13
Vanadium	0.19	6.7	0.24	9.9	55	2.2

Table 5-6
Coal Data

			Feed Coal			Raw Coal			Pulverizer Rejects		
Analyte Group	Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Anions	Chloride	µg/g	1,400	90		1,350	220		510	100	
	Fluoride	µg/g	100	0		123	38		323	29	
Metals	Aluminum	µg/g	14,500	1,400		14,300	3,100		27,200	9,600	
	Antimony	µg/g	0.61	0.16		0.62	0.33		1.2	0.45	
	Arsenic	µg/g	2.3	1.4		3.0	0		47	45	
	Barium	µg/g	80	51		112	19		330	520	
	Beryllium	µg/g	1.1	0		1.13	0.14		1.5	1.9	
	Boron	µg/g	100	0		110	25		120	120	
	Bromine	µg/g	7.44	0.53		7.4	1		4.3	1.5	
	Cadmium	µg/g	0.30	0		0.53	0.72		4.1	8.6	
	Calcium	µg/g	2,100	1,300		3,000	1,300		12,700	6,500	
	Chlorine	µg/g	1,240	100		1,210	140		590	130	
	Chromium	µg/g	24.8	2.9		25.8	0.37		64	14	
	Cobalt	µg/g	3.5	1.9		4.08	0.19		7.8	0.8	
	Copper	µg/g	36	62		42	50		68	85	14%
	Iron	µg/g	11,400	1,100		12,800	1,700		127,000	17,000	
	Lead	µg/g	8.0	2.5		9.0	4.3		37	32	
	Magnesium	µg/g	570	170		660	58		1,370	320	
	Manganese	µg/g	23.4	3.3		24.4	5.9		99	53	
	Mercury	µg/g	0.077	0.029		0.043	0.014		0.13	0.29	
	Molybdenum	µg/g	22.3	6.1		18	11		13	20	
	Nickel	µg/g	30.0	6.4		40	14		<120	–	66%
	Phosphorus	µg/g	84	16		100	120		1,500	2,200	
	Potassium	µg/g	3,300	720		3,100	2,300		2,700	6,600	
	Selenium	µg/g	2.3	1.4		2.3	1.4		8.7	3.8	
	Silver	µg/g	<0.52	–	100%	<0.41	–	100%	<1.9	–	59%
	Sodium	µg/g	631	82		679	89		1,110	240	
	Strontium	µg/g	74.9	9.3		88	14		450	460	
	Tin	µg/g	<16	–	100%	<17	–	100%	<31	–	49%
	Titanium	µg/g	890	170		850	170		1,980	110	
	Uranium	µg/g	1.8	0.6		1.60	0.37		4.1	1.9	
	Vanadium	µg/g	39.4	1.2		37.7	6.3		59.8	8.2	
Ultimate/Proximate	% Ash	%	11.1	1.4		12.2	2.5				
	% Carbon	%	72.0	0.52		70.8	1.2		38.5	4.2	
	% Hydrogen	%	4.83	0.014		4.76	0.17				
	% Moisture	%				11.7	2.2				
	% Nitrogen	%	1.52	0.14		1.45	0.052				
	% Oxygen (diff.)	%	7.74	0.62		7.92	0.93				
	% Sulfur	%	2.74	0.29		2.90	0.36		16.0	2.3	
	Fixed Carbon	%	50.8	2.5		50.7	0.74				
	Higher Heating Value	Btu/lb	12,697	64		12,590	270				
	Heating Value (MAF)	MAF Btu	14,290	160		14,330	150				
	Volatile Matter	%	37.0	2.7		37.1	1.9				

Table 5-6 (Continued)

Analyte Group	Specie	Units	Feed Coal Average	Feed Coal 95% CI	Feed Coal DL Ratio	Raw Coal Average	Raw Coal 95% CI	Raw Coal DL Ratio	Pulverizer Rejects Average	Pulverizer Rejects 95% CI	Pulverizer Rejects DL Ratio
Radionuclides	Actinium-228 @ 338 KeV	pCi/g	0.33	0.29							
	Actinium-228 @ 911 KeV	pCi/g	0.33	0.14							
	Actinium-228 @ 968 KeV	pCi/g	0.07	0.29							
	Bismuth-212 @ 727 KeV	pCi/g	ND	–							
	Bismuth-214 @ 1120.4 KeV	pCi/g	0.93	0.38							
	Bismuth-214 @ 1764.7 KeV	pCi/g	0.10	0.43							
	Bismuth-214 @ 609.4 KeV	pCi/g	0.67	0.14							
	K-40 @ 1460 KeV	pCi/g	1.4	3.6							
	Lead-210 @ 46 KeV	pCi/g	1.3	0.9							
	Lead-212 @ 238 KeV	pCi/g	0.20	0							
	Lead-214 @ 295.2 KeV	pCi/g	0.63	0.14							
	Lead-214@ 352.0 KeV	pCi/g	0.63	0.14							
	Radium-226 @ 186.0 KeV	pCi/g	1.17	0.72							
	Thallium-208 @ 583 KeV	pCi/g	0.30	0.25							
	Thallium-208 @ 860 KeV	pCi/g	ND	–							
	Thorium-234 @ 63.3 KeV	pCi/g	1.0	1.4							
	Thorium-234 @ 92.6 KeV	pCi/g	0.67	0.38							
	Uranium-235 @ 143 KeV	pCi/g	0.07	0.29							

Table 5-7
Boiler Process Solids Data

			Bottom Ash			Sluiced Fly Ash		
Analyte Group	Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Anions	Chloride	µg/g	130	170	13%	<100	–	100%
	Fluoride	µg/g	32	26		99	67	
Metals	Aluminum	µg/g	76,000	11,000		98,000	8,000	
	Antimony	µg/g	1.14	0.20		339	2.04	
	Arsenic	µg/g	7.2	6.2		61	37	
	Barium	µg/g	457	66		496	87	
	Beryllium	µg/g	7.7	2.9		11.1	3.1	
	Boron	µg/g	280	170		470	230	
	Cadmium	µg/g	0.32	0.39		4.10	3	
	Calcium	µg/g	20,300	3,400		13,800	2,000	
	Chromium	µg/g	192	18		185	21	
	Cobalt	µg/g	31.6	4.3		36.9	5.8	
	Copper	µg/g	77	18		104	23	
	Iron	µg/g	130,000	31,000		89,000	22,000	
	Lead	µg/g	20	3.8		83	40	
	Magnesium	µg/g	3610	820		4,880	350	
	Manganese	µg/g	270	56		245	46	
	Mercury	µg/g	<0.011	–	70%	0.150	0.12	
	Molybdenum	µg/g	<3.0	–	39%	<14	–	29%
	Nickel	µg/g	131	15		143	32	
	Phosphorus	µg/g	400	210		70	140	
	Potassium	µg/g	14,200	1,100		18,210	1,000	
	Selenium	µg/g	<1	–	100%	12	11	
	Silicon	µg/g	213,000	11,000		219,000	7,600	
	Sodium	µg/g	36,10	580		5,100	1,200	
	Strontium	µg/g	280	41		322	30	
	Titanium	µg/g	5,550	560		6,330	750	
	Vanadium	µg/g	277	29		327	58	
Ultimate/Proximate	% Carbon	%	2.3	4.2		4.50	2.7	
	% Sulfur	%	0.15	0.41		0.134	0.041	
Radionuclides	Actinium-228 @ 338 KeV	pCi/g	2.1	0		2.37	0.14	
	Actinium-228 @ 911 KeV	pCi/g	2.20	0.25		2.33	0.14	
	Actinium-228 @ 968 KeV	pCi/g	2.2	1		2.50	0.25	
	Bismuth-212 @ 727 KeV	pCi/g	3.0	1.2		2.60	0.99	
	Bismuth-214 @ 1120.4 KeV	pCi/g	7.4	1.3		6.50	2.4	
	Bismuth-214 @ 1764.7 KeV	pCi/g	6.8	2.2		5.90	1.8	
	Bismuth-214 @ 609.4 KeV	pCi/g	7.1	1.5		6.50	1.4	
	K-40 @ 1460 KeV	pCi/g	16.7	2.9		18.0	2.5	
	Lead-210 @ 46 KeV	pCi/g	1.37	0.52		6.40	2.7	
	Lead-212 @ 238 KeV	pCi/g	2.03	0.72		2.20	0.25	

Table 5-7 (Continued)

Analyte Group	Specie	Units	Bottom Ash Average	Bottom Ash 95% CI	Bottom Ash DL Ratio	Sluiced Fly Ash Average	Sluiced Fly Ash 95% CI	Sluiced Fly Ash DL Ratio
Radionuclides (Cont'd)	Lead-214 @ 295.2 KeV	pCi/g	7.3	1.9		6.50	1.4	
	Lead-214@ 352.0 KeV	pCi/g	7.6	1.8		6.60	1.3	
	Radium-226 @ 186.0 KeV	pCi/g	10.3	1.5		9.9	2.9	
	Thallium-208 @ 583 KeV	pCi/g	2.20	0.43		2.23	0.29	
	Thallium-208 @ 860 KeV	pCi/g	1.9	4.2		2.97	0.14	
	Thorium-234 @ 63.3 KeV	pCi/g	5.77	0.76		6.60	4.3	
	Thorium-234 @ 92.6 KeV	pCi/g	5.0	1.3		5.00	2.2	
	Uranium-235 @ 143 KeV	pCi/g	0.31	0.16		0.220	0.15	
Organics, Semivolatile	2-Methylnaphthalene	ng/g	34	97	22%	<26	–	100%
	bis(2-Ethylhexyl)phthalate	ng/g	<86	–	26%	230	520	2%

Table 5-8
ESP Hopper Ash

			ESP Hopper Ash-Field 1			ESP Hopper Ash-Field 2		
Analyte Group	Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Anions	Chloride	µg/g	350	650	5%	<100	–	100%
	Fluoride	µg/g	90	49		125	91	
Metals	Aluminum	µg/g	97,000	51,000		89,000	11,000	
	Antimony	µg/g	2.99	1.01		4.19	1.38	
	Arsenic	µg/g	46	11		71.9	9.8	
	Barium	µg/g	490	150		493	98	
	Beryllium	µg/g	10.9	3.3		17.2	3.4	
	Cadmium	µg/g	3.26	0.72		5.42	0.69	
	Calcium	µg/g	17,900	6,400		15,640	960	
	Chromium	µg/g	183	31		220	110	
	Cobalt	µg/g	34.0	4.1		42	6	
	Copper	µg/g	98	26		150	150	
	Iron	µg/g	90,000	17,000		80,000	8,600	
	Lead	µg/g	72	11		96	20	
	Magnesium	µg/g	4,600	2,700		4,100	1,000	
	Manganese	µg/g	219	52		216	25	
	Mercury	µg/g	0.119	0.087		0.18	0.18	
	Molybdenum	µg/g	25	19		49	32	
	Nickel	µg/g	127	28		158	31	
	Phosphorus	µg/g	100	140	12%	<72	–	100%
	Potassium	µg/g	17,400	3,100		18,100	1,100	
	Selenium	µg/g	9.3	4.7		16.6	3.3	
	Silicon	µg/g	223,000	35,000		215,000	15,000	
	Sodium	µg/g	5,200	1,200		6,000	1,400	
	Strontium	µg/g	320	120		327	41	
	Titanium	µg/g	6,120	190		6,450	290	
	Vanadium	µg/g	305	37		357	55	
Radionuclides	Actinium-228 @ 338 KeV	pCi/g	2.13	0.38		2.17	0.38	
	Actinium-228 @ 911 KeV	pCi/g	2.10	0.43		2.2	0.5	
	Actinium-228 @ 968 KeV	pCi/g	2.43	0.87		2.63	0.14	
	Bismuth-212 @ 727 KeV	pCi/g	2.8	1.6		2.8	1.3	
	Bismuth-214 @ 1120.4 KeV	pCi/g	6.1	2.6		6.27	0.76	
	Bismuth-214 @ 1764.7 KeV	pCi/g	5.9	2.3		5.7	0.9	
	Bismuth-214 @ 609.4 KeV	pCi/g	6.2	2.1		6.0	1.9	
	K-40 @ 1460 KeV	pCi/g	17.0	4.3		17.3	1.4	
	Lead-210 @ 46 KeV	pCi/g	5.43	0.72		7.8	1.4	
	Lead-212 @ 238 KeV	pCi/g	2.10	0.75		1.87	0.76	
	Lead-214 @ 295.2 KeV	pCi/g	6.1	1.5		6.0	1.2	
	Lead-214@ 352.0 KeV	pCi/g	6.2	2.1		6.1	1.1	
	Radium-226 @ 186.0 KeV	pCi/g	9.0	2.2		9.7	2.8	

Table 5-8 (Continued)

Analyte Group	Specie	Units	ESP Hopper Ash-Field 1 Average	ESP Hopper Ash-Field 1 95% CI	ESP Hopper Ash-Field 1 DL Ratio	ESP Hopper Ash-Field 2 Average	ESP Hopper Ash-Field 2 95% CI	ESP Hopper Ash-Field 2 DL Ratio
Radionuclides (Cont'd)								
	Thallium-208 @ 583 KeV	pCi/g	2.07	0.29		2.17	0.38	
	Thallium-208 @ 860 KeV	pCi/g	2.1	1.9		2.2	4.8	
	Thorium-234 @ 63.3 KeV	pCi/g	5.6	2.2		5.5	1.6	
	Thorium-234 @ 92.6 KeV	pCi/g	4.3	1.6		4.8	1.6	
	Uranium-235 @ 143 KeV	pCi/g	0.22	0.17		0.9	2.8	
Organics, Semivolatile	bis(2-Ethylhexyl)phthalate	ng/g	190	780	3%	200	590	2%

Table 5-9
FGD Process Solids Data

			JBR Underflow Slurry Solids			Limestone Slurry Solids			Raw Limestone		
Analyte Group	**Specie**	**Units**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**
Anions	Chloride	µg/g	9,550	720		4,100	2,900		179	47	
	Fluoride	µg/g	750	140		85.0	46		59.0	19	
	Sulfate	µg/g	496,300	8,700							
	Sulfite	µg/g	<240	–	100%						
Metals	Aluminum	µg/g	1,100	190		760	320		980	160	
	Antimony	µg/g	0.073	0.028		0.019	0.003		0.007	0.01	
	Arsenic	µg/g	<0.41	–	100%	<0.33	–	100%	<0.33	–	100%
	Barium	µg/g	4.02	0.94		5.39	0.66		4.87	0.59	
	Beryllium	µg/g	0.129	0.066		0.143	0.017		0.137	0.028	
	Boron	µg/g	425	43		202	88		3.5	1.3	
	Cadmium	µg/g	0.247	0.035		0.608	0.042		0.332	0.016	
	Calcium	µg/g	255,000	15,000		392,000	27,000		395,000	9,000	
	Chromium	µg/g	11.3	2.5		13.4	2.3		9.80	0.64	
	Cobalt	µg/g	0.99	0.43		1.48	0.51		1.30	0.62	
	Copper	µg/g	2.73	0.81		3.71	0.48		1.5	1.1	
	Iron	µg/g	2,190	370		2,510	670		1,787	57	
	Lead	µg/g	0.84	0.21		0.98	0.11		1.1	0.2	
	Magnesium	µg/g	810	100		1,390	190		1,233	29	
	Manganese	µg/g	103	11		429	33		207	6.6	
	Mercury	µg/g	0.178	0.055		<0.012	–	29%	0.005	0.012	40%
	Molybdenum	µg/g	1.48	0.56		0.230	0.4		<0.222	–	50%
	Nickel	µg/g	2.8	1.3		4.00	2.5		3.16	0.88	
	Phosphorus	µg/g	88	29		110	10		108	31	
	Potassium	µg/g	310	160		338	86		363	45	
	Selenium	µg/g	25.5	1.2		8.40	2.8		3.9	2	
	Silicon	µg/g	447	73		370	220		440	110	
	Sodium	µg/g	84.1	7.8		55.0	19		20.9	2.5	
	Strontium	µg/g	73.8	7.4		112	5.3		108	2.5	
	Titanium	µg/g	20.9	7.1		<0.16	–	100%	30	110	0.00-2%
	Vanadium	µg/g	9.9	2.1		6.7	4.3		8.13	0.41	
Moisture	Percent Moisture	wt%							8.7	1.4	
Radionuclides	Actinium-228 @ 338 KeV	pCi/g	ND	–					0.30	0.19	
	Actinium-228 @ 911 KeV	pCi/g	0.05	0.23					0.17	0.38	
	Actinium-228 @ 968 KeV	pCi/g	ND	–					ND	–	

Table 5-9 (Continued)

			JBR Underflow Slurry Solids			Limestone Slurry Solids			Raw Limestone		
Analyte Group	Specie	Units	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
	Bismuth-212 @ 727 KeV	pCi/g	ND	–					ND	–	
	Bismuth-214 @ 1120.4 KeV	pCi/g	0.25	0.54					ND	–	
	Bismuth-214 @ 1764.7 KeV	pCi/g	0.11	0.27					0.32	0.32	
	Bismuth-214 @ 609.4 KeV	pCi/g	0.11	0.23					0.15	0.14	
	K-40 @ 1460 KeV	pCi/g	ND	–					0.39	0.86	
	Lead-210 @ 46 KeV	pCi/g	0.30	1.1					0.2	1.1	
	Lead-212 @ 238 KeV	pCi/g	0.09	0.05					0.113	0.038	
	Lead-214 @ 295.2 KeV	pCi/g	0.05	0.23					0.19	0.11	
	Lead-214@ 352.0 KeV	pCi/g	0.140	0.075					0.193	0.072	
	Radium-226 @ 186.0 KeV	pCi/g	0.33	0.72					0.42	0.91	
	Thallium-208 @ 583 KeV	pCi/g	0.20	0.21					0.07	0.3	
	Thallium-208 @ 860 KeV	pCi/g	ND	–					ND	–	
	Thorium-234 @ 63.3 KeV	pCi/g	0.19	0.8					0.12	0.53	
	Thorium-234 @ 92.6 KeV	pCi/g	0.20	0.44					0.08	0.36	
	Uranium-235 @ 143 KeV	pCi/g	ND	–					ND	–	
Aldehydes	Acetaldehyde	µg	<0.10	–	100%						
	Formaldehyde	µg	<0.10	–	100%						
Organics, Semivolatile	bis(2-Ethylhexyl) phthalate	ng/g	100	350	15%						

Table 5-10
Liquid Ash Sluice System Data Summary

			Ash Pond Water			Bottom Ash Sluice Filtrate			ESP Fly Ash Sluice Filtrate		
Analyte Group	**Specie**	**Units**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**
Reduced Species	Cyanide	µg/mL	0.0019	0.0024	–	0.002	0.0011	–	0.0015	0.0016	–
	Ammonia as N	µg/mL	0.20	0.12	–	0.45	0.43	–	0.38	0.08	–
Anions	Chloride	µg/mL	8.9	1.9	–	7.9	1.1	–	10.4	1.6	–
	Fluoride	µg/mL	0.43	0.11	–	0.281	0.046	–	0.74	0.57	–
	Phosphate	µg/mL	<0.014	–	100%	0.025	0.037	13%	0.023	0.047	14%
	Sulfate	µg/mL	113	12	–	81	34	–	340	510	–
Metals, Soluble	Aluminum	µg/mL	0.014	0.012	–	0.31	0.31	–	1.0	3.3	–
	Antimony	µg/mL	<0.024	–	100%	<0.024	–	100%	<0.024	–	67%
	Arsenic	µg/mL	<0.00066	–	100%	0.024	0.088	–	0.017	0.049	–
	Barium	µg/mL	0.155	0.028	–	0.102	0.084	–	0.24	0.16	–
	Beryllium	µg/mL	<0.00055	–	31%	<0.00055	–	100%	<0.00055	–	100%
	Boron	µg/mL	1.08	0.23	–	0.87	0.64	–	10	15	–
	Cadmium	µg/mL	0.0011	0.0010	–	0.0011	0.0021	4%	0.0027	0.004	–
	Calcium	µg/mL	32.8	3.5	–	39	23	–	140	170	–
	Chromium	µg/mL	<0.0025	–	53%	0.0031	0.0026	–	0.0480	0.051	–
	Cobalt	µg/mL	<0.0034	–	60%	<0.0034	–	100%	<0.0034	–	98%
	Copper	µg/mL	0.0044	0.0049	–	0.0180	0.047	–	0.0026	0.0015	–
	Iron	µg/mL	5.40	3.8	–	0.0280	0.034	–	0.0060	0.015	–
	Lead	µg/mL	0.008	0.011	–	0.0100	0.013	–	0.0048	0.0036	–
	Magnesium	µg/mL	3.11	0.17	–	2.3	1.6	–	4.5	2	–
	Manganese	µg/mL	0.560	0.21	–	0.05	0.12	–	0.020	0.045	–
	Mercury	µg/mL	0.00006	0.000043	–	0.00004	0.00007	–	<0.00004	–	38%
	Molybdenum	µg/mL	0.035	0.021	–	0.072	0.083	–	0.62	0.98	–
	Nickel	µg/mL	0.0197	0.0055	–	0.005	0.014	–	0.024	0.026	–
	Phosphorus	µg/mL	0.070	0.18	16%	0.11	0.13	–	0.14	0.26	7%
	Potassium	µg/mL	5.34	0.78	–	4.4	2.7	–	12	17	–
	Selenium	µg/mL	0.0019	0.0037	–	0.0039	0.0009	–	0.035	0.04	–
	Silicon	µg/mL	3.45	0.7	–	4.7	0.5	–	4.1	2.7	–
	Sodium	µg/mL	12.4	0.75	–	9.4	2.2	–	22	25	–
	Strontium	µg/mL	0.342	0.020	–	0.28	0.31	–	0.62	0.66	–
	Tin	µg/mL	<0.014	–	84%	<0.014	–	43%	0.0040	0.015	–
	Titanium	µg/mL	<0.0024	–	62%	0.0013	0.0022	13%	0.016	0.067	–
	Vanadium	µg/mL	0.0050	0.016	–	0.029	0.049	–	0.07	0.12	–
Metals, Total	Aluminum	µg/mL	0.18	0.39	–						
	Antimony	µg/mL	0.018	0.012	–						
	Arsenic	µg/mL	0.0007	0.0014	–						
	Barium	µg/mL	0.153	0.032	–						
	Beryllium	µg/mL	0.00026	0.00064	–						
	Boron	µg/mL	1.03	0.16	–						

Table 5-10 (Continued)

			Ash Pond Water			Bottom Ash Sluice Filtrate			ESP Fly Ash Sluice Filtrate		
Analyte Group	**Specie**	**Units**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**
Metals, Total (Cont'd)	Cadmium	µg/mL	0.0018	0.0039	–						
	Calcium	µg/mL	33.7	2.7	–						
	Chromium	µg/mL	0.0016	0.0011	–						
	Cobalt	µg/mL	0.00638	0.00077	–						
	Copper	µg/mL	0.0073	0.0051	–						
	Iron	µg/mL	10.2	5.4	–						
	Lead	µg/mL	0.017	0.057	1%						
	Magnesium	µg/mL	3.17	0.20	–						
	Manganese	µg/mL	0.56	0.21	–						
	Mercury	µg/mL	0.00005	0.00007	–						
	Molybdenum	µg/mL	0.084	0.034	–						
	Nickel	µg/mL	0.024	0.013	–						
	Phosphorus	µg/mL	0.027	0.052	–						
	Potassium	µg/mL	5.74	0.83	–						
	Selenium	µg/mL	0.0048	0.0026	–						
	Silicon	µg/mL	3.70	0.73	–						
	Sodium	µg/mL	12.8	1.9	–						
	Strontium	µg/mL	0.34	0.026	–						
	Tin	µg/mL	<0.014	–	50%						
	Titanium	µg/mL	0.00068	0.00098	–						
	Vanadium	µg/mL	0.024	0.011	–						
Aldehydes	Acetaldehyde	µg/mL	0.08	0.17	–	0.080	0.16	–	0.04	0.11	–
	Formaldehyde	µg/mL	0.015	0.021	–	0.023	0.036	–	0.03	0.048	–
Organics, Semivolatile	Diethylphthalate	µg/L	<0.39	–	100%	0.5	1.3	24%	<0.38	–	100%
Organics, Volatile	Methylene Chloride	µg/L	<5.0	–	19%	<5.0	–	46%	4.9	2.9	–

Table 5-11
Liquid FGD Process Stream Data Summary

Analyte Group	Specie	Units	Gypsum Pond Water			JBR Underflow Slurry Filtrate			Limestone Slurry Filtrate		
			Average	95% CI	DL Ratio	Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Reduced Species	Cyanide	µg/mL	0.0486	0.0046	–	0.082	0.1	–	0.050	0.1	–
	Ammonia as N	µg/mL	15	3	–	<40	–	19%	14.1	2.4	–
Anions	Chloride	µg/mL	16,400	4,100	–	26,100	4,200	–	13,100	2,100	–
	Fluoride	µg/mL	14.9	3.1	–	31.0	16	–	1.84	0.95	–
	Phosphate	µg/mL	0.033	0.021	–	0.050	0.15	7%	<0.020	–	100%
	Sulfate	µg/mL	980	140	–	712	65	–	780	160	–
	Sulfite	µg/mL	–		–	0.033	0.038	–	–	–	–
Metals, Soluble	Aluminum	µg/mL	0.76	0.68	–	12.3	4.7	–	0.260	0.85	–
	Antimony	µg/mL	<0.24	–	100%	<0.19	–	100%	<0.24	–	100%
	Arsenic	µg/mL	0.127	0.027	–	0.200	0.26	–	0.070	0.13	–
	Barium	µg/mL	1.19	0.057	–	3.39	0.29	–	4.00	11	–
	Beryllium	µg/mL	<0.0055	–	68%	0.0069	0.0047	–	<0.0055	–	56%
	Boron	µg/mL	533	89	–	1,400	190	–	1,400	4,100	–
	Cadmium	µg/mL	0.149	0.035	–	0.456	0.065	–	0.0067	0.0026	–
	Calcium	µg/mL	8,100	2,100	–	17,000	10,000	–	7,070	190	–
	Chromium	µg/mL	0.101	0.03	–	0.070	0.091	–	0.063	0.047	–
	Cobalt	µg/mL	0.11	0.13	–	0.304	0.0029	–	0.090	0.3	–
	Copper	µg/mL	0.057	0.048	–	0.239	0.086	–	0.040	0.11	–
	Iron	µg/mL	<0.060	–	100%	<0.048	–	100%	<0.060	–	100%
	Lead	µg/mL	0.0022	0.0072	16%	0.013	0.0089	–	0.0017	0.0013	–
	Magnesium	µg/mL	690	120	–	1,800	100	–	1,900	5,600	–
	Manganese	µg/mL	120	20	–	307	41	–	40	110	–
	Mercury	µg/mL	0.00024	0.00022	–	0.0010	0.0011	–	0.000057	1e-05	–
	Molybdenum	µg/mL	0.087	0.068	–	0.064	0.016	–	0.210	0.63	–
	Nickel	µg/mL	0.62	0.14	–	1.52	0.32	–	0.800	2.3	–
	Phosphorus	µg/mL	0.34	0.13	–	0.72	0.13	–	0.160	0.19	–
	Potassium	µg/mL	52	12	–	123	8.6	–	140	420	–
	Selenium	µg/mL	0.36	0.23	–	0.5	1	0%	0.128	0.049	–
	Silicon	µg/mL	15.8	2.7	–	42	6	–	7	21	–
	Sodium	µg/mL	97	16	–	244	5	–	290	860	–
	Strontium	µg/mL	13.2	2.1	–	32.9	4.3	–	40	110	–
	Tin	µg/mL	0.18	0.6	13%	<0.14	–	100%	<0.14	–	95%
	Titanium	µg/mL	2.19	0.45	–	0.82	0.13	–	0.5	1	0.3%
	Vanadium	µg/mL	0.322	0.065	–	0.24	0.22	–	0.19	0.23	–
Metals, Total	Aluminum	µg/mL	2.04	0.69	–						
	Antimony	µg/mL	<0.14	–	100%						
	Arsenic	µg/mL	0.127	0.031	–						
	Barium	µg/mL	1.19	0.25	–						
	Beryllium	µg/mL	<0.0055	–	35%						
	Boron	µg/mL	540	150	–						

Table 5-11 (Continued)

Analyte Group	Specie	Units	Gypsum Pond Water Average	Gypsum Pond Water 95% CI	Gypsum Pond Water DL Ratio	JBR Underflow Slurry Filtrate Average	JBR Underflow Slurry Filtrate 95% CI	JBR Underflow Slurry Filtrate DL Ratio	Limestone Slurry Filtrate Average	Limestone Slurry Filtrate 95% CI	Limestone Slurry Filtrate DL Ratio
Metals, Total (Cont'd)	Calcium	μg/mL	9,500	6,000	–						
	Cadmium	μg/mL	0.177	0.018	–						
	Chromium	μg/mL	0.075	0.094	–						
	Cobalt	μg/mL	0.143	0.065	–						
	Copper	μg/mL	0.053	0.029	–						
	Iron	μg/mL	0.68	0.73	–						
	Lead	μg/mL	0.0036	0.0048	–						
	Magnesium	μg/mL	720	210	–						
	Manganese	μg/mL	123	39	–						
	Mercury	μg/mL	0.00030	0.00004	–						
	Molybdenum	μg/mL	0.076	0.012	–						
	Nickel	μg/mL	0.63	0.18	–						
	Phosphorus	μg/mL	0.236	0.024	–						
	Potassium	μg/mL	52	13	–						
	Selenium	μg/mL	0.27	0.17	–						
	Silicon	μg/mL	18.4	3.2	–						
	Sodium	μg/mL	102	25	–						
	Strontium	μg/mL	13.7	4.6	–						
	Tin	μg/mL	<0.086	–	100%						
	Titanium	μg/mL	1.10	2.8	–						
	Vanadium	μg/mL	0.22	0.28	–						
Aldehydes	Acetaldehyde	μg/mL	0.05	0.11	–	0.06	0.12	–	0.050	0.1	–
	Formaldehyde	μg/mL	0.023	0.027	–	0.08	0.26	–	0.021	0.025	–
Organics, Semivolatile	Dimethylphthalate	μg/L	1.3	2.2	–	2.1	4.2	2%	<0.36	–	100%
	bis(2-Ethylhexyl)phthalate	μg/L	8.0	81	–	4.4	1.5	–	140	560	–
Organics, Volatile	Acetone	μg/L	<10	–	26%	<10	–	60%	22.3	7.2	–

Table 5-12
Liquid Ancillary Stream Data Summary

Analyte Group	Specie	Units	Cooling Water			Coal Pile Run-off		
			Average	95% CI	DL Ratio	Average	95% CI	DL Ratio
Reduced Species	Cyanide	μg/mL	0.00148	0.00091	–			
	Ammonia as N	μg/mL	0.047	0.014	–			
Anions	Chloride	μg/mL	5.7	1.8	–			
	Fluoride	μg/mL	0.134	0.018	–			
	Phosphate	μg/mL	0.094	0.07	–			
	Sulfate	μg/mL	6.3	1.4	–			
Metals, Soluble	Aluminum	μg/mL	0.031	0.047	–			
	Antimony	μg/mL	<0.024	–	65%			
	Arsenic	μg/mL	<0.0007	–	100%			
	Barium	μg/mL	0.0131	0.0081	–			
	Beryllium	μg/mL	<0.0006	–	100%			
	Boron	μg/mL	0.9	3.4	–			
	Cadmium	μg/mL	0.0020	0.007	–			
	Calcium	μg/mL	19	53	–			
	Chromium	μg/mL	0.0020	0.0027	–			
	Cobalt	μg/mL	<0.0034	–	85%			
	Copper	μg/mL	0.03	0.13	–			
	Iron	μg/mL	0.11	0.13	–			
	Lead	μg/mL	0.027	0.097	–			
	Magnesium	μg/mL	3.1	4	–			
	Manganese	μg/mL	0.07	0.25	–			
	Mercury	μg/mL	0.00005	0.00003	–			
	Molybdenum	μg/mL	0.00152	0.00069	–			
	Nickel	μg/mL	0.0021	0.0048	–			
	Phosphorus	μg/mL	<0.061	–	21%			
	Potassium	μg/mL	2.42	0.49	–			
	Selenium	μg/mL	<0.0014	–	100%			
	Silicon	μg/mL	4.6	4.3	–			
	Sodium	μg/mL	8	12	–			
	Strontium	μg/mL	0.049	0.08	–			
	Tin	μg/mL	<0.014	–	68%			
	Titanium	μg/mL	0.0011	0.0012	–			
	Vanadium	μg/mL	0.0027	0.0006	–			
Metals, Total	Aluminum	μg/mL	2.9	4.4	–			
	Antimony	μg/mL	0.022	0.034	–			
	Arsenic	μg/mL	0.007	0.031	3%			
	Barium	μg/mL	0.031	0.028	–			
	Beryllium	μg/mL	<0.0006	–	55%			
	Boron	μg/mL	0.32	0.35	–			

Table 5-12 (Continued)

			Cooling Water			Coal Pile Run-off		
Analyte Group	**Specie**	**Units**	**Average**	**95% CI**	**DL Ratio**	**Average**	**95% CI**	**DL Ratio**
Metals, Total (Cont'd)	Cadmium	µg/mL	0.001	0.0024	–			
	Calcium	µg/mL	5.9	1.6	–			
	Chromium	µg/mL	0.0049	0.0046	–			
	Cobalt	µg/mL	0.005	0.004	–			
	Copper	µg/mL	0.010	0.0081	–			
	Iron	µg/mL	4.1	5.4	–			
	Lead	µg/mL	0.030	0.058	–			
	Magnesium	µg/mL	1.69	0.71	–			
	Manganese	µg/mL	0.18	0.17	–			
	Mercury	µg/mL	0.00004	0.00003	–			
	Molybdenum	µg/mL	0.0024	0.0015	–			
	Nickel	µg/mL	<0.0099	–	34%			
	Phosphorus	µg/mL	0.12	0.2	9%			
	Potassium	µg/mL	2.76	0.97	–			
	Selenium	µg/mL	0.008	0.03	6%			
	Silicon	µg/mL	6.6	4.8	–			
	Sodium	µg/mL	5.4	1.9	–			
	Strontium	µg/mL	0.0276	0.0076	–			
	Tin	µg/mL	<0.014	–	100%			
	Titanium	µg/mL	0.16	0.21	–			
	Vanadium	µg/mL	0.0083	0.0095	–			
Aldehydes	Acetaldehyde	µg/mL	0.06	0.12	–	0.09	0.27	–
	Formaldehyde	µg/mL	0.026	0.049	–	0.06	0.39	–
Organics, Semivolatile	Butylbenzylphthalate	µg/L	<0.45	–	100%	0.54	–	–
	bis(2-Ethylhexyl)phthalate	µg/L	3.5	7.2	3%	3.3	–	–
Organics, Volatile	Acetone	µg/L	<10	–	45%	40	250	–

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DATA EVALUATION AND ANALYSIS

This section presents an evaluation of data presented in Section 5. In evaluating these data, the following question is fundamental:

- Are the measured concentration data representative?

Since there is insufficient information to address this question directly, statistics, along with engineering and scientific judgment, must be used to answer this question. This is done by addressing related topics which can be evaluated quantitatively:

- Were analytical techniques accurate and precise?
- Were sampling techniques accurate and precise?
- Was process operation steady and representative?

If the answer to each of the above questions is "yes," then the measurements are considered representative and no qualifications made to their use. If analysis turns up potential problems with one or more of the above areas for certain data, caution must be exercised in using these data, since there is a good chance that they are not representative.

Assessment of sampling and analytical techniques is the purview of the QA/QC program. Detailed QA/QC results are presented in Appendix D, and these results are summarized below. An evaluation of process operation and a discussion of mass balance closures, which are used as an additional check on data representativeness, are also presented in this section. Finally, a discussion of the organic results concludes this section.

Evaluation of Sampling Techniques

Several factors are evaluated to determine acceptable sample collection. Key components of the sampling equipment including the Pitot tubes, thermocouples, orifice meters, dry gas meters, and sampling nozzles were calibrated in the Radian Source Sampling Laboratory before use in the field. These calibrations were also checked after the equipment was returned to the laboratory after completion of the field activities. Standard EPA methods or other acceptable sampling methods were used to collect the organic, metal, and anion samples. The sampling runs were well documented, and all gas samples were collected at rates of between 90 and 110% of the isokinetic rates. Sufficient data were collected to ensure acceptable data completeness and comparability of the measurements.

Gas samples were collected from the ESP inlet, ESP outlet, and stack as integrated samples for most analyses over a specified time period. Solid samples of coal, limestone, bottom ash, ESP fly ash, and FGD slurry were collected at hourly intervals over each of the test runs. These individual grabs were combined to provide a single composite sample of each stream for each of the three test runs. Liquid streams were also collected as hourly grabs which were combined to provide a single composite for analysis for each test run. All sampling was conducted while the plant was operating at 85 to 100% of full load and should be representative of typical operation for Plant Yates.

Thus, the applicable QA/QC evaluation indicates that sampling techniques were acceptable and effective in providing measurement data reliability within the expected limits of sampling error.

Evaluation of Analytical Techniques

Generally, the type of quality control information obtained pertains to measurement precision, accuracy (which includes precision and bias), and blank effects that are 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 the blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. The QA/QC measures used as part of this program data evaluation protocol and the characteristic information obtained are provided in Appendix D.

Different QC checks provide different types of information, particularly pertaining to the sources of inaccuracy, imprecision, and blank effects. As part of this program, measurement precision and accuracy are typically being estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Precision and accuracy measurements are based primarily on the actual sample matrix. The precision and accuracy estimates obtained experimentally during the test program are compared to the data quality objectives (DQOs) established for the program as listed in the project QAPP.

Appendix D includes a presentation of the types of quality control data reported for the program and 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.

- Chloromethane, methylene chloride, and tetrachloroethene were found in one or more of the field blanks analyzed for volatile organics. In many cases, the same concentrations were also found in the field samples.

- A standard limestone sample (NIST 1C) was submitted blind as a performance audit sample. Aluminum, silicon, and sodium recoveries in this sample were below 50%, and the recovery of potassium was greater than 200 percent. This may indicate a similar bias for these elements in the limestone process streams.

- Selenium showed no spike recovery in the impinger solutions analyzed by GFAAS.

These and other QA/QC findings are summarized, according to major species categories, in the discussions below.

Semivolatile Organics

Precision. The precision of the semivolatile organic analyses was estimated using matrix spiked duplicate pairs. The precision objective was met for all of the gas-phase solid samples, the gas vapor-phase samples, the solid stream samples, and aqueous-phase sample streams.

Accuracy. The accuracy of the semivolatile analyses was estimated using matrix spiked duplicate samples. All of the spiked compounds analyzed in the gas solid-phase samples and the aqueous process streams were within the accuracy objectives. Matrix spikes into the solid process streams were all within the recovery objects for all analytes in the FGD solid stream and all except pyrene in the ESP ash solids. Recovery for pyrene was 51% and 56% (project objective--52-115%) for the ESP ash sample and 48% and 37% for the ESP ash field duplicate.

Blank Effects. Acetophenone and benzoic acid were found in one or more of the field blanks associated with the gas-phase solids analyses. The concentrations of these compounds in the blanks, however, were not significant in comparison to the concentrations found in the samples. Several phthalates were also found in the field blanks. The concentrations found in the samples were about the same level as found in the blanks and are therefore considered an artifact of the sampling and handling process.

Volatile Organics

Precision. Precision for volatile organic analysis of the aqueous process streams was estimated using matrix spiked duplicate samples. The 50% precision objectives were met for each of the volatile analytes used for the matrix spikes.

Accuracy. Accuracy for the volatile organic analyses in the aqueous process streams was estimated using matrix spiked samples, and accuracy for the gas vapor-phase streams was estimated using surrogates spiked into each sample prior to analysis. The method specified accuracy objectives for matrix spike recoveries (0.1-234% were met for all analytes of interest (actual recoveries ranged from 70-136%) for the aqueous streams. Accuracy objectives for surrogate recoveries of 70 to 130% for the gas-phase streams were met for all samples except for toluene-d8 in one stack sample. Accuracy based on the analysis of two laboratory method spikes met the recovery objectives for all analytes of interest except for one acetone, chloromethane, chloroethane, and methylene chloride spike.

Blank Effects. Chloromethane, methylene chloride, and tetrachloroethene were found in one or more of the field gas vapor-phase blank samples. In most cases these compounds were found in the investigative field samples at about the same level as in the field blank or at lower concentrations. Chloromethane and methylene chloride were also found in one laboratory blank. The presence of these compounds in both blanks and samples merely raises the uncertainty about their presence in the flue gas.

Aldehydes

Precision. Precision for the aldehyde analyses was estimated using duplicate sample analyses. The precision objectives of 50% were met for both formaldehyde and acetaldehyde in the gas vapor-phase samples and the aqueous process stream sample analyses.

Accuracy. Accuracy for the aldehydes was estimated using matrix spiked samples. The project accuracy objectives of recoveries of 50-150% were met for the gas vapor-phase and aqueous stream sample spikes for both formaldehyde and acetaldehyde.

Metals

Precision. The precision of metals analyses by ICP-AES, GFAAS, and CVAAS was estimated for samples using matrix-spiked duplicate samples. The precision objectives (RPD <20%) were met for all target analytes analyzed by ICP-AES except aluminum and barium in the gas solid-phase spiked samples and boron in the process solid-spiked samples. The precision objectives for the GFAAS analyses were met except for lead in the gas vapor-phase matrix-spiked samples, selenium in the process solid matrix-spiked samples, and mercury and selenium in the aqueous process stream matrix spikes.

Accuracy. The accuracy of metals analyses was estimated for the gas solid-phase samples using standard reference material (NIST 1633a fly ash) submitted blind to the laboratory as a performance audit sample. All of the metals analyzed by ICP-AES were within the 75-125% accuracy objectives except for beryllium (147%) which was recovered above the objectives.

The accuracy of the metals analyses was estimated for coal samples using a standard reference coal sample (NIST 1632b) submitted blind to the laboratory. All of the metals analyzed by INAA in the reference sample were within the 75-125% accuracy objective.

The accuracy of the metals analyses was estimated for the limestone samples using a standard reference limestone (NIST Limestone 1C) submitted blind to the laboratory. The results show that the recoveries for most of the metals were outside the 75-125% accuracy objectives. Aluminum, silicon, and sodium recoveries were 50%, and the recovery for potassium was greater than 200 percent. The recoveries of these analytes may show a similar bias in the limestone process streams.

The accuracy of the metals analyses for the gas vapor-phase samples and the aqueous process streams were estimated using performance audit samples prepared from EPA reference standards. The results show that the recoveries of all the metals analyzed by ICP-AES and GFAAS were within the 75-125% accuracy objectives except Ca (368%) and Sb (127%), Ca (169%, 520%), Fe (139%), and Mg (131%, 246%) by ICP-AES and Se (50%) by GFAAS . The concentrations of these elements in the samples were at or near the detection limit.

Matrix-spiked samples were also used to determine the accuracy of the metals analyses in the gas, process solids, and aqueous process matrices. Recoveries for the target analytes were within the 75-125% accuracy objectives except for selenium (0% recovery) in the gas vapor-phase matrix and mercury (35% recovery) in the aqueous process stream matrix.

Blank Effects. Aluminum, iron, manganese, and nickel were found at concentrations above the reporting limits in the field blanks to the gas vapor-phase sampling train. These elements were also found to a lesser extent in the impinger reagent blank solutions.

Anions

Precision. Precision for the anions analyses was estimated for the gas vapor-phase samples, process solid streams, and aqueous process streams by the analysis of matrix spiked samples. The precision objectives of 20% were met for chloride, fluoride, and sulfate except for chloride and sulfate in one matrix spike pair from the stack with RPDs of 22% and 24%, respectively.

Accuracy. Accuracy for the anions analyses was estimated using matrix spiked duplicate samples. The accuracy objectives of 80-120% recovery was met for all analytes and all sample matrices except for the fluoride spikes into the ESP ash solid samples with recoveries of 56% and 60 percent.

Cyanide, Ammonia, and Phosphate

Precision. Precision for the cyanide, ammonia, and phosphate analyses was estimated using matrix spiked duplicate sample analyses. The precision objectives of 20% were met for each of the analytes for both the gas vapor phase and aqueous process streams except for ammonia spikes into the JBR process liquids. The spike concentration was too low in comparison to the level found in the native process sample.

Accuracy. Accuracy for ammonia, cyanide and phosphate was estimated using both matrix spiked duplicate samples and "double blind" performance audit samples. The accuracy objectives (cyanide, 75-125%; ammonia, 80-120%; phosphate, 75-125%) were met for all matrix spiked samples except for the ammonia spikes into the JBR process liquids with recoveries at 60 and 273 percent. Recoveries for the performance audit samples met the accuracy objectives for all analytes with recoveries of 88% for ammonia, 80% for cyanide, and 97% for phosphate. Recoveries for performance audit samples spiked into the gas vapor-phase impinger solutions were not as good as the aqueous spiked audit samples. The recovery for ammonia in the impinger solutions was 63% and the recovery for cyanide was 50 percent. The aqueous spikes and impinger spikes were performed using the same spiking solutions and were spiked at the same concentration levels.

Evaluation of Process Operation

Plant operating data were examined to ensure that process operation was stable and representative of normal operation during the sampling periods. Excessive scatter or significant trends can indicate periods where operational problems were encountered. The availability of data from the CT-121 data acquisition system allowed for a comprehensive review of process operation. Data points were logged as 15-minute averages. Plots of unit load, furnace gas O_2, JBR ΔP, JBR pH, stack SO_2, CO, and NO_x concentrations are located in Section 2. The range of normal operation is indicated on most of these figures. A statistical summary of process data is presented in Table 6-1. Daily average values for process parameters are presented along with the minimum and maximum values. Variability is expressed by the standard deviation. Note that high standard deviations are to be expected for some variables, such as return water flow rates, which are controlled by on/off controllers. Table 6-1 was used to identify areas of concern with process operation. A parameter with values steadily increasing or decreasing over the course of the test period may indicate a period of non-steady operation. The following paragraph summarizes the process analysis and points out areas of concern.

Analysis of the process data revealed that process operation was steady and representative during sampling periods. Problems with data quality are not likely to be the result of process variability. Some comments on process operation are as follows:

- Due to problems with the JBR inlet O_2 monitor, the JBR inlet SO_2 concentration, which is corrected with the O_2 meter reading, is biased low on 6/26 and 6/27. Additionally, the stack O_2 monitor calibration check showed it to be biased on 6/26. However, the average stack CEM O_2 data are not significantly different from the O_2 concentration measured using the Orsat method.

- The average FGD makeup water was approximately twice as high on 6/25 than on other days. This was revealed to be an instrument problem.

- SO_2 removal was slightly lower than expected, even accounting for the bias in the inlet O_2 monitor. The slightly lower SO_2 removal should not raise concerns about the representativeness of the data, however, as SO_2 removal was still within the range of normal operation for this type of scrubber. A possible explanation for the lower removal involves modifications made to the JBR limestone inlet piping. Modifications to the piping are suspected to have created a region of higher limestone concentration in the JBR where the pH indicators are located. As a result, the pH in this region was slightly higher than in the remainder of the reactor. Therefore, the average reactor pH may have been slightly lower than was indicated, resulting in lower SO_2 removal.

- A brief dip in load occurred on 6/24 between 1700 and 1730. The lowest point reached is unknown since the process data are reported on 15 minute average basis, the lowest of which was 86 MW. Since testing was completed by this time on 6/24, there is no effect on data representativeness.

Data Analysis: Mass Balances, Removal Efficiencies, and Emission Factors

Calculations based on measured data have two general purposes: they can be used to assess the representativeness of the measured data or to evaluate process performance. Mass

Table 6-1
Daily Summary

	Date						
	6/21	**6/22**	**6/23**	**6/24**	**6/25**	**6/26**	**6/27**
Gross Load, MW							
Average, daily	100	100	100	100	100	100	100
Sample Std. Dev.	0.5	0.24	0.32	1.5	0.44	0.34	0.22
Maximum Value	100	100	100	100	100	100	100
Minimum Value	98	100	100	86	98	100	100
Raw Coal Flow, lb/hr							
Average, daily	89,000	88,000	89,000	88,000	90,000	91,000	92,000
Sample Std. Dev.	3,000	3,400	3,300	3,000	2,400	2,900	4,000
Maximum Value	94,000	94,000	99,000	95,000	96,000	98,000	100,000
Minimum Value	85,000	82,000	84,000	81,000	84,000	85,000	84,000
Furnace Gas O_2, %							
Average, daily	3.5	3.6	3.5	3.5	3.3	3.3	3.4
Sample Std. Dev.	0.062	0.17	0.19	0.28	0.078	0.23	0.3
Maximum Value	3.6	4.0	3.7	3.9	3.4	3.8	3.8
Minimum Value	3.4	3.2	3.1	3.0	3.0	2.8	2.6
Opacity, %							
Average, daily	15	14	16	17	17	18	19
Sample Std. Dev.	3.6	0.96	1.7	2.5	1.3	1.3	1.5
Maximum Value	31	18	27	33	23	22	23
Minimum Value	12	13	14	14	14	15	16
Stack O_2, % on Dry Basis[a]							
Average, daily	8.2	8	7.9	8	7.7	7.7	7.6
Sample Std. Dev.	0.12	0.23	0.18	0.22	0.072	0.18	0.1
Maximum Value	8.5	8.6	8.1	9	7.9	9	7.7
Minimum Value	7.8	6.6	6.3	6.7	7.6	7.5	7
Stack SO_2, ppm at 3% O_2[a]							
Average, daily	160	180	200	200	240	180	190
Sample Std. Dev.	38	47	37	65	31	25	38
Maximum Value	230	250	260	340	300	230	270
Minimum Value	88	41	120	74	180	130	140

Table 6-1 (Continued)

				Date			
	6/21	**6/22**	**6/23**	**6/24**	**6/25**	**6/26**	**6/27**
JBR pH							
Average, daily	4.6	4.5	4.5	4.5	4.5	4.5	4.5
Sample Std. Dev.	0.22	0.066	0.037	0.049	0.038	0.045	0.027
Maximum Value	4.9	4.7	4.6	4.6	4.7	4.6	4.6
Minimum Value	4.3	4.3	4.4	4.4	4.4	4.3	4.4
JBR ΔP, inches water							
Average, daily	14	14	14	14	14	14	14
Sample Std. Dev.	0.086	0.086	0.08	0.17	0.071	0.076	0.073
Maximum Value	14	14	14	15	14	14	14
Minimum Value	14	14	14	14	14	14	14
SO_2 Removal							
Average, daily	93	92	91	90	89	b	b
Sample Std. Dev.	1.7	1.8	1.7	3.5	1.4		
Maximum Value	96	97	94	96	92		
Minimum Value	90	89	88	83	86		
Transition Duct PW Flow (Gypsum Pond Return, FT 128), gpm							
Average, material balance period					78.6	78.7	79.3
Average, daily	80	79	79	79	79	79	79
Sample Std. Dev.	0.28	0.49	0.4	0.94	0.58	0.5	0.45
Maximum Value	80	81	82	81	83	83	83
Minimum Value	78	78	79	71	77	78	0.12
Transition Duct MU Water Flow, gpm							
Average, daily	0.092	0.09	0.12	0.096	0.14	0.11	0.094
Sample Std. Dev.	0.0055	0.0069	0.23	0.006	0.44	0.15	0.0071
Maximum Value	0.1	0.11	2.4	0.11	4.3	1.6	0.11
Minimum Value	0.08	0.073	0.075	71	0.08	0.084	0.066
Reagent Flow, gpm							
Average, material balance period					35.9	37.3	36.3
Average, daily	48	35	36	35	36	37	38
Sample Std. Dev.	36	7.3	2.8	3.0	1.9	2.9	1.7
Maximum Value	88	61	43	45	39	46	42
Minimum Value	0.1	0.2	26	28	27	30	34

Table 6-1 (Continued)

	Date						
	6/21	**6/22**	**6/23**	**6/24**	**6/25**	**6/26**	**6/27**
JBR Level, ft							
Instantaneous Values (used in accumulation calculations)							
Beginning (t-Δt)					14.1	14.1	14.1
Ending (t)					14.1	14.1	14.1
Average, daily	14	14	14	14	14	14	14
Sample Std. Dev.	0.011	0.017	0.022	0.042	0.026	0.013	0.014
Maximum Value	14	14	14	14	14	14	14
Minimum Value	14	14	14	14	14	14	14
JBR Density, wt% solids							
Average, material balance period					22.8	23.0	23.0
Instantaneous Values (used in accumulation calculations)							
Beginning (t-Δt)					22.2	23.7	22.7
Ending (t)					22.3	23.3	23.5
Average, daily	23	23	23	23	23	23	23
Sample Std. Dev.	0.51	0.55	0.55	0.52	0.51	0.56	0.51
Maximum Value	24	24	24	24	24	24	24
Minimum Value	22	22	22	22	22	22	22
Mist Eliminator/Deck Wash PW Flow (Ash Pond Return FT 150A), gpm[c]							
Average, material balance period					26.1	25.5	28.8
Average, daily	25	25	28	28	25	26	26
Sample Std. Dev.	29	28	32	35	30	32	32
Maximum Value	110	110	120	130	100	120	120
Minimum Value	-0.33	-0.33	-0.34	-0.37	-0.37	-0.37	-0.29
Mist Eliminator Makeup Water Flow (FT 150B), gpm[c]							
Average, material balance period					6.7	6.6	6.0
Average, daily	-2	-4	-4.1	-4.1	-4	-4	-4.2
Sample Std. Dev.	27	25	25	22	24	28	18
Maximum Value	180	240	240	210	230	260	140
Minimum Value	-6.9	-7.2	-7.5	-7.5	-7.3	-7.6	-7.6
JBR Level Control Line PW Flow (Ash Pond Return, FT 142), gpm							
Average, material balance period					36.4	29.4	53.4
Average, daily	44	50	56	54	39	37	48
Sample Std. Dev.	56	84	86	79	68	66	72
Maximum Value	200	270	270	250	220	200	210
Minimum Value	0.27	0.27	0.24	0.24	0.25	0.26	0.3

Table 6-1 (Continued)

	Date						
	6/21	6/22	6/23	6/24	6/25	6/26	6/27
Mist Eliminator Differential Pressure, inches water							
Average, daily	0.67	0.65	0.64	0.64	0.63	0.65	0.66
Sample Std. Dev.	0.014	0.016	0.017	0.022	0.013	0.02	0.013
Maximum Value	0.7	0.68	0.68	0.7	0.66	0.7	0.68
Minimum Value	0.62	0.62	0.61	0.52	0.6	0.62	0.64
Reagent Slurry Density, wt% solids							
Average, material balance period					37.2	37.2	33.9
Average, daily	33	30	33	37	37	37	34
Sample Std. Dev.	0.18	2.9	2.1	0.15	0.025	0.045	2.1
Maximum Value	33	34	38	38	37	37	39
Minimum Value	32	25	30	37	37	37	32
Furnace Pressure, inches water							
Average, daily	-0.21	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22
Sample Std. Dev.	0.017	0.013	0.012	0.016	0.012	0.0095	0.016
Maximum Value	-0.12	-0.19	-0.19	-0.16	-0.19	-0.19	-0.18
Minimum Value	-0.24	-0.27	-0.25	-0.28	-0.26	-0.25	-0.26
JBR Agitator Running[d]							
Average, daily	1	1	1	1	1	1	1
Sample Std. Dev.	0	0	0	0	0	0	0
Maximum Value	1	1	1	1	1	1	1
Minimum Value	1	1	1	1	1	1	1
Oxidation Air "A", scfm							
Average, daily	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Sample Std. Dev.	20	40	50	40	30	50	60
Maximum Value	2,200	2,200	2,200	2,200	2,200	2,200	2,200
Minimum Value	2,100	2,100	2,000	2,000	2,100	2,000	2,000
Oxidation Air "B", scfm							
Average, daily	2,100	2,000	2,000	2,100	2,100	2,000	2,000
Sample Std. Dev.	20	30	50	40	30	40	50
Maximum Value	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Minimum Value	2,000	2,000	2,000	2,000	2,000	2,000	2,000

Table 6-1 (Continued)

				Date			
	6/21	6/22	6/23	6/24	6/25	6/26	6/27
JBR Blowdown (FT 162A), gpm[c]							
Average, material balance period					73.7	68.9	92.0
Average, daily	80	74	83	84	74	78	84
Sample Std. Dev.	73	75	78	80	73	72	79
Maximum Value	200	210	210	210	210	210	210
Minimum Value	-0.36	-0.38	-0.35	-0.49	-0.37	-0.37	-0.41
FGD MU Water Flow, gpm							
Average, daily	94	90	87	90	200[e]	120[e]	77
Sample Std. Dev.	16	14	13	44	120	140	49
Maximum Value	180	210	200	450	430	320	190
Minimum Value	83	83	78	77	78	14	12
SO_2 at JBR Inlet Duct, ppm @ 3% O_2							
Average, daily	2,300	2,100	2,200	2,000	2,100	1,900[f]	1,400[f]
Sample Std. Dev.	11	220	45	86	38	280	200
Maximum Value	2,300	2,300	2,300	2,200	2,200	2,300	1,900
Minimum Value	2,300	1,300	2,100	1700	2,000	1,000	990
O_2 at JBR Inlet Duct, %							
Average, daily	7.8	7.7	7.6	7.6	7.4	14[f]	15[f]
Sample Std. Dev.	0.07	0.31	0.086	0.3	0.27	4.1	0.97
Maximum Value	8	9.6	7.7	8.7	7.7	18	17
Minimum Value	7.5	6	7.2	7.0	6.9	7.4	14
JBR Inlet Duct Pressure, inches water							
Average, daily	-11	-11	-10	-10	-10	-10	-10
Sample Std. Dev.	0.17	0.23	0.13	0.23	0.079	0.19	0.091
Maximum Value	-9.8	-10	-10	-8.5	-9.8	-10	-10
Minimum Value	-11	-11	-11	-10.5	-10	-11	-11
JBR Inlet Duct Temperature, °F							
Average, daily	280	280	280	280	280	280	280
Sample Std. Dev.	4.9	4.3	6	4.2	3.6	5.3	5.8
Maximum Value	280	290	290	290	290	290	290
Minimum Value	260	270	270	280	280	280	270

[a] A bias in the stack O_2 monitor was found during calibration check on 6/27. However, the average CEM stack O_2 concentrations are not significantly different from the stack gas O_2 concentration determined using the Orsat method.

[b] These values not reported since they are known to be biased due to faulty inlet O_2 monitor readings.

[c] Negative values result of instrumentation bias.

[d] Value of 1 indicates agitator on, 0 indicates off.

[e] High average due to instrumentation problem.

[f] Problems with inlet O_2 monitor have biased these values.

balance closures were calculated as a check on data representativeness. Since the mass of trace elements must be conserved, an examination of the mass balance can provide clues to sampling and/or analytical deficiencies. Removal efficiencies and emission factors are evaluations of process performance. Removal efficiencies provide an insight into the fate of a substance in power plant processes. Emission factors express plant emissions on a unit-energy basis.

The method used to determine uncertainties in calculated results is based on the ANSI/ASME PTC 19.1-1985, "Measurement Uncertainty" and is consistent with the approach to handling data used in EPRI's Field Chemical Emission Monitoring (FCEM) program. This method, along with an example calculation, is presented in Appendix F. In statistical calculations, a distinction was made between "raw data," such as gas flow rates and concentrations, and calculated data, such as mass balance closures and emission factors. The term "raw" is in quotation marks because some calculations were necessary to obtain these data. The distinction between raw and calculated data was made based on the goal of a particular measurement, i.e., the goal of a Pitot-tube traverse is to determine a gas flow rate, so the flow rate is considered a raw data point and not the individual ΔP measurements. Calculated data are determined using mean raw data. Therefore, calculated data are not presented on a daily or run basis but as mean values for the entire material balance period. Fundamental to obtaining calculated data is the assumption that the power plant processes are reasonably close to steady state. In this project, stream flow rates not directly measured, emission factors, removal efficiencies, and mass balance closures are all treated as calculated data.

Data were reviewed and justifiable eliminations and substitutions made prior to the calculation of material balance closures and removal efficiencies. The following modifications were made to the data set:

- The ESP outlet gas particulate-phase data for Runs 1 and 3 were invalidated for Al, Ba, Be, Cd, Ca, Cr, Co, Pb, Mg, P, K, Na, and Sr due to the filter background concentration comprising greater than 20% of the measured concentration.

- The stack gas particulate-phase data for Run 1 were invalidated for all elements except As, Se, and V due to the filter background concentration comprising greater than 20% of the measured particulate concentration.

- The limestone slurry filtrate Run 3d was substituted for Run 3a. 46% of the detected elements in Run 3a are statistical outliers. An analytical error is suspected to have occurred for Run 3a. No further details are available.

- The ESP inlet gas vapor-phase data for Run 2 were invalidated due to particulate breakthrough into the impinger solutions. This event caused a high bias in the vapor-phase concentrations.

- No flue gas particulate-phase analyses were performed for boron, since boric acid is included in the chemicals used to digest the particulate filters. The sluiced fly ash analyses were substituted so that mass balances could be performed.

- For As, Cr, and Hg, certain analyses are suspected to be biased and cause poor mass balance closures. For these elements, mass balance closures are also calculated with certain data substitutions made (see Table 6-2 for details).

Mass Balances

The results of mass balance closures, emission factors, and removal efficiencies are presented in the following sections. Following the results section are summaries of the equations used. Example calculations are presented in Appendix I.

Table 6-2 presents mass balance closures for selected elements. Mass balances were performed about the boiler, ESP, JBR, and the total plant. Figure 6-1 depicts the mass balance boundaries. Steady-state process operation was assumed for all vessels but the JBR. Due to the short test periods, significant accumulation of a substance could occur in the JBR. Small fluctuations in the JBR level and solids concentration are part of normal operation.

A general mass balance equation which applies to any system is:

$$\begin{bmatrix}\text{Accumulation of}\\ \text{Mass in System}\end{bmatrix} = \begin{bmatrix}\text{Mass into}\\ \text{System}\end{bmatrix} - \begin{bmatrix}\text{Mass out}\\ \text{of System}\end{bmatrix} + \begin{bmatrix}\text{Mass Generated}\\ \text{in System}\end{bmatrix} \qquad \textbf{(6-1)}$$

Over a long period of steady operation, the accumulation in the JBR also could be considered negligible. The following general equation was used to calculate mass balance closures.

For all vessels but the JBR, the accumulation term should be negligible and was assumed to be zero. Development of specific mass balance equations is presented in Appendix I.

The mass balance closure for each element met the project objective if it was between 70 and 130 percent. Poor closures and high uncertainties have their root cause in sampling, analytical, or process problems. Since an analysis of the process showed that process operation was steady and representative of normal operation, problems with mass balance closures for some substances may reflect problems with analytical or sampling techniques.

Concerns with mass balance closures fall into three categories:

- Out-of-range mass balance closure is outside target range of 70-130 percent;

- High uncertainty--uncertainty in closure exceeds ±50 percent; and

- Clear bias--closure ± uncertainty does not encompass 100% closure.

Table 6-2
Mass Balance Closures

	Boiler		ESP		JBR		Plant	
	% Closure	95% CI	% Closure	95% CI	% Closure	95% CI	% Closure	95% CI
Anions								
Chloride	104	25	115	45	76	24	77	25
Fluoride	103	16	105	30	97	33	104	39
Elements								
Aluminum[a]	74	17	101	--[b]	65	--[b]	75	6.5
Antimony[c]	67	44	92	52[d]	91	124[e]	65	26
Arsenic	214 (103)[f]	94 (43)[f]	136	67[g]	38[h]	28	270 (135)[f]	142 (71)[f]
Barium	69	30	100	--	76	--	69	27
Beryllium[i]	105	16	107	--	55	--	111	24
Boron [m]	131	110[j]	105	--	109	--	114	32
Cadmium[d]	100	63	155	--	109	--	136	51
Calcium	94	35	76	--	82	--	81	31
Chromium	144 (91)[k]	225 (30)[k]	58 (92)[k]	--	89	--	83	8.9
Cobalt	98	36	120	--	80	--	114	40
Copper[c]	26	24	122	22	74	23	33	30
Iron	89	18	99	21	77	26	87	17
Lead	109	37	106	--	36	--	113	44
Magnesium	92	22	104	--	107	--	103	21
Manganese	113	19	104	18	101	31	103	27
Mercury	205 (110)[l]	84 (35)[l]	55 (102)[l]	18 (26)[l]	88	13	101	30
Molybdenum[c]	18	20	23	27	111	39	4.5	3.6
Nickel	84	86[d]	63	39	121	357[d]	55	9.5
Phosphorus[c]	31	19	34	--	91	--	20	13
Potassium[c]	59	13	104	--	84	--	62	9.6
Selenium[d]	65	31	141	81	188	106	145	54
Sodium	91	12	99	--	100	--	91	15
Strontium[c]	48	7.9	99	--	95	--	59	7.8
Titanium	77	18	103	23	31	10	78	12
Vanadium	87	13	106	17	91	32	92	13

[a] Spike recovery in ESP inlet gas-phase particulate for aluminum was 62%, indicating possible analytical bias.

[b] Since the ESP outlet gas-phase particulate Runs 1 and 3 were invalidated, confidence intervals for the ESP and JBR mass balance closures could not be calculated for many elements.

Table 6-2 (Continued)

[c] These elements are consistently enriched in the coal ash over the process stream solid-phase concentrations, suggesting that the coal analyses are biased high for these elements.

[d] High uncertainties for mass balance closure are caused by high variability in the gas particulate-phase concentrations.

[e] High uncertainty in JBR closure for antimony is the result of high detection limits in liquid-phase samples; antimony was not detected in the JBR blowdown filtrate or limestone slurry filtrate.

[f] Values in parentheses are those obtained when INAA coal analyses are substituted for the GFAA data.

[g] High uncertainty in the ESP closure for arsenic is mostly due to high variability in ESP sluiced ash concentration.

[h] Arsenic concentration was below detection limit in JBR blowdown solid phase.

[i] Spike recovery for beryllium in the performance evaluation ash sample was 147%, indicating possible analytical bias.

[j] High variability in the boiler closure for boron is caused by high variability in the ESP inlet gas vapor-phase analyses.

[k] ESP inlet gas-phase particulate Run 2 Cr concentration, at 550 ng/g, is a statistical outlier. In comparison with sluiced ash, hopper ash, and size fractionated particulate data for chromium, this value is likely to be biased high. The mass balance data in parentheses are calculated with this value replaced with the Run 2 ESP sluiced ash concentration.

[l] ESP inlet particulate data for mercury are suspected to be biased high based on comparison with sluiced ash hopper ash analyses. This is also supported by the high boiler and low ESP mass balance closures. The mass balance data in parentheses are calculated with the ESP sluiced ash analyses substituted for the ESP inlet gas-phase particulate analyses.

[m] Gas particulate-phase data are not available. ESP sluiced ash data were substituted for the boron particulate concentration.

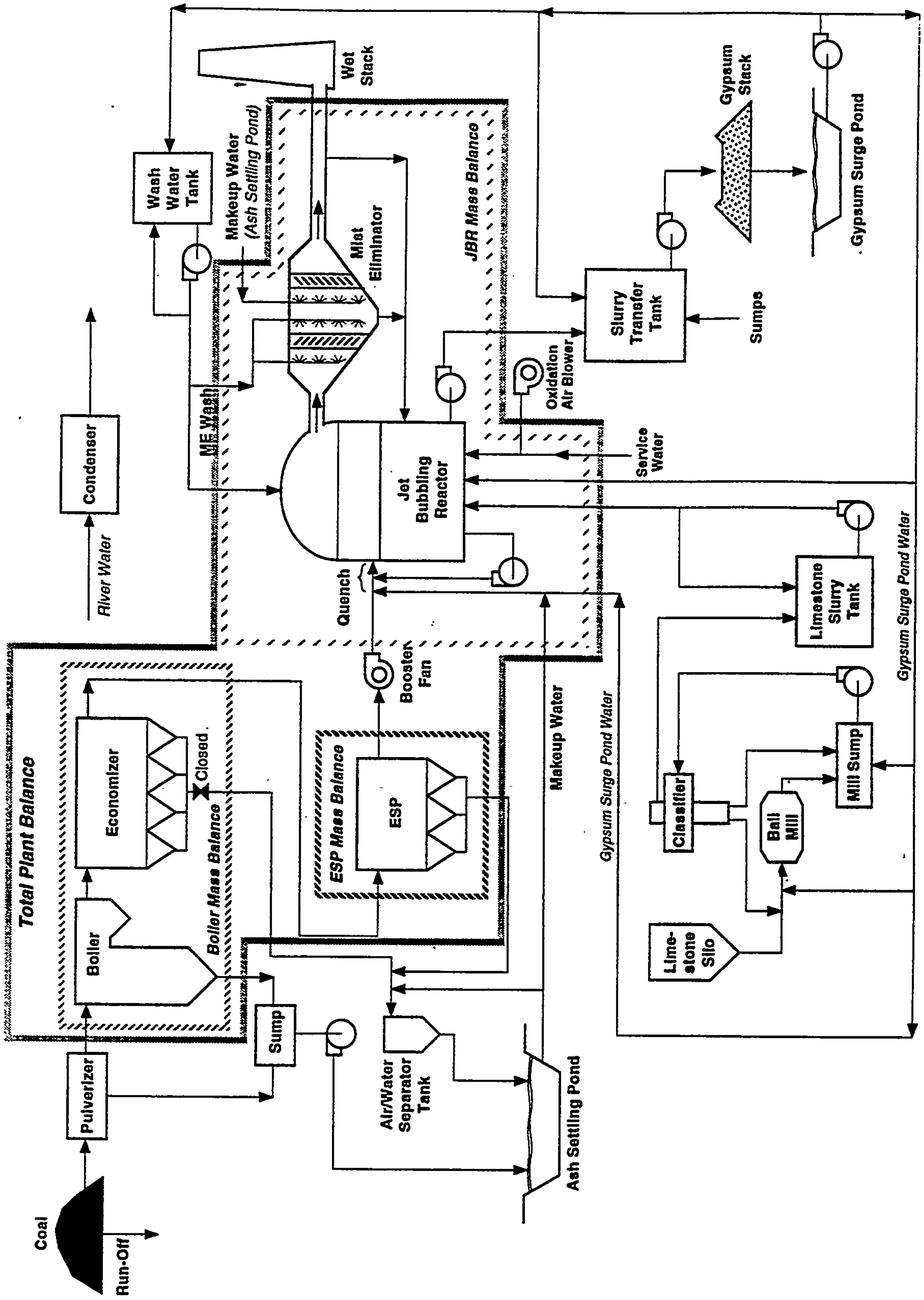

Figure 6-1
Mass Balance Boundaries

$$\text{Mass Balance Closure (\%)} = 100 * \left[1 - \frac{\text{Total Mass Out}}{(\text{Mass In} - \text{Mass Accumulated})}\right] \qquad (6\text{-}2)$$

For the boiler closure, 70% of the mass balances performed fell within the target range. The percentage within the target range for the ESP, JBR, and Total Plant were 85%, 78%, and 59%, respectively.

Confidence intervals are not presented for many elements for the ESP and JBR mass balance closures. The precision error for the ESP outlet gas, particulate-phase analyses is unknown for many elements due to the rejection of data from Runs 1 and 3. Discussion of concerns with specific substances is presented in the following paragraphs.

Substitutions. For some elements, both a review of the analytical data and initial mass balance closures suggested that some data were biased. For these elements, data substitutions were made, and the material balances were recalculated. These results are in parentheses on Table 6-2. Specific cases are discussed in the following paragraphs.

As. The arsenic coal analyses by GFAA yield mass balance closures about the boiler and plant of 214 and 270%, respectively, suggesting a bias in the coal or ash analyses. When the coal concentration for each run was replaced by the corresponding analysis by INAA, the closures about the boiler and plant were 103 and 134% respectively. This suggests that the GFAA analysis performed for coal may have been biased.

Cr. The ESP inlet gas, particulate-phase Run 2 analysis for Cr at 550 μg/g is a statistical outlier when compared with all available ash analyses. This value is strongly suspected to be the result of analytical bias or non-representative sampling. This is supported by the boiler mass balance closure, at 144%. When this value is replaced with the Run 2 sluiced ash concentration, the closure is 91%.

Hg. The ESP inlet, particulate-phase data are suspected to be biased high, based on other ash analyses and prior experience with mercury data. This is also supported by the high mass balance closure about the boiler (205%) and correspondingly lower closure about the ESP (55%). When these data are replaced with the sluiced fly ash analyses, the closures are a much more reasonable 110% about the boiler and 102% about the ESP.

Out-of-Range Mass Balance Closures. Many mass balance closures lie outside the target range. For some of these, poor closure can be attributed to high variability in the concentration in one or more process streams. Other elements have closures which are clearly biased. The following paragraphs provide explanations for poor and clearly biased mass balance closures.

Sb, Cu, Mo, K, P, Sr. Antimony, copper, molybdenum, potassium, phosphorus, and strontium have mass balance closures well outside the target range for two or more devices. The confidence intervals for these closures indicate that a clear analytical or sampling bias exists or that the mass balance closure model is inadequate for these substances. Problems closing material balances for copper, molybdenum, and phosphorus have been encountered in previous work by Radian. For antimony, copper, potassium, and strontium, the boiler and plant closures are out of range, while the ESP and JBR closures are reasonable. Since the boiler and plant closures are driven by the coal analyses, this suggests a high bias in the INAA analyses for coal for these substances. All of these elements show enrichment in the coal ash over bottom ash, collected ash, and the gas particulate phase at all locations (except phosphorus in the ESP outlet). None of these elements are expected to be in the vapor phase. This pattern suggests that the coal analyses for antimony, copper, molybdenum, potassium, phosphorus, and strontium are biased high in varying degrees. See Section 8 for further details on enrichment.

Al and Be. Al and Be analytical QA/QC procedures reveal a possible analytical bias in gas particulate-phase analyses for Al. The Al spike recovery for this matrix was 62%, indicating a possible low bias. This could explain the slight bias apparent in the mass balance closure (74% ±17%). In addition, the spike recovery of Be in the performance evaluation sample for fly ash was 147%. Only the JBR mass balance was outside the target range for Be, however. In addition, QA/QC procedures revealed possible analytical problems with some elements in the gas vapor-phase and limestone samples. For these elements, the limestone and vapor-phase concentrations have a very small effect on mass balance closures, however.

As. Arsenic was not detected in the JBR blowdown solids. This may explain the 36% mass balance closure.

Be, Pb, Se, and Ti. These elements have poor closures about the JBR. No cause for these poor closures was determined, with the exception of the previously mentioned possibility for analytical bias for Be in the solid phase.

High Uncertainties in Mass Balance Closures. Some mass balance closures, both within and outside the target range, have high uncertainties. For those elements outside the target range, high variability in one or more measurements is the usual cause. The causes for high uncertainties in some elements is discussed below.

Cd, Ni, and Se. For these elements, uncertainty in the mass balance closure exceeds 50% for most devices. The cause is high uncertainty in the gas particulate-phase analyses. The Ni closure about the JBR, at 120 ±357%, is especially high because the Run 1 stack gas particulate-phase analyses were invalidated. The cause of the high variability in particulate-phase analyses for these elements in unknown. Insufficient data are available to make a reasonable hypothesis; however, the measurement error associated with the small sample mass collected at the stack is a likely contributor to the data variability.

Sb. The high uncertainty (95% ±120%) in the antimony closure about the JBR is the result of high detection limits in the liquid-phase samples analyzed. Antimony was not detected in the JBR blowdown filtrate or limestone slurry filtrate. The high uncertainty in the boiler closure is the result of variability in the ESP inlet gas particulate-phase analyses.

B. The high uncertainty (131% ±110%) in the boron closure about the boiler is the result of variability in the ESP inlet gas-phase analyses.

As. The high uncertainty in the ESP closure is mostly due to high variability in the ESP inlet gas vapor-phase analyses.

Emission Factors

The emission factor expresses stack emissions on an energy basis. Emission factors for elements are located in Table 6-3. The following general equation was used in calculating emission factors:

$$\text{Emission Factor} = \frac{\text{Mass of Species in Stack Gas}}{\text{Energy of Coal Burned}} \qquad (6\text{-}3)$$

Detailed emission factor equations and an example calculation are presented in Appendix I.

Removal Efficiencies

Removal efficiencies of elements were calculated for the boiler, ESP, and JBR. Results are presented in Table 6-4. Since all elements but B, Hg, and Se should be present primarily in the solid phase, most of the removal of trace species occurs with the removal of fly ash in the ESP. The following equation defines the removal efficiency for a substance:

$$\text{Removal Efficiency} = 100 * \left(1 - \frac{\text{Mass of Species in Gas Stream Exiting System}}{\text{Mass of Species in Gas Stream (or Coal) Entering System}}\right) \qquad (6\text{-}4)$$

An example calculation of a removal efficiency is provided in the Example Calculations in Appendix I.

Organic Compound Results

The organic compounds detected in the samples from all three gas streams can be grouped into three categories: plasticizers, outside source contaminants, and process

Table 6-3
Emission Factors

	lb/10^{12} Btu	95% CI
Anions		
Chloride	742	647
Fluoride	122	67
Selected Elements[a]		
Antimony	0.06	0.01
Arsenic	1.2	0.2
Barium	2.8	9.9
Beryllium	0.1	0.1
Cadmium	0.6	2.1
Chromium	5.3	49.5
Cobalt	0.7	0.8
Copper	2.0	2.3
Lead	0.6	0.6
Manganese	7.2	48
Mercury	3.0	0.3
Molybdenum	1.5	2.6
Nickel	40.1	435
Selenium	26.5	58
Vanadium	2.1	0.5
Aldehydes		
Acetaldehyde	8.6	9.2
Formaldehyde	24	36
Volatile Organics[b,c]		
Benzene	1.3	0.3
Carbon Disulfide	2.2	1.2
Toluene	2.0	1.0

Table 6-3 (Continued)

	$lb/10^{12}$ Btu	95% CI
Semivolatile Organics[d]		
2-Methylphenol (o-cresol)	2.9	3.8
4-Methylphenol (p-cresol)	0.95	1.9
Acetophenone	3.2	0.7
Benzoic Acid	120	7
Benzyl Alcohol	2.8	12
Naphthalene	1.5	1.0
Phenol	9.2	8.8

[a] Run 1 particulate-phase data were invalidated for all elements included here except arsenic, selenium, and vanadium due to the filter background comprising 20% or greater of the measured concentration.

[b] Only those compounds with an average concentration above the detection limit are included.

[c] Methylene chloride, acetone, and other halogenated hydrocarbons are not included because their presence is strongly suspected to be the result of contamination.

[d] Phthalate esters are not included because their presence is suspected to be the results of contamination.

Table 6-4
Removal Efficiencies (Includes Particulate and Vapor Phase)

	Boiler		ESP		JBR	
	% Removal	95% CI	%Removal	95% CI	% Removal	95% CI
Anions						
Chloride	-7	126	-12	49	99	1
Fluoride	1.4	15	1.6	37	98	1
Elements						
Aluminum[a]	26.0	16.8	98.6	–[b]	98.4	–
Antimony	32.8	45	98.8	0.6	84.1	3.1
Arsenic	-113.5 (-2.4)[c]	94.7 (43.6)[c]	95.9	1.5	92.7	2.1
Barium	31.5	29.7	98.3	–	96.1	–
Beryllium	-4.3[d]	18.2	98.1	–	92.6	–
Boron[h]	-30.6	114.7	34.3	–	93.5	–
Cadmium	0.5	62.9	95.1	–	46.2	–
Calcium	6.9	44.1	98.8	–	85.3	–
Chromium	-43.2 (10.2)[e]	228.7 (33.3)[e]	98.7	–	76.6	–
Cobalt	3.1	35.2	98.2	–	85.3	–
Copper[f]	73.8	25.4	97.8	0.3	88.1	13.5
Iron	12.5	10.1	98.9	0.1	98.0	7.0
Lead	-9.1	36.9	97.4	–	96.7	–
Magnesium	8.5	24.1	98.4	–	93.3	–
Manganese	-11.4	12.8	98.4	–	78.4	144
Mercury	-105 (-10)[g]	84.1 (35)[g]	55.2 (16.5)[g]	14.4 (20.6)[g]	45.9	7.4
Molybdenum[f]	82.5	19.9	97.2	2.2	82.5	27.2
Nickel	16.4	88.1	98.8	0.7	-75.5	1890
Phosphorus[f]	69.6	21.3	94.8	–	91.1	–
Potassium[f]	41.5	13.9	98.6	–	96.4	–
Selenium	34.8	30.9	38.1	85.1	66.9	56.1
Sodium	10.1	11.9	97.6	–	94.0	–
Strontium[f]	52.1	7.9	98.5	–	96.6	–
Titanium	24.0	18.5	98.6	0.4	98.3	0.4
Vanadium	13.7	12.4	98.0	0.3	96.0	0.9

[a] Spike recovery in ESP inlet gas-phase particulate for Al was 62%, indicating possible analytical bias.

[b] Since the ESP outlet gas-phase particulate Runs 1 and 3 were discarded, confidence intervals for the ESP and JBR removal efficiencies could not be calculated for many elements.

[c] Values in parentheses are those obtained when INAA coal analyses are substituted for the GFAA data.

[d] Spike recovery for Be in the PE ash sample was 147%, indicating possible analytical bias.

[e] ESP inlet gas-phase particulate Run 2, at 550 ng/g, is a statistical outlier. In comparison with sluiced ash, hopper ash, and size fractionated particulate data for chromium, this value is likely to be biased high. The removal efficiency data in parentheses are calculated with this value rejected.

[f] These elements are consistently enriched in the coal ash over the process stream solid-phase concentrations, suggesting that the coal analyses are biased high for these elements.

[g] ESP inlet gas-phase particulate data are suspected to be biased high compared with sluiced ash hopper ash analyses. This is also supported by the high boiler and low ESP mass balance closures. The removal efficiency data in parentheses are calculated with the ESP sluiced ash analyses substituted for the ESP inlet gas-phase particulate analyses.

[h] Gas particulate-phase data were unavailable. ESP sluiced ash data were substituted.

related compounds. The phthalate esters detected in the MM5 gas samples are typical plasticizers commonly attributed to plastic bottles, bags, etc. used in the field laboratory environment. Sample and field blank concentrations are comparable; since phthalates are ubiquitous in the terrestrial environment, their presence is most likely due to contamination.

Methylene chloride and acetone are common reagents used in the field for sample recovery, and the detection of these compounds in the VOST samples is attributed to their presence in the field laboratory environment. Also detected in the VOST samples were chloromethane, trichloroethane, tetrachloroethene, and trichlorofluoromethane. These compounds were also found in the field blanks, but not in the trip blanks. Their presence is attributed to an unknown source of solvents or refrigerants in the field environment and they are not considered to be process-generated compounds.

Six semivolatile organic compounds and two volatile organic compounds detected consistently in the three gas streams are likely associated with the coal combustion process. These are benzene, toluene, phenol, 2-methylphenol (o-cresol), 4-methylphenol (p-cresol), acetophenone, naphthalene, and benzoic acid. The average measurable concentrations of these compounds across all three gas streams are less than 1 ppbv except phenol (2.5 ppbv), formaldehyde (8.2 ppbv), and benzoic acid (37 ppbv). (Note that benzoic acid is not included on the Title III list of compounds in the Clear Air Act Amendments.)

Benzene, toluene, and the phenols are known products of coal devolatilization, and their presence indicates partial oxidation of the coal or the possible presence of lower-temperature combustion zones within the boiler. The presence of naphthalene, in addition to being a process related compound, is sometimes attributed to inadequate cleanup of the XAD resin material used as the sorbent in the MM5 sampling train. At this site, however, naphthalene concentrations in the blank resin samples were less than three times the detection limit indicating a relatively clean resin matrix. The gas sample concentrations were all less than eight times the detection limit with most of the measurable naphthalene concentrations near the levels found in the blank samples. Consequently, the confidence intervals around the naphthalene concentrations are large, and any definitive conclusion about the presence of naphthalene in the flue gas is not possible from these data.

Conversely, benzoic acid is present in the flue gas samples at an average concentration of 37 ppbv, over ten times greater than any other process related compound. The presence of benzoic acid in the flue gas may be explained by at least two well known mechanisms:

- **Oxidation of naphthalene followed by decarboxylation at 300°C.** This route was used commercially to produce benzoic acid until recently, when it was phased out in favor of liquid-phase oxidation of toluene. Naphthalene is oxidized to phthalic acid anhydride then decarboxylated, which takes place spontaneously at 300°C, with about 40% conversion. It is not unreasonable to assume that a similar reaction could occur during the combustion process when naphthalene is present.

- **Oxidation of toluene to benzoic acid.** The catalytic oxidation of toluene to benzoic acid using V_2O_5 was also used to produce benzoic acid commercially in Germany during

> World War II. Although it has also been replaced by the liquid-phase oxidation mechanism, the fact that the process existed indicates that benzoic acid can be obtained by the oxidation of toluene. The oxidation yields benzoic acid and benzaldehyde, which can also be oxidized to benzoic acid.

Benzoic acid is not on the Clean Air Act list of 189 toxic substances, but it is noteworthy that all of the detected organic compounds are aromatic and share a common toluene or substituted-benzene structure. Although benzoic acid may be a degradation product of XAD resin, there is no evidence confirming this compound is generated as a sampling artifact. Another likely hypothesis is that the semivolatile compounds detected in the flue gas are attributed to various oxidation and substitution products of naphthalene, xylene (detected in only one sample), and toluene, with benzoic acid being the predominant product.

Similarly, the presence of acetaldehyde and formaldehyde in the flue gas may be attributed to the oxidation of ethane and methane possibly produced from the partial oxidation of coal. Gas samples were not analyzed for acetic or formic acid, which are the oxidation products of acetaldehyde and formaldehyde, respectively. The analysis of these organic acids, if detected, could provide some insight into the behavior of acetaldehyde and formaldehyde and the level of oxidation possible in the system.