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Project: Emissions Report For Sites
103-109. Preliminary Draft Report

Radian Corp

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March 1993

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**FIELD CHEMICAL EMISSIONS
MONITORING PROJECT: EMISSIONS REPORT
FOR SITES 103 - 109**

PRELIMINARY DRAFT REPORT

Prepared for:

**Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94303**

Prepared by:

**Radian Corporation
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Austin, Texas 78759**

Testing and Analyses Conducted by:

**Host Utility
Carnot
KVB - Analect**

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Electric Power
Research Institute

Leadership in Science and Technology

March 10, 1993

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

Dear Mr. Maxwell:

In 1988, the Electric Power Research Institute (EPRI) initiated the PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) program to better characterize the source, distribution, and fate of trace chemicals from utility fossil-fuel-fired power plants. With passage of the Clean Air Act Amendments of 1990, the Field Chemical Emissions Monitoring (FCEM) portion of the PISCES program was accelerated to sample at a number of utility sites, encompassing a range of fuels, boiler configurations, and particulate, SO₂ and NO_x control technologies. To date, 24 sites have been sampled or are planned in the near future.

The enclosed site report represents a preliminary summary of data gathered during sampling programs conducted at seven electric utility plants in California - Sites 103 through 109. The sites tested consist of utility boilers sampled during both oil and natural gas-fired operation. None of the units tested were equipped with particulate control devices. Unlike the majority of the FCEM sampling programs (including the first five reports from Group 1 delivered to EPA in October and December 1992), the sampling and analysis at each of these sites were managed by the sponsoring utility. At Site 103, EPRI provided some assistance and input to the utility. The host utilities for Sites 104 through 109 voluntarily contributed data from these tests to EPRI for use in the PISCES program.

The primary objective of these sampling programs was to satisfy the requirements of the State of California's Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB2588). AB2588 required utilities to define and measure potentially toxic substances that may be present in the stack emissions. As discussed in the introduction to the report, the sampling and analytical protocol followed the state of California's requirements and did not necessarily meet the PISCES FCEM program objective.

The primary objective of submitting this report is to transmit the preliminary results from Sites 103 - 109 to the EPA for use in evaluating select trace chemical emissions from fossil-fuel-fired steam generating plants. **It should be noted that the results presented in this report are considered PRELIMINARY.** The results are believed to be essentially correct except as noted. As additional data from other sites are collected and evaluated, however, EPRI may conduct verification tests at this site. If this is done, the new data will be made available to the Environmental Protection Agency (EPA).

In addition to the raw data in the Appendix, the report discusses the data quality, provides an assessment of the trace metals material balances, identifies suspect data, and offers possible explanations for the questionable data. Because the discussion only focuses upon the suspect data, please keep in mind that most of the data meet the standards of quality established for the AB2588 study. This report does not compare the results from Sites 103 - 109 with the results from previous utility sites. Nor does this site report attempt to address the environmental and health risk impacts associated with the trace chemical emissions.

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

Sincerely,



Paul Chu
Manager, Toxic Substances Control
Environment Division

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INTRODUCTION

This report summarizes emissions data gathered during tests at seven electric utility plants in California. The seven test sites have been designated Sites 103 through 109. The data were gathered by Carnot Inc. (formerly Energy Systems Associates) and KVB - Analect (formerly R-C Environmental) for the host utilities pursuant to California's Air Toxics "Hot spots" Information and Assessment Act of 1987 (AB 2588). The Electric Power Research Institute (EPRI) supplied limited funding to support the testing at Site 103 but did not fund the testing at Sites 104 through 109. The host utilities have voluntarily contributed data from these tests to EPRI for use in its Power Plant Integrated Systems: Chemical Emissions Studies (PISCES) Field Chemical Emissions Monitoring (FCEM) Program.

Because these data were collected as part of a state regulatory program and not specifically for use in EPRI's FCEM Program, the data were not collected using the EPRI sampling and analytical protocols. The objectives of the FCEM Program are to (1) measure the levels of selected organic and inorganic substances in power plant process and discharge streams, and (2) examine the distribution and fates of the selected substances around the entire plant and individual process units. In the testing described in this report, the primary objective of the utilities was to satisfy the requirements of AB 2588. The "Hot Spots" program requires California utilities to define and measure potentially toxic substances that may be present in emissions from stationary sources. The utilities use the results of these measurements to prepare air toxics emission inventories and, eventually, risk assessments. Therefore, the focus of the testing at Sites 103 through 109 was to collect stack emissions data. Less emphasis was placed on the collection and analysis of other process streams, including fuels.

Under contract to EPRI, Radian Corporation has evaluated the test data from Sites 103 through 109 and has reported the data in a format suitable for the Environmental Protection Agency to use in their study of emissions from fossil-fueled power plants, as mandated by the Clean Air Act Amendments (CAAA) of 1990. The objective of this report is to document the results and the quality of the results.

Radian used several methods, listed below, to evaluate the test data from Sites 103 through 109:

- Sampling and analysis protocols were reviewed to determine how the data compared with other FCEM data generated using standard protocols;
- The type and number of quality assurance samples were reviewed to qualitatively determine the confidence that can be placed in the results; and

- The QA/QC data results were compared with data quality indicators to qualitatively define the validity of the data in terms of variability and accuracy.

The detailed results of the data evaluations for each test site are discussed in Parts 1 through 7 of this report. Each part is a stand-alone document. Table 1 summarizes the test site information. The host utility and Carnot (formerly Energy Systems Associates) shared sampling and analysis responsibilities at Site 103. Carnot performed all the sampling and analyses at Sites 104 through 108, and KVB - Analect (formerly R-C Environmental) conducted the tests at Site 109. Tests were run on utility boilers during both residual oil and gas-fired operation. None of the tested units were equipped with particulate control devices.

Table 2 lists the test matrix for the sites. Since the primary objective of the testing was to collect data to satisfy California's Air Toxics Act, most of the substances in Table 2 are identified in AB 2588 as potentially toxic substances. These substances are also measured during FCEM testing. A few substances listed in the test matrix were not measured at all sites. At Site 103, for example, antimony and cobalt were measured because they are listed as air toxics in the Clean Air Act Amendments of 1990. At the same site, barium, molybdenum, and vanadium were measured because these substances are included in the FCEM test protocol.

All the testing was conducted during full-load operation. At Site 109, two reduced-load tests were also conducted. Boiler operation during all test conditions at all sites was normal.

Comparison of Sampling and Analysis Protocols

Tables 3 and 4 list the sampling and analysis protocols for Sites 103 through 109 and those for the FCEM program. A comparison of the sampling protocols reveals the following general differences:

- There were slight differences in the multi-metals methods used in the California tests and in the FCEM program.
- Tedlar bags were used in the California tests to collect samples for benzene and toluene analyses; the volatile organic sampling train (VOST) method was used in the FCEM program.
- Single grab samples of the fuel (oil) were collected for analyses in the California tests; composite grab samples of the fuel were gathered in the FCEM program.

These differences in sampling protocols should not adversely affect the comparability of the emission test results with other FCEM data. Note, however, that the collection of single grab samples of fuel oil, which at times did not coincide with stack gas sampling, can prevent the use of material balances to verify the test results.

Table 1

Test Site Information for Sites 103 through 109

<u>Site Number</u>	<u>Test Dates</u>	<u>Rated Capacity (MW)</u>	<u>Test Contractor</u>
103	April/May 1990	150	Host Utility & Carnot
104	March 1990	350	Carnot
105	February 1990	750	Carnot
106	March 1990	480	Carnot
107	February/April 1990	175	Carnot
108	March 1990	50	Carnot
109	November 1990 - January 1991	230	KVB - Analect

Table 2
Summary of Test Matrix for Sites 103 through 109

<u>Substances</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
Antimony ^a	X		X
Arsenic ^b	X		X
Barium ^c	X		X
Beryllium ^b	X		X
Cadmium ^b	X		X
Chlorine ^b	X		
Chromium ^b	X		X
Chromium, hexavalent ^b	X		X
Cobalt ^a	X		X
Copper ^b	X		X
Lead ^b	X		X
Manganese ^b	X		X
Mercury ^b	X		X
Molybdenum ^c	X		X
Nickel ^b	X		X
Selenium ^b	X		X
Vanadium ^c	X		X
Benzene		X	X
Toluene ^c			X
Formaldehyde			X
Polycyclic Aromatic Hydrocarbons			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ -C ₆ Hydrocarbons		X	
Sulfur Content	X		

^aOnly measured at Site 103. Included in 1990 CAAA list of hazardous air pollutants.

^bMeasured at all sites specified by California's AB 2588 regulations.

^cOnly measured at Site 103. Included in FCEM project protocol.

Table 3
Comparison of Sampling Protocols for the FCEM Project and Sites 103 through 109

<u>Substances</u>	<u>Process Stream</u>	<u>Sampling Methods</u>	
		<u>Sites 103 through 109</u>	<u>FCEM Protocol^a</u>
Antimony	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations) ^b
Arsenic	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Barium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Beryllium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Cadmium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89) and CARB Method 424	EPA Multi-Metals Method (BIF Regulations)
Chromium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89) and CARB Method 424	EPA Multi-Metals Method (BIF Regulations)
Chromium, hexavalent	Stack Gas	CARB Method 425	NS ^c
Cobalt	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Copper	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Lead	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Manganese	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Mercury	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Molybdenum	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Nickel	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Selenium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Vanadium	Stack Gas	EPA Draft Multi-Metals Method (8/28/89)	EPA Multi-Metals Method (BIF Regulations)
Benzene	Stack Gas	CARB Method 410 (Tedlar Bag)	EPA SW 0030 (VOST)
Toluene	Stack Gas	CARB Method 410 (Tedlar Bag)	EPA SW 0030 (VOST)
Formaldehyde	Stack Gas	CARB Method 430 (DNPH Impingers)	SW 0011 (DNPH Impingers)
Polynuclear Aromatic Hydrocarbons	Stack Gas	CARB Method 429 (ASME Modified Method 5)	EPA SW 0010 (Modified Method 5)

Table 3 (Continued)

Substances	Process Stream	Sampling Methods	
		Sites 103 through 109	FCEM Protocol ^a
Antimony	Oil	Single Grab Sample	Composite Grab Samples
Arsenic	Oil	Single Grab Sample	Composite Grab Samples
Barium	Oil	Single Grab Sample	Composite Grab Samples
Beryllium	Oil	Single Grab Sample	Composite Grab Samples
Cadmium	Oil	Single Grab Sample	Composite Grab Samples
Chlorine	Oil	Single Grab Sample	Composite Grab Samples
Chromium	Oil	Single Grab Sample	Composite Grab Samples
Chromium, hexavalent	Oil	Single Grab Sample	Composite Grab Samples
Cobalt	Oil	Single Grab Sample	Composite Grab Samples
Copper	Oil	Single Grab Sample	Composite Grab Samples
Lead	Oil	Single Grab Sample	Composite Grab Samples
Manganese	Oil	Single Grab Sample	Composite Grab Samples
Mercury	Oil	Single Grab Sample	Composite Grab Samples
Molybdenum	Oil	Single Grab Sample	Composite Grab Samples
Nickel	Oil	Single Grab Sample	Composite Grab Samples
Selenium	Oil	Single Grab Sample	Composite Grab Samples
Vanadium	Oil	Single Grab Sample	Composite Grab Samples
Benzene	Natural Gas	On-Line Automatic Sampler	NS

^aReflects the most recent FCEM sampling and analytical protocol.

^bCombined impinger solution not concentrated before analysis. Based on the method specified in U.S. EPA's "Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations," March 1992.

^cNS indicates substance was not specified in test objectives.

Table 4
Comparison of Analytical Protocols for the FCEM Project and Sites 103 through 109

Substances	Process Stream	Analytical Methods			
		Site 103	Sites 104 through 109	FCEM Protocol ^a	
Antimony	Stack Gas	GFAAS	NS ^b	EPA SW 6010 (ICP-AES)	
Arsenic	Stack Gas	EPA Method 7061 (HGAAS)	EPA Method 7060 (GFAAS)	EPA SW 7060 (GFAAS)	
Barium	Stack Gas	EPA Method 7080 (Flame AAS)	NS	EPA SW 6010 (ICP-AES)	
Beryllium	Stack Gas	EPA Method 7091 (GFAAS)	EPA Method 6010 (ICP-AES)	EPA SW 6010 (ICP-AES)	
Cadmium	Stack Gas	EPA Method 7131 (GFAAS)	EPA Method 7190 (Flame AAS), EPA Method 6010 (ICP-AES)	EPA SW 7131 (GFAAS)	
Chromium	Stack Gas	EPA Method 7191 (GFAAS)	EPA Method 7190 (Flame AAS)	EPA SW 7191 (GFAAS)	
Chromium, hexavalent	Stack Gas	CARB Method 425 (IC)	CARB Method 425 (IC)	NS	
Cobalt	Stack Gas	EPA Method 6010 (ICP-AES)	NS	EPA SW 6010 (ICP-AES)	
Copper	Stack Gas	EPA Method 7211 (GFAAS)	EPA Method 6010 (ICP-AES)	EPA SW 6010 (ICP-AES)	
Lead	Stack Gas	EPA Method 7421 (GFAAS)	EPA Method 6010 (ICP-AES)	EPA SW 7421 (GFAAS)	
Manganese	Stack Gas	EPA Method 7461 (GFAAS)	EPA Method 6010 (ICP-AES)	EPA SW 6010 (ICP-AES)	
Mercury	Stack Gas	EPA Method 7470 (CVAAAS)	EPA Method 7470 (CVAAAS)	EPA SW 7470 (CVAAAS)	
Molybdenum	Stack Gas	EPA Method 6010 (ICP-AES)	NS	EPA SW 6010 (ICP-AES)	
Nickel	Stack Gas	EPA Method 7520 (Flame AAS)	EPA Method 6010 (ICP-AES)	EPA SW 7060 (GFAAS)	
Selenium	Stack Gas	EPA Method 7741 (HGAAS)	EPA Method 6010 (ICP-AES)	EPA SW 7060 (GFAAS)	
Vanadium	Stack Gas	EPA Method 7911 (GFAAS)	NS	EPA SW 6010 (ICP-AES)	
Benzene	Stack Gas	CARB Method 410 (GC/PID)	CARB Method 410 (GC/PID)	EPA SW 0030 (GC/MS)	
Toluene	Stack Gas	CARB Method 410 (GC/PID)	CARB Method 410 (GC/PID)	EPA SW 0030 (GC/MS)	
Formaldehyde	Stack Gas	CARB Method 430 (HPLC)	CARB Method 430 (HPLC)	TO 5 (HPLC)	
Polynuclear Aromatic Hydrocarbons	Stack Gas	CARB Method 429 (High Resolution GC/MS)	CARB Method 429 (High Resolution GC/MS)	EPA SW 8270 (High Resolution GC/MS)	
Antimony	Oil	EPA Method 6010 (ICP-AES)	NS	NS	
Arsenic	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA) ^c	
Barium	Oil	EPA Method 6010 (ICP-AES)	NS	Hofstadter, et al. (INAA)	
Beryllium	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	GFAAS	
Cadmium	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)	
Chlorine	Oil	ASTM D808-87	ASTM D808-87	Hofstadter, et al. (INAA)	
Chromium	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)	
Chromium, hexavalent	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	NS	
Cobalt	Oil	EPA Method 6010 (ICP-AES)	NS	Hofstadter, et al. (INAA)	
Copper	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)	

Table 4 (Continued)

Substances	Process Stream	Analytical Methods		
		Site 103	Sites 104 through 109	FCEM Protocol ^a
Lead	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	GFAAS
Manganese	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)
Mercury	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA), CVAAS
Molybdenum	Oil	EPA Method 6010 (ICP-AES)	NS	Hofstadter, et al. (INAA)
Nickel	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)
Selenium	Oil	EPA Method 6010 (ICP-AES)	EPA Method 6010 (ICP-AES)	Hofstadter, et al. (INAA)
Vanadium	Oil	EPA Method 6010 (ICP-AES)	NS	Hofstadter, et al. (INAA), GFAAS
Benzene	Natural Gas	GC/PID	GC/PID	NS

^aReflects the most recent FCEM sampling and analytical protocol.

^bNS indicates substance was not specified in test objectives.

^cHofstadter, R.A., O.I. Milner, and J.W. Runnel (editors). "Analysis of Petroleum for Trace Metals," *Advances in Chemistry Series*, 156 (1976), pp. 41-45.

CVAAS = Cold Vapor Atomic Absorption Spectrophotometry

Flame AAS = Flame Atomic Absorption

GC/MS = Gas Chromatography/Mass Spectroscopy

GC/PID = Gas Chromatography/Photo Ionization Detector

GFAAS = Graphite Furnace Atomic Absorption Spectrophotometry

HGAAS = Hydride Generation Atomic Absorption Spectrophotometry

HPLC = High Performance Liquid Chromatography

IC = Ion Chromatography

ICP-AES = Inductively Coupled Argon Plasma Emissions Spectrophotometry

INAA = Neutron Activation Analysis

VOST = Volatile Organic Sampling Train

Table 4 summarizes the analytical methods used in the California and FCEM test programs. In general, the procedures used to analyze stack gas samples were similar in both programs; therefore, the emissions test data from the two programs should be comparable.

Less sensitive analytical techniques than called for in the FCEM protocol were used at the California sites for some substances (e.g., beryllium, mercury, and selenium) in the fuel oil. For this reason, it was more difficult to develop material balances to verify some of the test results (for instance, emission values cannot be compared to fuel concentrations for many substances).

Quality Assurance/Quality Control: Data Completeness and Validity

Radian reviewed the quality assurance/quality control (QA/QC) data for each test to judge whether these data could be validated with the available information. Table 5 lists the QC indicators used to evaluate the reported data for Sites 103 through 109. In general, there is sufficient information to indicate the majority of the data are of good quality. The objective of this testing, as stated earlier, was to satisfy California AB 2588. Other EPRI FCEM testing has had other objectives, which can require the generation of more QA/QC information than performed in this study.

The absence of some or all of the "standard" QA/QC checks from the site reports does not necessarily reflect negatively on the quality of the data. It does, however, limit the ability to measure the various components of measurement error. In general, the results of the QC checks available for Sites 103 through 109 suggest that the reported sampling and analysis results are well characterized, with the following general caveats:

- Background levels in the sampling media (i.e., blanks) were significant for many of the substances measured in the stack gas using the multi-metals train. These data have been identified and should be considered questionable and used with caution.
- Background levels for the multi-metals train results at Site 109 could not be evaluated because the blank samples were not analyzed; therefore, the validity of these results is uncertain and the data should be used with caution.
- At several test sites, high levels were noted in field blank gas samples analyzed for polyaromatic hydrocarbons (PAH) and formaldehyde. Ambient levels of these substances could cause field blank contamination. In these cases, the test results should be considered questionable, and they should be used with caution.

Report Organization

Detailed information, results, data evaluation, example calculations, and data appendices for each of the test sites are provided in Parts 1 through 7 of this document. Each part contains all of the information for a particular site. A glossary containing definitions of terms common to all the test sites appears after this introduction.

Table 5
QC Indicators Used to Evaluate Testing Data Reported for Sites 103 - 109^a

Analysis	Precision				Lab Control Sample Dup.	Accuracy			Blank			
	Replicate Runs	Dup. Field Samples	Dup. Lab Analysis	Matrix or Media Spiked Dup.		Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals by ICP/AAS ^b	✓		✓			✓						
Ultimate & Proximate ^c	✓											
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by ICP ^d	✓		✓			✓			✓			✓
Arsenic by GFAAS	✓								✓			✓
Lead by GFAAS	✓								✓			✓
Mercury by CVAAS	✓		✓			✓			✓			✓
Hexavalent Chromium by IC	✓		✓			✓			✓			
Total Chromium by AAS	✓		✓			✓			✓			✓
Benzene by GC/PID	✓								✓			
Formaldehyde by HPLC	✓			✓		✓			✓			✓
Polynuclear Aromatic Hydrocarbons by GC/MS	✓						✓			✓		

^aLimited QC data were reported for Site 109. Refer to Table 4-3 in Part 7 of this document for details about Site 109 QA/QC procedures.

^bIncludes Sb, As, Be, Cd, Cr, Cr (VI), Cu, Pb, Hg, Mn, Ni, and Se by EPA SW-846 Methods, 6010 (ICP-AES) and 7000 series (AAS).

^cAsh, carbon, hydrogen, nitrogen, oxygen, sulfur, specific gravity, and chlorine.

^dIncludes Be, Cd, Cu, Pb, Mn, Ni, and Se by ICP-AES.

✓ = QC data available for Sites 103-109, with some differences from site to site.

GLOSSARY

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

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PART I: SITE 103

PRELIMINARY DRAFT REPORT

Test Contractor:

Host Utility

and

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15991 Red Hill Avenue, Suite 110
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3 March 1993

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Section 1

INTRODUCTION

This part of the document summarizes data gathered by the host utility and Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 103, during a sampling program sponsored by the electric utility. The power plant, a Babcock and Wilcox front wall-fired boiler, was tested during both residual fuel oil- and natural gas-firing in April and May of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The primary emphasis of the sampling effort was collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the plant and sample locations. Section 3 discusses the results of the chemical analyses of the fuel oil, natural gas, and fuel gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data using traditional QA/QC techniques and engineering calculations. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 103

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Antimony	X		X
Arsenic	X		X
Barium	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Cobalt	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Molybdenum	X		X
Nickel	X		X
Selenium	X		X
Vanadium	X		X
<u>Organic</u>			
Benzene			X
Formaldehyde			X
Polycyclic Aromatic Hydrocarbons			X
<u>Additional</u>			
Heating Value	X	X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section gives a description of the test site, Site 103, and the locations of the sampling points.

Facility Information

Testing was conducted at an oil-fired steam electric generating unit with a nominal capacity of 150 megawatts (MW). During the testing at Site 103, the unit operated at a consistent 150 MW during both oil and natural gas firing. Testing was conducted during both 100% fuel oil and 100% natural gas operation.

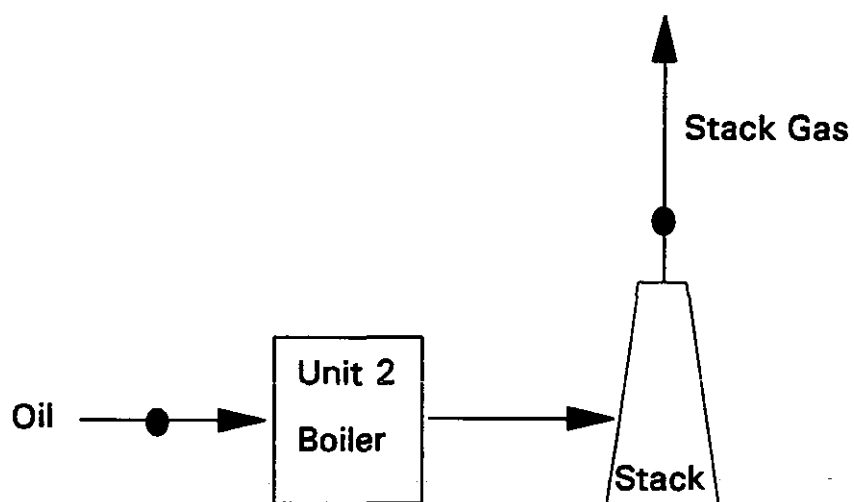
Figure 2-1 is a simplified block flow diagram. Steam is generated in a Babcock and Wilcox front wall-fired boiler that can be fueled by either natural gas or fuel oil. Bottom ash is intermittently collected (only during shutdown) in 55-gallon drums and sent to a landfill. No emission control devices are located downstream of the boiler. Magnesium oxide is injected into the boiler at a rate of 1 part MgO per 10,000 parts of oil.

The residual oil feed at this site has a sulfur content of 0.19% and a higher heating value (HHV) of approximately 19,100 Btu/lb. The natural gas had a higher heating value of 1,030 Btu/scf (22,600 Btu/lb).

Sampling Locations

The fuel oil feed to the boiler and the emitted gases through the stack were the two streams sampled in this study. Brief descriptions of the sampling locations are given below:

- Oil samples were collected from one of two fuel tanks that feed the boiler.
- Emitted gas samples were collected at four sample ports on the stack 130 feet above ground level.



Legend:

● Sampling Locations

Figure 2-1. Process Flow Diagram for FCEM Site 103

Section 3

RESULTS

This section summarizes the fuel oil and emitted gas stream data collected at Site 103. These results were calculated from laboratory and field data reported by Carnot and the host utility. Only formaldehyde and benzene emissions were measured during natural gas firing; metals, PAHs, benzene and formaldehyde emissions were measured during fuel oil firing.

Appendix A presents the raw analytical data generated by Carnot, the host utility, and their contracting laboratories during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 103 was sampled in late April and early May of 1990. Figure 3-1 shows the sequence of tests performed on the stack gas of Site 103. Samples are numbered in chronological order. Each fuel type has its own unique set of run numbers. The run numbers are shown in Figure 3-1 and the summary tables.

Four collection trains were used to sample the stack gas during fuel oil firing. These trains included a Method 5 particulate train with impingers (Draft EPA Method) for multi-metals, a California Air Resources Board (CARB) Method 424 train for cadmium, a CARB Method 425 train for total chromium and hexavalent chromium, and a semi-VOST (MM5) train for polycyclic aromatic hydrocarbons (PAHs). CARB Method 410A was used to collect benzene, and CARB Method 430 was used to sample formaldehyde to compare emissions during both natural gas and oil firing. All of the trains except for CARB Method 430 (formaldehyde) and CARB Method 410A (benzene) require full traversing of the ducts. Appendix C presents the details of the analytical and sampling methods used at this site.

Data Treatment

Several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

Blank Corrections

The convention for using blank results to correct the data in this group of reports was to use the reagent blank results when they were available. If a reagent blank analysis was

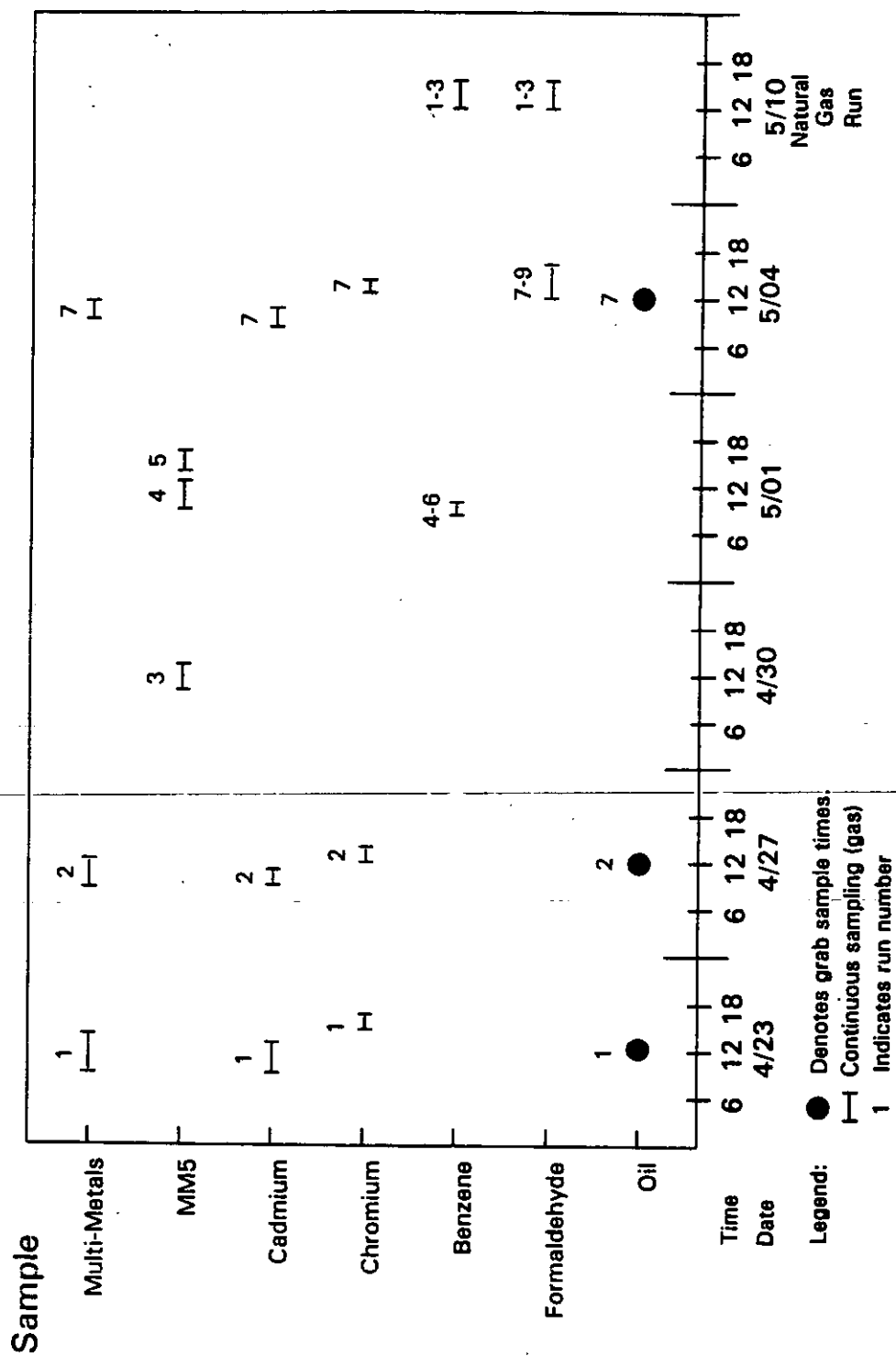


Figure 3-1. Summary Schedule for Site 103, Including Run Numbers

not performed, field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no such correcting was done.

At Site 103, the individual run measurements were corrected for the field blank analysis. Since the solid and vapor phases were combined before analysis, the field blanks were subtracted from the total micrograms detected. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration was flagged with a "B". When the blank correction resulted in a value less than the detection limit, the concentration is presented as ND(DL), which means that the concentration is below the detection limit (DL), which appears in parentheses. The test contractor has defined the term "detection limit" as three to ten times the instrument detection limit.

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all values are above the detection limit, the arithmetic mean concentration is calculated using the reported quantities.
- For results that include values both above and below the detection limit, one-half of the DL is used for values below the detection limit to calculate the mean. For example:

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

By convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8. This is less than the largest detection limit, so the reported mean becomes ND(4).

<u>Analytical Values</u>	<u>Mean Value</u>
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the three residual oil analyses. Most of the substances in the table were determined using Flame Atomic Absorption Spectrophotometry. Other values were obtained with Inductively Coupled Plasma Emission Spectrophotometry. For each reported substance, a mean concentration has been calculated, along with the 95% confidence interval about the mean. The confidence interval is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean nickel oil concentration is 9.7 ± 1.1 mg/L (between 8.6 and 10.8 mg/L),

Table 3-1
Oil Composition Data for Site 103

	<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	<u>Mean</u>	<u>95% CI^a</u>
Mass Flow Rate (lb/hr)	73,000	73,500	73,500	73,333	3,736
Sulfur (%)	0.2	0.2	0.2	0.2	0
Higher Heating Value (Btu/lb)	19,129	19,109	19,174	19,137	33
<u>Elements (mg/L)</u>					
Arsenic	ND(1.1) ^b	ND(1.1)	ND(1.1)	ND(1.1)	--
Barium	0.4	0.5	1.0	0.6	0.9
Beryllium	ND(.23)	ND(0.23)	ND(0.23)	ND(0.23)	--
Cadmium	0.49	ND(0.23)	ND(0.23)	0.24	0.55
Chlorine	230	51	110	130	230
Chromium	ND(0.23)	ND(0.23)	ND(0.23)	ND(0.23)	--
Chromium, hexavalent	ND(0.23)	ND(0.23)	ND(0.23)	ND(0.23)	--
Cobalt	0.6	0.6	0.6	0.6	0
Copper	ND(0.5)	0.6	ND(0.5)	ND(0.5)	--
Lead	ND(1.1)	ND(1.1)	ND(1.1)	ND(1.1)	--
Manganese	ND(0.23)	ND(0.23)	ND(0.23)	ND(0.23)	--
Mercury	ND(0.09)	ND(0.09)	ND(0.09)	ND(0.09)	--
Molybdenum	ND(0.3)	0.5	ND(0.3)	ND(0.3)	--
Nickel	9.2	10	10	9.7	1.1
Selenium	ND(1.1)	ND(1.1)	ND(1.1)	ND(1.1)	--
Vanadium	1.3	1.2	1.2	1.2	0.1

^aCI = Confidence interval.

^bND indicates that the concentration was below the detection limit.

according to the three results presented in Table 3-1]. Calculation of the confidence interval is discussed in Section 5.

The natural gas feed was not sampled at Site 103.

Stack Gas

Table 3-2 presents concentration data for the emitted gas at Site 103. The analyzing laboratory combined the filter, probe and nozzle rinse, and the impinger catch for the multi-metals train before analysis. Therefore, the data presented in Table 3-2 represent the total (particulate plus vapor) concentration in the stack gas. The field blank corrections were fairly significant in some cases, i.e., values denoted with a "B" had a blank value of 50% or more of the initial sample value. Appendix A presents the results of the blank analyses, as well as the test results for each run. The total concentrations from each run were averaged (according to the conventions outlined previously) to obtain an overall mean concentration and 95% confidence interval for each measured substance.

Except for naphthalene, the other PAH concentrations were all below detection limits before blank corrections were made. The levels of naphthalene in the samples were well below the detection limits when the field blank result was subtracted from the initial sample value.

Table 3-3 compares the volatile organic emissions from the same boiler fired with two different fuels--residual oil and natural gas. Grab samples were taken in Tedlar bags and analyzed for formaldehyde, benzene, and toluene. Toluene results were discarded because the Tedlar bags were contaminated with levels of toluene up to 50 ppbv that could not be purged with nitrogen. All analyses of benzene and formaldehyde were below detection limits, except for one formaldehyde analysis. The high field blank correction corresponding to this run results in a formaldehyde concentration at the detection limit.

Appendix D presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperatures, and the degree of isokinesis for each sampling event.

Table 3-4 presents the average unit-energy-based emission factors in pounds of substance emitted per 10^{12} Btu input to the boiler. The emission factors were calculated from the mean stack gas concentrations shown in Table 3-2 and 3-3. Section 5 contains an example calculation.

Table 3-2
Stack Gas Composition Data at Site 103
Residual Oil Firing

<u>Substance</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Stream Flow</u>					
<u>Rate (Nm³/hr)</u>	472,000	464,500	480,700	472,400	20,100
<u>Particulate</u>					
<u>Loading (μg/Nm³)</u>	17,199	19,656	14,742	17,199	6,142
<u>Elements (μg/Nm³)</u>					
Arsenic	0.5 B ^b	8.4	5.8	4.9	9.9
Barium	ND(170) ^c B	ND(170) B	ND(170) B	ND(170)	--
Beryllium	0.3 ^d	0.4 ^d	ND(0.3) ^d	ND(0.3)	--
Cadmium	4.4	7.0	1.5	4.3	6.8
Chromium	6.8 B	2.2 B	5.0 B	4.7	5.8
Chromium, hexavalent	1.2 ^d	ND(1.0) ^d	1.9 ^d	1.2	1.7
Cobalt	15.7 ^d	14.2 ^d	11.1 ^d	13.6	5.8
Copper	1.9 B	5.3 B	0.1 B	2.4	6.5
Lead	4.3	5.2	5.5	5.0	1.6
Manganese	13.3	25.7	22.6	20.6	16.1
Mercury	ND(4.8) ^d	ND(4.8) ^d	ND(4.8) ^d	ND(4.8)	--
Molybdenum	ND(9) ^d	ND(9) ^d	11.5 ^d	ND(9)	--
Nickel	465	470	471	469	9
Selenium	0.32	0.43	0.32	0.36	0.15
Vanadium	62.0 ^d	50.8 ^d	86.5 ^d	66.5	45.6
	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI</u>
<u>Polynuclear Aromatic</u>					
<u>Hydrocarbons (μg/Nm³)</u>					
Acenaphthene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Acenaphthylene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Anthracene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Benz(a)anthracene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Benzo(a)pyrene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Benzo(b+k)fluoranthene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Benzo(g,h,i)perylene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Chrysene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Dibenz(a,h)anthracene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)
Fluoranthene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	ND(0.01)

Table 3-2 (Continued)

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI</u>
Fluorene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	--
Indeno(1,2,3-c,d)pyrene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	--
Naphthalene	ND(0.007) B	ND(0.007) B	ND(0.01) B	ND(0.01)	--
Phenanthrene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	--
Pyrene	ND(0.007)	ND(0.007)	ND(0.01)	ND(0.01)	--

^aCI = Confidence interval.

^bB indicates that the blank measurement is equal to or more than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-3

**Volatile Organic Stack Emissions at Site 103
Residual Oil and Natural Gas Firing**

<u>Volatile Organic Compounds</u>	<u>Sample 1</u>	<u>Sample 2</u>	<u>Sample 3</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Residual Oil Fired</u>					
Stack Flow Rate: 475,400 Nm ³ /hr					
Formaldehyde (μg/Nm ³)	ND(27) ^{b,c}	ND(27) ^c	ND(27) ^c	ND(27)	--
Benzene (μg/Nm ³)	ND(8.8) ^c	ND(8.8) ^c	ND(8.8) ^c	ND(8.8)	--
<u>Natural Gas Fired</u>					
Stack Flow Rate: 425,900 Nm ³ /hr					
Formaldehyde (μg/Nm ³)	ND(27) B ^d	ND(27) B	ND(27) B	ND(27)	--
Benzene (μg/Nm ³)	ND(8.8) ^c	ND(8.8) ^c	ND(8.8) ^c	ND(8.8)	--

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit, which is shown in parentheses.

^cA blank correction is not applied since the substance was not detected in the blank sample.

^dB indicates that the blank measurement is equal to or more than 50% of the uncorrected-sample measurement. -- Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-4
Stack Gas Emission Factors at Site 103
(lb/10¹² Btu)

<u>Substance</u>	<u>Residual Oil Fired</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Elements</u>		
Arsenic	3.6	7.4
Barium	ND(127) ^b	--
Beryllium	ND(0.24)	--
Cadmium	3.2	5.1
Chromium	3.5	4.4
Chromium, hexavalent	0.9	1.3
Cobalt	10.1	4.4
Copper	1.8	4.8
Lead	3.7	1.2
Manganese	15.3	12
Mercury	ND(3.6)	--
Molybdenum	ND(6.7)	--
Nickel	348	21
Selenium	0.27	0.11
Vanadium	49.3	34
<u>Polynuclear Aromatic Hydrocarbons</u>		
Acenaphthene	ND(0.006)	--
Acenaphthylene	ND(0.006)	--
Anthracene	ND(0.006)	--
Benz(a)anthracene	ND(0.006)	--
Benzo(a)pyrene	ND(0.006)	--
Benzo(b + k)fluoranthene	ND(0.006)	--
Benzo(g,h,i)perylene	ND(0.006)	--
Chrysene	ND(0.006)	--
Dibenz(a,h)anthracene	ND(0.006)	--
Fluoranthene	ND(0.006)	--
Fluorene	ND(0.006)	--
Indeno(1,2,3-c,d)pyrene	ND(0.006)	--
Naphthalene	ND(0.006)	--

Table 3-4 (Continued)

<u>Substance</u>	<u>Residual Oil Fired</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons</u>		
Phenanthrene	ND(0.006)	--
Pyrene	ND(0.006)	--
<u>Volatile Organic Compounds</u>		
Formaldehyde	ND(19.9)	--
Benzene	ND(6.5)	--
<u>Natural Gas Fired</u>		
<u>Volatile Organic Compounds</u>		
Formaldehyde	ND(17.7)	--
Benzene	ND(4.4)	--

^aCI - Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Btu), which is shown in parentheses.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 103, two methods were used to evaluate the quality of the data. First, and most important, was evaluation of the traditional QA/QC protocol for the sampling and analytical procedures used at Site 103, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 103 QA/QC data are compared with FCEM project objectives for similar QA/QC procedures. The second data evaluation tool involves calculating material balances around for various substances the entire plant. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., mass closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute a significant amount to the overall inlet or outlet mass rate (e.g., coal, bottom ash, collected fly ash, etc).

Evaluation of Measurement Data Quality

Evaluation of the quality of the measurement data is based on quality control data obtained experimentally during the sampling and analysis process. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. Table 4-1 summarizes the QA/QC measures commonly used as part of the FCEM data evaluation protocol and the characteristic information obtained. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data, but does limit the ability to measure the various components of measurement error.

As indicated in the table, different QC checks provide different types of information, particularly pertaining to the source of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. The precision and accuracy estimates are based on the actual sample matrix. The actual precision and accuracy estimates obtained experimentally during the test programs are compared with the Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 summarizes the precision and accuracy estimates.

Evaluation of the quality control data suggests that there is reason to conclude that the data reported are acceptable, although there is not enough information to unequivocally validate the data. The QC indicators reported are generally good, accepted methods were used for sampling and analysis, and stack gas sample collection records are strongly supportive. The confidence in some measurements is low because of the relatively high blank results. No quality measurements were performed for benzene, formaldehyde, or for proximate and ultimate analyses.

A discussion of precision and accuracy is presented below for each measurement type, followed by a review of the stack gas sampling quality control data. This review includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias, or persistent positive or negative deviation from the "true" value.

The efficiency of the analytical procedure for the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes or other quality assurance measures, as necessary. Spiked samples usually provide a measure of accuracy or bias at medium concentration levels, expressed as percent recovery; blank samples also provide a measure of bias, although at low or near-detection levels.

Table 4-2

Types of Quality Control Data Reported

Analysis	Precision				Accuracy			Blank				
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil (Residual)</u>												
Metals by ICP/AAS	✓		✓	✓								
Ultimate and Proximate	✓											
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by Flame AA	✓							✓	✓			
Metals by GFAAS	✓							✓	✓			
Metals by ICP	✓							✓	✓			
Mercury by CVAAS	✓							✓	✓			
Hexavalent Chromium by IC	✓							✓	✓			
Total Chromium by AAS	✓							✓	✓			
Benzene by GC/PID (oil fuel)	✓								✓			
Formaldehyde by HPLC (oil fuel)	✓								✓			
Polynuclear Aromatic Hydrocarbons by GC/MS	✓							✓	✓		✓	

Table 4-3

Summary of Precision and Accuracy Estimates

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
PAH in Stack Gas	Precision and Accuracy - Surrogate Recoveries				
d10-Acenaphthene		35% CV	50-150%	27% CV	110-190%
d10-Anthracene		35% CV	50-150%	2% CV	86-90%
d12-Crysene		35% CV	50-150%	31% CV	85-140%
d12-Benzo(a)pyrene		35% CV	50-150%	36% CV	65-140%
Metals in Stack Gas ^a	Precision- Data not produced Accuracy - Laboratory control sample				
Arsenic		20% RPD	75-125%	NA	98
Barium		20% RPD	75-125%	NA	120
Beryllium		20% RPD	75-125%	NA	100
Cadmium		20% RPD	75-125%	NA	121
Cobalt		20% RPD	75-125%	NA	111
Copper		20% RPD	75-125%	NA	98
Lead		20% RPD	75-125%	NA	103
Manganese		20% RPD	75-125%	NA	91
Mercury		20% RPD	75-125%	NA	80
Molybdenum		20% RPD	75-125%	NA	98
Nickel		20% RPD	75-125%	NA	105
Selenium		20% RPD	75-125%	NA	84
Vanadium		20% RPD	75-125%	NA	97
Total Chromium in Stack Gas		20% RPD	75-125%	NA	100

Table 4-3 (Continued)

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spikes				
Arsenic		20% RPD	75-125%	12 RPD	111
Barium		20% RPD	75-125%	NA	NA
Beryllium		20% RPD	75-125%	<1 RPD	108
Cadmium		20% RPD	75-125%	15 RPD	85
Cobalt		20% RPD	75-125%	NA	NA
Copper		20% RPD	75-125%	3 RPD	107
Lead		20% RPD	75-125%	<1 RPD	99
Manganese		20% RPD	75-125%	3 RPD	103
Mercury		20% RPD	75-125%	16 RPD	100
Molybdenum		20% RPD	75-125%	NA	NA
Nickel		20% RPD	75-125%	<1 RPD	101
Selenium		20% RPD	75-125%	4 RPD	89
Vanadium		20% RPD	75-125%	NA	NA
Chromium		20% RPD	75-125%	15 RPD	101
Cr(VI)		20% RPD	75-125%	NA	NA

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicates, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) among the duplicate results.

^cAccuracy is expressed as the range of recoveries expected for individual analytical results.

NA - Not available.

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

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

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

Metals

Precision. Table 4-3 shows the precision estimates for the analysis of metals in fuel samples. No precision data were collected for the analysis of metals in stack gas samples. As shown in Table 4-3, the precision estimates for metals in fuel oil samples are within the 20% objective. The precision values measured, however, are based on duplicate analyses, whereas the objectives are intended for matrix-spike duplicates or duplicate field samples. Sample variability would not be expected to contribute significantly to the total imprecision, so the precision estimates given are considered good indicators of acceptable performance.

Accuracy. Recoveries of metals in the fuel oil matrix spike and laboratory controls for stack gas are all within the 75-125% objective.

Blanks. The stack gas concentrations were corrected for the field blank results except when a substance in the field blank was not detected. For some elements, the blank levels were similar to the levels in the sample.

The stack gas results for barium, chromium, and copper are flagged with a "B," which indicates that the field blank result is equal to or greater than 50% of the measured result. For barium, the field blank level was higher than all three of the measured results, indicating a potential contamination problem, either with the sampling apparatus or with the analytical procedure. The other two elements had field blanks between 50% and 98% of the measured values.

PAHs

Precision. Precision estimates for PAH analyses in stack gas samples, shown in Table 4-3, are based on the surrogate recoveries in the replicate sample analyses, expressed as

the percent coefficient of variation (%CV). These data show the precision to be within expected limits, with CVs for three out of the four surrogate compounds within the 35% objective, and the fourth, for d12-benzo(a)pyrene, only slightly higher at 36% CV. The results for PAHs across the three replicate runs are equally consistent, although most of the target analytes were not detected.

Accuracy. Accuracy estimates for PAHs in the stack gas, according to surrogate spike recoveries in three samples, were within the 50-150% recovery objective, with two exceptions. Recoveries for d10-accnaphthene in two of the three samples were outside these objectives (190% and 180%). Because all other accuracy indicators were within expected limits, these two exceptions do not affect data quality.

Blanks. With respect to the list of FCEM substances listed under polynuclear aromatic compounds in Table 1-1, only naphthalene was found in the replicate samples and in the blanks. Naphthalene concentrations in the field blanks were twice those found in the sample runs. When the field blank results are subtracted, field sample naphthalene values are below the detection limit. Method blank data also indicate the presence of naphthalene, but at much lower concentrations. Naphthalene is cited by Carnot as a contaminant in the XAD-2 sorbent used to collect PAH samples.

Formaldehyde

No information on precision or accuracy was reported.

Blanks. Formaldehyde was not detected in any of the samples or field blanks taken during the residual oil test. The results for only one sample collected during the natural gas test indicated the presence of formaldehyde; however, the field blank result was much higher than that of the sample, which could indicate possible problems in the sampling or analytical procedures.

Stack Gas Sampling Quality Control

Sampling quality control was addressed in a summary of the quality assurance program used by Carnot and a letter of certification from the California Air Resources Board. Also included were calibration records for the dry gas meters and a table outlining the schedule and procedures used to calibrate these and other equipment. No calibration records were presented for the sampling performed by the utility (however, they have these records on file). Correction factors and constants were properly employed.

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location.

Sampling accuracy is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases that may be caused by contamination of the equipment or location,

or operator errors. Blanks were included for all tests except the CARB 410 (benzene), which are grab bag samples.

Sampling representativeness depends on precision and accuracy and also on the characteristics of the sampling locations. The sampling location at the stack was nearly ideal in terms of undisturbed flow distances upstream and downstream of the ports. The particulate and metals tests were performed using a 24-point traverse, when only 16 were required, and the PAH tests used the requisite 16 points. The isokinetic variation is a measure of the operational performance of sampling for particulate matter, and can be used as an indicator of precision with consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011, using the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 method for semivolatile organic compounds, dioxins, and furans is well established both for sampling and analysis. The EPA multimetals procedure is still in the evaluation process, but it is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures, although, in this particular case, water instead of caustic solution was used in the impingers. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag.

Sampling completeness is mainly a function of providing the requisite number of samples and proper documentation. In particular, the data necessary for calculating the results, including the calibration of the equipment and all pertinent entries on the run data sheets, should be present. The necessary number of samples were successfully taken and sample custody was transferred properly to the analytical laboratories.

Material Balance Results

A material balance at Site 103 involves only two streams, the inlet fuel oil and the flue gas. Although magnesium oxide is injected into the boiler, its flow rate is small (1 part MgO per 10,000 parts of oil) and any contributions to the inlet mass rate are considered to be negligible. It could be a component of the emitted particulate matter. This cannot be verified because the filter was not analyzed for magnesium.

Stream flow rates and concentrations and the bias and precision errors associated with these measurements were entered into a statistical error propagation model to estimate the overall material balance closure. Appendix E contains a detailed discussion of the statistical error propagation analysis.

Closure is defined as the ratio of outlet to inlet mass. A 100% closure indicates perfect agreement. When trace substances are analyzed, closures of between 70% and 130% have been set as a goal for the FCEM project. This range reflects the typical level of analytical uncertainty and, therefore, permits one to interpret the inlet and outlet stream mass rates as being statistically equivalent. Poor closure values or a large scatter (high uncertainty) may indicate measurement problems in one or more of the sample matrices.

The measured oil flow rate was compared with the generating capacity by calculating the heat input using the oil flow rate, HHV, and an efficiency of 30%. The flow rate and generating capacity were in good agreement. The stack gas flow rate has a small confidence interval and was measured at an optimal point on the stack free of disturbances (7.3 diameters length after the air heaters, 3 diameters length from the stack outlet). This indicates that the measured values for the fuel oil and flue gas flow rates are accurate.

The substance material balances, along with the results of the error propagation analysis, are shown in Table 4-4. Material balances for most of the elements could not be developed because the substances were neither detected in the fuel oil nor the stack gas. Those elements for which a material balance could be calculated are discussed below.

Cadmium and Cobalt

Material balance closures for cadmium and cobalt are roughly equivalent at 23 and 28%, respectively, thus they are discussed together. The QA/QC checks for these elements in both the fuel and stack gas show accurate spike recoveries; therefore, the analytical methods were appropriate. The concentrations of the elements detected in the fuel are only slightly above detection limits. Cadmium was only detected in one of the three fuel oil samples. Cobalt levels in the emitted gas were within five times the detection limit. Thus there is a considerable degree of uncertainty about the levels of these elements in both the fuel oil and the emitted gas.

Nickel and Vanadium

The closures for nickel and vanadium are similar at 63 and 71%, respectively. The concentrations of these elements in the fuel are well above the detection limits of the analytical method. The QA/QC checks for these elements show accurate spike recoveries. The gas concentrations are also above the detection limits. These data result in closures for both substances at or just slightly below the desired 70 to 130% range.

Table 4-4
Material Balance Closure Results for Site 103

<u>Substance</u>	<u>Mean Closure (%)</u>	<u>95% CI ^a</u>
Cadmium	23	32
Cobalt	28	12
Nickel	63	4
Vanadium	71	50

^aCI = Confidence interval.

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

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

where:

- C = Concentration, $\mu\text{g}/\text{Nm}^3$
- M = Mass measured in the sample, μg
- B = Mass measured in the field blank, μg
- SV = Sample volume (at 68°F), dscf
- 35.3 = Conversion of ft^3 to m^3 (standard)
- $\frac{528}{492}$ = Temperature correction for normal S.I. conditions, i.e., 32°F (68°F to 32°F)

Unit Energy Calculations

The unit-energy based emission factors (Table 3-4) were determined from the mass flow rate of a substance being emitted divided by the fuel heat input to the boiler during testing.

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

E	=	Mean stack emission factor, lb/10 ¹² Btu
g	=	Mean flue gas flow rate, Nm ³ /hr
c	=	Mean total flue gas concentration, μg/Nm ³
HHV	=	Mean oil higher heating value, Btu/lb
oil	=	Mean oil feed rate, lb/hr
2202.6	=	Unit conversion coefficient, lb/10 ¹² μg

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

g	=	472,400 Nm ³ /hr
c	=	469 μg/Nm ³
HHV	=	19,137 Btu/lb
oil	=	73,333 lb/hr

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

$$E = \frac{472,400 * 469 * 2202.6}{19,137 * 73,333} = 348 \text{ lb/10}^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{ng * HHV} * 2202.6 \quad (5-3)$$

where:

ng = Natural gas feed rate, scf/hr

HHV = Natural gas higher heating value, Btu/scf

Confidence Interval Calculations

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

CIs for Stream Concentrations

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

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

where:

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

β_r = Bias component

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

S_r = Standard deviation of the individual run measurements

N = Number of measurements

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

$$\beta_r = \sqrt{\sum_{i=1}^N (\beta_{pm} * \theta_{pm})^2} \quad (5-5)$$

where:

$\beta_{pm} =$ Individual bias for each run m

$\theta_{pm} =$ Sensitivity to the run $m = 1/N$

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Table 3-2 will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>Standard Deviation</u>
Nickel	465	470	471	469	3.61
Chromium, hexavalent	1.2	ND(1.0)	1.9	1.2	0.7

The 95% confidence interval for nickel is calculated using the following values inserted into Equation 5-4:

$\beta_r =$ 0 (no values below the detection limit)

$t =$ 4.3

$S_r =$ 3.61

$N =$ 3

The 95% CI (U_{TOT}) for the total nickel concentration is $9 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for hexavalent chromium is calculated the same way. Since the concentration for Run 2 is below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>
β_p	0	0.5	0

The bias component is then calculated from Equation 5-5, using these values. In this example, the sensitivity is 0.33 or $1/3$.

$$\beta_r = \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{0.5}{3}\right)^2 + \left(\frac{0}{3}\right)^2}$$

$$= 0.17$$

The standard deviation (S_r) calculated from the three individual hexavalent chromium concentrations is 0.7. Substituting these values into Equation 5-4,

$$U_{TOT} = \sqrt{(0.17)^2 + \left(\frac{4.3 * 0.7}{\sqrt{3}}\right)^2}$$

$$= 1.7 \mu\text{g}/\text{Nm}^3$$

CI's for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors and material balance closures were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A

Analytical Data from the Carnot and the Host Utility Reports

Table A-1 presents the test results for each run, as well as the results of the blank analyses. Field blanks were analyzed for multi-metals, PAHs, and volatile organic data.

Table A-1

**Mass Results for the Sample and Field Blank
Analyses for FCEM Site 103**

<u>Oil Firing</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	<u>Field Blank</u>
<u>Substance</u>				
Gas Sample Volume, Nm ³	1.43	1.44	1.52	
<u>Elements (μg)</u>				
Arsenic	4.25	16.1	12.8	4.0
Barium	835	625	2,165	2,955
Beryllium	0.5	0.6	ND(0.5)	ND(0.5)
Cadmium	6.7	10.5	2.7	0.4
Chromium	19.7	13.2	17.6	10
Chromium, hexavalent	1.67	ND(1.5)	2.90	ND(1.5)
Cobalt	22.5	20.5	16.9	ND(6.5)
Copper	10.7	15.6	8.2	8
Lead	10.6	12.0	12.9	4.5
Manganese	23.5	41.5	38.8	4.5
Mercury	ND(7)	ND(7)	ND(7)	ND(7)
Molybdenum	ND(12.5)	ND(12.5)	17.4	ND(12.5)
Nickel	885	897	936	220
Selenium	0.95	1.12	0.99	0.5
Vanadium	88.5	73.2	131.5	ND(25)

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Field Blank</u>
Gas Sample Volume, Nm ³	3.25	3.24	2.58	
<u>PAHs (μg)</u>				
Naphthalene	180	230	200	500
Acenaphthylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Acenaphthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Fluorene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Phenanthrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Fluoranthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Chrysene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Benz(a)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Benzo(b+k)fluoranthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Benzo(a)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Ideno(1,2,3-c,d)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Dibenz(a,h)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Benzo(g,h,i)perylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)

Table A-1 (Continued)

<u>Volatile Organics</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Field Blank</u>
Formaldehyde, $\mu\text{g}/\text{Nm}^3$	ND(26.8)	ND(26.8)	ND(26.8)	ND(26.8)
	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	
Benzene, $\mu\text{g}/\text{Nm}^3$	ND(8.75)	ND(8.75)	ND(8.75)	ND(8.75)
<u>Natural Gas Firing</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
<u>Volatile Organics</u>				
Formaldehyde, $\mu\text{g}/\text{Nm}^3$	ND(26.8)	ND(26.8)	165.3	704.1
Benzene, $\mu\text{g}/\text{Nm}^3$	ND(8.75)	ND(8.75)	ND(8.75)	ND(8.75)

Appendix B

FCEM Site 103 Individual Stream Concentrations

This appendix presents the results from the Site 103 sampling event during April and May 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 103 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented by the host utility and Carnot, which are shown in Appendix A. These concentrations were corrected for the field blank analysis. The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration is presented as the detection limit.

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Antimony	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	< 9	< 5		
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3	B	8.4		
Barium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	B< 170	B< 170		
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Benzene	CARB method 410A, GC	ug/Nm3			< 0.007	< 8.8
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Beryllium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	0.3	0.4		
Cadmium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	4.4	7		
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	B	2.2		
Chromium, hexavalent	Colorimetry	ug/Nm3	1.2	< 1		
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Cobalt	EPA method 6010, ICP-AES	ug/Nm3	15.7	14.2		
Copper	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	B	5.3		
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Formaldehyde	High performance liquid chromatography (HPLC)					
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	4.3	5.2		
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	13.3	25.7		
Mercury	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	< 4.8	< 4.8		
Molybdenum	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	< 9	< 9		
Naphthalene	EPA method 6010, ICP-AES	ug/Nm3				
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	464.8	470.4	B< 0.007	B< 0.007
Phenanthrene	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			< 0.007	< 0.007
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			< 0.007	< 0.007
Selenium	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3	0.3	0.4		
Thallium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	< 3.4	< 3.4		
Vanadium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	61.9	50.6		
Zinc	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	B	368.8		

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Antimony	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			<	9
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				5.8
Barium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			B<	170
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Benzene	CARB method 410A, GC	ug/Nm3	<	8.8		
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Benzo(b,k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Beryllium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	<		<	0.3
Cadmium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			8	1.5
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				5
Chromium, hexavalent	Colorimetry	ug/Nm3			1.9	
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Cobalt	EPA method 6010, ICP-AES	ug/Nm3			11.1	
Copper	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			8	0.11
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	<			
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			26.8	26.8
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				5.5
Mercury	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				22.6
Molybdenum	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				4.8
Naphthalene	EPA method 6010, ICP-AES	ug/Nm3			11.5	
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	8<			
Phenanthrene	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	<		471.2	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<			
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Thallium	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/Nm3				0.3
Vanadium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				3.4
Zinc	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			86.5	
					B	10

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run	Run
>>>> Emitted gas <<<<					
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Antimony	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Arsenic	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/nm3			
Barium	Atomic absorption spectrophotometry (AAS), flame	ug/nm3			
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Benzene	CARB method 410A, GC	ug/nm3			
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Beryllium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Cadmium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Chromium, hexavalent	Colorimetry	ug/nm3			
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Cobalt	EPA method 6010, ICP-AES	ug/nm3			
Copper	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Formaldehyde	High performance liquid chromatography (HPLC)	ug/nm3			
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	26.8		
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3			
Molybdenum	EPA method 6010, ICP-AES	ug/nm3			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/nm3			
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3			
Selenium	Atomic absorption spectrophotometry, hydride generation (HGAAS)	ug/nm3			
Thallium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Vanadium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Zinc	Atomic absorption spectrophotometry (AAS), flame	ug/nm3			

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Oil <<<<						
Antimony	EPA method 6010, ICP-AES	mg/kg	1	0.8		
Arsenic	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 1.2	< 1.2		
Barium	EPA method 6010, ICP-AES	mg/kg	0.4	0.5		
Beryllium	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.25	< 0.25		
Cadmium	Atomic absorption spectrophotometry (AAS), flame	mg/kg	0.54	< 0.25		
Chloride	Atomic absorption spectrophotometry (AAS), flame	mg/kg	250	56		
Chromium	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.25	< 0.25		
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.25	< 0.25		
Cobalt	EPA method 6010, ICP-AES	mg/kg	0.7	0.7		
Copper	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.5	0.7		
Lead	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 1.2	< 1.2		
Manganese	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.25	< 0.25		
Mercury	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 0.1	< 0.1		
Molybdenum	EPA method 6010, ICP-AES	mg/kg	< 0.3	0.5		
Nickel	Atomic absorption spectrophotometry (AAS), flame	mg/kg	10	11		
Selenium	Atomic absorption spectrophotometry (AAS), flame	mg/kg	< 1.2	< 1.2		
Sulfur	ASTM D4294	wt %	0.2	0.2		
Vanadium	EPA method 6010, ICP-AES	mg/kg	1.4	1.3		
Zinc	Atomic absorption spectrophotometry (AAS), flame	mg/kg	7.4	2.2		

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Oil <<<<						
Antimony	EPA method 6010, ICP-AES	mg/kg			0.8	
Arsenic	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	1.2	
Barium	EPA method 6010, ICP-AES	mg/kg			1.1	
Beryllium	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.25	
Cadmium	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.25	
Chloride	Atomic absorption spectrophotometry (AAS), flame	mg/kg			120	
Chromium	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.25	
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.25	
Cobalt	EPA method 6010, ICP-AES	mg/kg			0.7	
Copper	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.5	
Lead	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	1.2	
Manganese	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.25	
Mercury	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	0.1	
Molybdenum	EPA method 6010, ICP-AES	mg/kg		<	0.3	
Nickel	Atomic absorption spectrophotometry (AAS), flame	mg/kg			11	
Selenium	Atomic absorption spectrophotometry (AAS), flame	mg/kg		<	1.2	
Sulfur	ASTM D4294	wt %			0.2	
Vanadium	EPA method 6010, ICP-AES	mg/kg			1.3	
Zinc	Atomic absorption spectrophotometry (AAS), flame	mg/kg			1.3	

Table B-1 Site 103 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run	Run
>>> Oil <<<<					
Antimony	EPA method 6010, ICP-AES	mg/kg			
Arsenic	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Barium	EPA method 6010, ICP-AES	mg/kg			
Beryllium	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Cadmium	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Chloride	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Chromium	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Cobalt	EPA method 6010, ICP-AES	mg/kg			
Copper	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Lead	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Manganese	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Mercury	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Molybdenum	EPA method 6010, ICP-AES	mg/kg			
Nickel	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Selenium	Atomic absorption spectrophotometry (AAS), flame	mg/kg			
Sulfur	ASTM D4294	wt %			
Vanadium	EPA method 6010, ICP-AES	mg/kg			
Zinc	Atomic absorption spectrophotometry (AAS), flame	mg/kg			

Table B-2 Site 103 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<<						
Benzene	CAR8 method 410A, GC	ug/Nm3	<	<	<	
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	B<	B<	B<	
			8.75	8.75	8.75	
			26.8	26.8	26.8	

Appendix C

Detailed Sample Collection/Preparation/Analysis Tables

Table C-1

Reference Table for Sampling Methods - By Sample Stream

<u>Stream</u>	<u>Collection Method</u>	<u>Fraction Description</u>
Stack Gas	EPA Draft Procedure dated 8/2892	Multi-metals
	CARB Method 424	Cadmium
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410	Benzene
	ASME Modified Method 5	Semi-VOST (PAH)
	CARB Method 430	Formaldehyde
Oil	Grab	

Table C-2
Preparation Methods and Chemical
Analysis Methods Applied to Oil for FCEM Site 103

<u>Substance</u>	<u>Method Reference</u>
Nitrogen	Chemiluminescence Nitrogen Analyzer
Heating Value	ASTM D240
Sulfur	ASTM D4294
Arsenic	EPA Method 6010/7000*
Barium	EPA Method 6010/7000
Beryllium	EPA Method 6010/7000
Cadmium	EPA Method 6010/7000
Chlorine	ASTM D808
Chromium	EPA Method 6010/7000
Cobalt	EPA Method 6010/7000
Copper	EPA Method 6010/7000
Hexavalent Chromium	EPA Method 6010/7000
Lead	EPA Method 6010/7000
Manganese	EPA Method 6010/7000
Mercury	EPA Method 6010/7000
Molybdenum	EPA Method 6010/7000
Nickel	EPA Method 6010/7000
Selenium	EPA Method 6010/7000
Vanadium	EPA Method 6010/7000

*Description of analytical method provided in Appendix B.

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds Measured in Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>Volatile Organic Compounds</u>	
Sample Collection	
Tedlar Bags	CARB Method 410
Analysis by GC/MS	
Benzene	CARB Method 410
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by HPLC	
Formaldehyde	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons</u>	
Sample Collection	
MM5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by High Performance Liquid Chromatography (HPLC)	
Naphthalene	CARB Method 429
Acenaphthylene	CARB Method 429
Acenaphthene	CARB Method 429
Fluorene	CARB Method 429
Phenanthrene	CARB Method 429
Anthracene	CARB Method 429
Fluoranthene	CARB Method 429
Pyrene	CARB Method 429
Chrysene	CARB Method 429
Benzo(a)anthracene	CARB Method 429
Benzo(b+k)fluoranthene	CARB Method 429
Benzo(a)pyrene	CARB Method 429
Indeno(1,2,3-cd)pyrene	CARB Method 429
Dibenzo(a,h)anthracene	CARB Method 429
Benzo(g,h,i)perylene	CARB Method 429

Table C-4

**Summary of Preparation Procedures and Analytical Methods
Used to Measure Inorganic Compounds in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>	<u>Stack Gas</u>
<u>FCEM Target Elements by GFAAS</u>		
Preparation		
Parr Bomb Digestion for Filters	EPA Draft Procedure Dated 8/28/89	X
Analysis by GFAAS		
Beryllium	EPA Method 7091	X
Cadmium	EPA Method 7131	X
Chromium	EPA Method 7191	X
Copper	EPA Method 7211	X
Lead	EPA Method 7421	X
Manganese	EPA Method 7461	X
Vanadium	EPA Method 7911	X
<u>FCEM Target Elements by Flame AAS</u>		
Preparation		
Parr Bomb Digestion for Filters	EPA Draft Procedure Dated 8/28/89	X
Analysis by Flame AAS		
Barium	EPA Method 7080	X
Nickel	EPA Method 7520	X
<u>FCEM Target Elements by HGAAS</u>		
Preparation		
Parr Bomb Digestion for Filters	EPA Draft Procedure Dated 8/28/89	X
Analysis by HGAAS		
Arsenic	EPA Method 7061	X
Selenium	EPA Method 7741	X
<u>FCEM Target Elements by CVAAS</u>		
Preparation		
Parr Bomb Digestion for Filters	EPA Draft Procedure Dated 8/28/89	X
Analysis by CVAAS		
Mercury	EPA Method 7470	X
<u>FCEM Target Elements by ICP</u>		
Preparation		
Parr Bomb Digestion for Filters	EPA Draft Procedure Dated 8/28/89	X
Analysis by ICP		
Cobalt	EPA Method 6010	X
Molybdenum	EPA Method 6010	X

Table C-4 (Continued)

<u>Component</u>	<u>Method Reference</u>	<u>Stack Gas</u>
FCEM Target Elements by <u>Ion Chromatography</u>		
Preparation		
Extraction by Alkaline Solution	CARB Method 475	X
Analysis by IC		
Hexavalent Chromium		

Table C-5
Sampling Periods for Flue Gas and Oil

<u>Stack Gas</u>	<u>4/23/90</u>	<u>4/27/90</u>	<u>4/30/90</u>	<u>5/01/90</u>	<u>5/04/90</u>	<u>5/10/90*</u>
Technique						
Multi-Metals	1018-1231	0930-1059			0916-1044	
Cadmium	1015-1231	0930-1058			0915-1045	
Chromium	1347-1519	1217-1329			1206-1326	
MM5			0947-1302	0900-1217 1316-1603		1255-1505
Benzene				1000-1030		1255-1505
Formaldehyde					1255-1505	
<u>Oil</u>						
Technique						
Grab Sample	1200	1200			1200	

*Natural gas used as fuel.

Appendix D
Process Stream Information

Table D-1

**Process Stream Flow Rates, Stack Gas Characterization Data,
and Degree of Isokinetic Sampling**

<u>Stream</u>	<u>Units of Measure</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	<u>Average</u>
<u>Oil</u>	lb/hr	73,000	73,500	73,500	73,333
<u>Stack Gas</u>					
<u>Multi-Metals</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	
Unit Load	MW	150	150	150	150
Flow Rate	dscfm ^a	298,000	293,300	303,500	298,300
	NM ³ /hr ^b	471,800	464,300	480,500	472,200
Isokinetic	%	97.4	98.2	99.1	98.2
Moisture	%	10.9	11.0	10.9	10.9
Oxygen	%	6.4	6.0	5.9	6.1
Carbon Dioxide	%	10.6	11.0	11.0	10.9
Stack Temperature	°F	271	278	279	276
<u>Cadmium</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	
Unit Load	MW	150	150	150	150
Flow Rate	dscfm ^a	295,700	293,500	303,000	297,400
Isokinetic	Nm ³ /hr ^b	468,300	464,900	479,900	471,000
Moisture	%	103.6	99.1	102.6	101.8
Oxygen	%	12.0	12.0	11.5	10.8
Carbon Dioxide	%	6.4	6.0	5.9	6.1
Stack Temperature	°F	259	255	288	267
<u>Chromium</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 7</u>	
Unit Load	MW	150	150	150	150
Flow Rate	dscfm ^a	299,400	294,700	299,100	297,700
Isokinetic	Nm ³ /hr ^b	474,200	466,800	473,700	471,600
Moisture	%	100.4	100.1	99.2	99.9
Oxygen	%	10.9	11.2	11.5	11.2
Carbon Dioxide	%	6.4	6.0	5.9	6.1
Stack Temperature	°F	273	275	279	276
<u>PAHs</u>		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	
Unit Load	MW	150	150	150	150
Flow Rate	dscfm ^a	315,200	301,600	299,700	305,500
Isokinetic	Nm ³ /hr ^b	499,200	477,700	474,700	483,900
Moisture	%	98.54	102.70	100.55	100.6
Oxygen	%	9.5	13.0	10.3	10.9
Carbon Dioxide	%	5.5	4.9	4.8	5.0
		<u>Runs 1-3</u>			
<u>Natural Gas</u>	scfh	1,380,000			
<u>Stack Gas</u>					
<u>Formaldehyde and Benzene (Natural Gas Firing)^c</u>					
Unit Load	MW	150			
Flow Rate	dscfm ^a	269,022			
Isokinetic	Nm ³ /hr ^b	426,100			
Moisture	%	96.7			
Oxygen	%	17.6			
Carbon Dioxide	%	4.0			

^aStandard conditions: 1 atm, 68°F.

^bNormal conditions: 1 atm, 32°F.

^cNo stack gas characterization data or degree of isokinesis was reported for formaldehyde and benzene sampling during fuel oil firing.

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

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

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

Nomenclature

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

$v_r =$ Degrees of freedom in result.

For a result, r , (such as an emission factor) the uncertainty in r is calculated as:

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

The components in Equation 1 are calculated by combining the errors in the parameters used in the result calculation.

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

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

where:

$$S_{pi} = \frac{S_{pi}}{\sqrt{N_i}} \quad (4)$$

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

$$\theta_i = \frac{\partial r}{\partial P_i} \quad (5)$$

A perturbation method can also be used (useful in computer applications):

$$\theta_i = \frac{r(P_i + \Delta P_i) - r(P_i)}{\Delta P_i} \quad (6)$$

where:

$r(P_i + \Delta P_i)$ = Result calculated using a value of $(P_i + \Delta P_i)$ for P_i

$r(P_i)$ = Result calculated using the original value, P_i .

The degrees of freedom for each parameter is found from

$$v_i = N_i - 1 \quad (7)$$

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

$$v_r = \frac{S_r^4}{\sum_{i=1}^j \left[\frac{(S_{p_i} * \theta_i)^4}{v_i} \right]} \quad (8)$$

The student "t" factor in Equation 1 is related to the degrees of freedom in the result and the desired confidence interval percentage.

The precision error terms are easily generated using collected data. When calculating the S_{p_i} , care is taken in assigning degrees of freedom to each parameter. For example, if 15-minute average fuel oil flow rate data are used to generate a mean oil feed rate for each of three days, the degrees of freedom in the average fuel oil feed rate for the trip should reflect all of the 15 minute averages and not just the three daily averages.

However, as another example, duplicate analyses do not increase the degrees of freedom in an analytical result.

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

- 5% bias error in the fuel oil flow rate.
- No bias in the gas flow rate.
- No bias in analytical results unless the result is less than the reporting limit. Then one-half the reporting limit is used for both the parameter value and its bias in calculations.

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

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

The uncertainty is only calculated for the reported sampling period. The uncertainty does not represent long-term process variations. In other words, the calculated uncertainty does not include a bias term to reflect the fact that the sampled system may not have been operating (and emitting) at conditions equivalent to the average conditions for that system over a longer period. Accounting for long-term system variability would require repeated sampling trips to the same location.

The following example shows a sample calculation for the 95% confidence interval around the mean emission factor. This procedure utilizes the same procedure outlined earlier in this section and used in the computer program.

The mean stack emission factor for any substance is calculated from the following equation:

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (9)$$

where:

E =	Mean stack emission factor for arsenic, lb/10 ¹² Btu
g =	Mean flue gas flow rate, Nm ³ /hr
c =	Mean total flue gas concentration for arsenic, μg/Nm ³
HHV =	Mean oil higher heating value, Btu/lb
oil =	Mean oil feed rate, lb/hr
2202.6 =	Unit conversion coefficient, lb Btu/μg 10 ¹² Btu

The data used in the example below are generic and do not represent data collected at Site 103. The data are provided for illustrative purposes only. The data used to calculate the arsenic (As) emission factor include:

<u>Parameter</u>	<u>Units</u>	<u>Symbol</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>
As Concentration	μg/Nm ³	c	0.5	7.8	5.4	4.6
Stack Gas Flow Rate	Nm ³ /hr	g	506,292	498,308	515,677	507,000
Oil Feed Rate	lb/hr	oil	73,000	73,500	73,500	73,300
HHV	Btu/lb	HHV	19,129	19,109	19,174	19,100

The calculations for the concentration parameters used in this method are included for reference.

Total mean concentration: $4.6 \mu\text{g}/\text{Nm}^3$.

The standard deviation, S_{pc} , calculated from the individual runs is $3.7 \mu\text{g}/\text{Nm}^3$.

From Equation 4, where $N_c = 3$:

$$S_{pc} = \frac{3.7}{\sqrt{3}} = 2.1$$

As explained in Section 3, the bias, β , for analytical results above the reporting limit are assigned as zero, i.e., $\beta_{pc} = 0$.

The sensitivity is calculated from Equation 6 using the perturbation method, with a $2.1 \mu\text{g}/\text{Nm}^3$ perturbation. The perturbation for each parameter is the larger value of the normalized standard deviation, S_{pi} , or the bias error, β_{pi} .

$$\theta_c = \frac{E_{P_i + \Delta P_i} - E_{P_i}}{\Delta P_i} = \frac{E_{c=6.7} - E_{c=4.6}}{2.1}$$

$$E_{c=6.7} = \frac{g * c * 2202.6}{\text{HHV} * \text{oil}} = \frac{507,000 * 6.7 * 2202.6}{19,100 * 73,300} = 5.34$$

$$E_{c=4.6} = \frac{507,000 * 4.6 * 2202.6}{19,100 * 73,300} = 3.67$$

$$\theta_c = \frac{5.34 - 3.67}{2.1}$$

$$= 0.8$$

Similar calculations can be done for each parameter giving the following results:

	Parameter			
	$\frac{\text{g}}{\text{Nm}^3/\text{hr}}$	$\frac{\text{c}}{\mu\text{g}/\text{Nm}^3}$	$\frac{\text{HHV}}{\text{Btu}/\text{lb}}$	$\frac{\text{oil}}{\text{lb}/\text{hr}}$
Mean	507,000	4.6	19,100	73,300
S_{pi}	8,700	3.7	30	300
S_{pi}^-	5,000	2.1	20	170
N_i	3	3	3	3
β_{pi}	0	0	0	3,700
θ_i	8×10^{-6}	0.8	-2×10^{-4}	-5×10^{-5}
v_i	2	2	2	2
ΔP_i	5,000	2.1	20	3,700

The precision component is then found by root-sum-squaring the product of the parameter S_{pi}^- and the sensitivity (see Equation 3).

$$S_r = \sqrt{(\theta_g S_{pg})^2 + (\theta_c S_{pc})^2 + (\theta_{HHV} S_{pHHV})^2 + (\theta_{oil} S_{p oil})^2}$$

$$S_r = 1.68$$

The bias component is found using Equation 2:

$$\beta_r = \sqrt{(\theta_g \beta_{pg})^2 + (\theta_c \beta_{pc})^2 + (\theta_{HHV} \beta_{p HHV})^2 + (\theta_{oil} \beta_{p oil})^2}$$

$$\beta_r = 0.19$$

The degrees of freedom is found from Equation 8:

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

$$= \frac{7.97}{3.98} = 2.0$$

The student "t" factor is determined from the degrees of freedom and the desired confidence interval. For a 95% CI and $v_r = 2$, the student "t" factor is 4.3. The uncertainty is then calculated from Equation 1:

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

$$U_r = \sqrt{(0.19)^2 + (1.68 * 4.3)^2}$$

$$= 7.2$$

The emission factor is calculated from Equation 9.

$$E = \frac{g * c * 2202.6}{HHV * oil}$$

$$= \frac{507,000 * 4.6 * 2202.6}{19,100 * 73,300}$$

$$= 3.6 \text{ lb}/10^{12} \text{ Btu}$$

The emission factor for arsenic is reported as $3.6 \pm 7.2 \text{ lb}/10^{12} \text{ Btu}$.

The tables which follow are the computer-generated results from the emission factor and material balance calculations and error propagation analysis. Each table provides the results for an individual element (e.g., pp. E-15 provides emission factor error propagation results for arsenic and beryllium).

Emission Factor Results

Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	3.633038	1.73E-01	7.35E+00	7.4E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted arsenic	ug/Nm3	4.9	PREC	5.40E+01	7.41E-01	1.72E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	2.99E-02	-4.72E-05	3.67E+03	-
3) gas	stack gas	Nm3/hr	472400	PREC	2.39E-02	7.69E-06	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	1.15E-03	-4.72E-05	1.24E+03	3
5) hhv	Higher heating value	Btu/lb	19137.3	PREC	2.46E-04	-1.90E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	3.188177	1.52E-01	5.05E+00	5.1E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Cadmium	ug/m3	4.3	PREC	2.55E+01	7.41E-01	1.18E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	2.31E-02	-4.14E-05	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	1.84E-02	6.75E-06	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	8.84E-04	-4.14E-05	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	1.90E-04	-1.66E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Appendix E

Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	3.484751	1.66E-01	4.37E+00	4.4E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Chromium	ug/m3	4.7	PREC	1.91E+01	7.41E-01	1.02E+01	3
2) oil	OIL FLOW RATE	lb/hr	73333	BIAS	2.75E-02	-4.53E-05	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	2.20E-02	7.38E-06	3.49E+04	3
4) oil	OIL FLOW RATE	lb/hr	73333	PREC	1.06E-03	-4.53E-05	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	2.26E-04	-1.82E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot \text{Srbar}$

** $(Bp \cdot \text{SIGMap})^2$ FOR BIAS ERRORS; $(t \cdot \text{Spbar} \cdot \text{SIGMap})^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $\text{Sp}/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Chrome VI

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	.8897237	1.19E-01	1.33E+00	1.3E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Chrome +6	ug/m3	1.2	PREC	1.76E+00	7.41E-01	3.10E+00	3
2) baconc	emitted Chrome +6	ug/m3	1.2	BIAS	1.24E-02	7.41E-01	1.50E-01	-
3) oil	OIL FLOW RATE	lb/hr	73333	BIAS	1.80E-03	-1.16E-05	3.67E+03	-
4) gas	stack gas	m3/hr	472400	PREC	1.44E-03	1.88E-06	3.49E+04	3
5) oil	OIL FLOW RATE	lb/hr	73333	PREC	6.88E-05	-1.16E-05	1.24E+03	3
6) hhv	Higher heating value	BTU/lb	19137.3	PREC	1.48E-05	-4.64E-05	1.43E+02	3

* PRECISION COMPONENT = $t \cdot \text{Srbar}$

** $(Bp \cdot \text{SIGMap})^2$ FOR BIAS ERRORS; $(t \cdot \text{Spbar} \cdot \text{SIGMap})^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $\text{Sp}/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Cobalt

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	10.08354	4.80E-01	4.33E+00	4.4E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Cobalt	ug/m3	13.6	PREC	1.86E+01	7.41E-01	1.01E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	2.31E-01	-1.31E-04	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	1.84E-01	2.13E-05	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	8.84E-03	-1.31E-04	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	1.90E-03	-5.26E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	1.779447	8.47E-02	4.83E+00	4.8E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Copper	ug/m3	2.4	PREC	2.33E+01	7.41E-01	1.13E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	7.18E-03	-2.31E-05	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	5.75E-03	3.77E-06	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	2.75E-04	-2.31E-05	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	5.91E-05	-9.29E-05	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Lead

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	3.707182	1.77E-01	1.17E+00	1.2E+00	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Lead	ug/m3	5	PREC	1.35E+00	7.41E-01	2.71E+00	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	3.12E-02	-4.81E-05	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	2.49E-02	7.85E-06	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	1.19E-03	-4.81E-05	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	2.56E-04	-1.94E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ =PRECISION INDEX OF THE MEAN, $Sp/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	15.27359	7.27E-01	1.20E+01	1.2E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Manganese	ug/m3	20.6	PREC	1.42E+02	7.41E-01	2.79E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	5.29E-01	-1.98E-04	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	4.23E-01	3.23E-05	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	2.03E-02	-1.98E-04	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	4.35E-03	-7.97E-04	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ =PRECISION INDEX OF THE MEAN, $Sp/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	347.7337	1.66E+01	1.23E+01	2.1E+01	3.18E+00	3.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAP)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) oil	Oil FLOW RATE	lb/hr	73333	BIAS	2.74E+02	-4.52E-03	3.67E+03	-
2) gas	stack gas	m3/hr	472400	PREC	1.20E+02	7.36E-04	2.58E+04	3
3) baconc	emitted Nickel	ug/m3	469	PREC	2.44E+01	7.41E-01	1.16E+01	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	5.75E+00	-4.52E-03	9.20E+02	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	1.23E+00	-1.82E-02	1.06E+02	3

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(Bp \cdot SIGMAP)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAP)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Selenium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	.2669171	1.27E-02	1.11E-01	1.1E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAP)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Selenium	ug/m3	.36	PREC	1.22E-02	7.41E-01	2.58E-01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	1.62E-04	-3.47E-06	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	1.29E-04	5.65E-07	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	6.19E-06	-3.47E-06	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	1.33E-06	-1.39E-05	1.43E+02	3

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(Bp \cdot SIGMAP)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAP)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Vanadium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	49.30552	2.35E+00	3.38E+01	3.4E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAP)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Vanadium	ug/m3	66.5	PREC	1.14E+03	7.41E-01	7.87E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	5.51E+00	-6.40E-04	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	4.41E+00	1.04E-04	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	2.11E-01	-6.40E-04	1.24E+03	3
5) hhv	Higher heating value	BTU/lb	19137.3	PREC	4.53E-02	-2.57E-03	1.43E+02	3

* PRECISION COMPONENT = $t \cdot S_r \bar{b}$

** $(B_p \cdot \text{SIGMAP})^2$ FOR BIAS ERRORS; $(t \cdot S_p \bar{b} \cdot \text{SIGMAP})^2$ FOR PRECISION ERRORS

-WHERE $S_p \bar{b}$ = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; S_p FOR PRECISION ERRORS

Material Balance Closure Results

Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closet	total closure	%	23.14494	1.10E+00	3.24E+01	3.2E+01	2.78E+00	4.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) asec	emitted Cadmium	ug/m3	4.29	PREC	5.57E+02	5.40E+00	7.58E+00	3
2) ascc	Concentration in Oil	ppmw	.263	PREC	4.92E+02	-5.76E+01	6.66E-01	3
3) oil	Oil FLOW RATE	lb/hr	73333	BIAS	1.21E+00	-3.01E-04	3.67E+03	-
4) gas	stack gas	m3/hr	472400	PREC	4.05E-01	4.90E-05	2.25E+04	3
5) oil	Oil FLOW RATE	lb/hr	73333	PREC	1.94E-02	-3.01E-04	8.02E+02	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Cobalt

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closet	total closure	%	27.83089	1.33E+00	1.19E+01	1.2E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) asec	emitted Cobalt	ug/m3	13.73	PREC	1.40E+02	2.03E+00	1.01E+01	3
2) oil	Oil FLOW RATE	lb/hr	73333	BIAS	1.76E+00	-3.61E-04	3.67E+03	-
3) gas	stack gas	m3/hr	472400	PREC	1.41E+00	5.89E-05	3.49E+04	3
4) oil	Oil FLOW RATE	lb/hr	73333	PREC	6.73E-02	-3.61E-04	1.24E+03	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Appendix E

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closet	total closure	%	62.51445	2.98E+00	2.93E+00	4.2E+00	2.78E+00	4.4E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) oil	Oil FLOW RATE	lb/hr	73333	BIAS	8.86E+00	-8.12E-04	3.67E+03	-
2) ascc	Concentration in Oil	ppmw	10.67	PREC	4.95E+00	-5.78E+00	6.66E-01	3
3) gas	stack gas	m3/hr	472400	PREC	2.95E+00	1.32E-04	2.25E+04	3
4) asec	emitted Nickel	ug/m3	470.1	PREC	5.56E-01	1.33E-01	9.72E+00	3
5) oil	Oil FLOW RATE	lb/hr	73333	PREC	1.41E-01	-8.12E-04	8.02E+02	3

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Vanadium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closet	total closure	%	70.94545	3.38E+00	4.94E+01	5.0E+01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) asec	emitted Vanadium	ug/m3	66.5	PREC	2.37E+03	1.07E+00	7.91E+01	3
2) ascc	Concentration in Oil	ppmw	1.33	PREC	6.01E+01	-5.20E+01	2.58E-01	3
3) oil	Oil FLOW RATE	lb/hr	73333	BIAS	1.14E+01	-9.21E-04	3.67E+03	-
4) gas	stack gas	m3/hr	472400	PREC	9.13E+00	1.50E-04	3.49E+04	3
5) oil	Oil FLOW RATE	lb/hr	73333	PREC	4.38E-01	-9.21E-04	1.24E+03	3

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Appendix F

Quality Assurance/Quality Control Data

This section presents QA/QC results for the gas and fuel samples. The blank analyses are presented as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Field blank analyses were performed for the metals. A field blank consisting of a complete MM5 sampling train was analyzed for PAHs. A field blank was analyzed for formaldehyde and benzene.

Table F-2 presents the recovery results from an ash standard and an oil standard for the analytical methods used with these multi-metals. A relative percent difference (RPD) between duplicate analyses of the oil standard is also presented.

Table F-3 presents surrogate spike recovery results for PAH species for Site 103.

Table F-1
Summary of Blank Sample Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Quantity Detected</u>	<u>Detection Limit</u>
Multi-Metals				
<u>Field Blank</u>				
Arsenic	1	1	4.0	0.1 µg
Barium	1	1	2,955	250 µg
Beryllium	1	0		0.5 µg
Cadmium	1	1	0.4	0.25 µg
Chromium	1	1	10	5 µg
Chromium, hexavalent	1	0		1.5 µg
Cobalt	1	0		6.5 µg
Copper	1	1	8	0.25 µg
Lead	1	1	4.5	1.5 µg
Managanese	1	1	4.5	2.5 µg
Mercury	1	0		7.0 µg/train
Molybdenum	1	0		12.5 µg
Nickel	1	1	220	100 µg
Selenium	1	1	0.5	0.5 µg
Vanadium	1	0		25 mg
PAHs				
<u>Method Blank</u>				
Naphthalene	1	1	0.23	0.025 µg
Acenaphthylene	1	0		0.025 µg
Acenaphthene	1	0		0.025 µg
Fluorene	1	0		0.025 µg
Phenanthrene	1	0		0.025 µg
Anthracene	1	0		0.025 µg
Fluoranthene	1	0		0.025 µg
Pyrene	1	0		0.025 µg
Chrysene	1	0		0.025 µg
Benz(a)anthracene	1	0		0.025 µg
Benzo(b+k)fluoranthene	1	0		0.025 µg
Benzo(a)pyrene	1	0		0.025 µg
Indeno(1,2,3-c,d)pyrene	1	0		0.025 µg

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Quantity Detected</u>	<u>Detection Limit</u>
Dibenz(a,h)anthracene	1	0		0.025 µg
Benzo(g,h,i)perylene	1	0		0.025 µg
<u>Field Blank</u>				
Naphthalene	1	1	500	0.025 µg
Acenaphthylene	1	0		0.025 µg
Acenaphthene	1	0		0.025 µg
Fluorene	1	0		0.025 µg
Phenanthrene	1	0		0.025 µg
Anthracene	1	0		0.025 µg
Fluoranthene	1	0		0.025 µg
Pyrene	1	0		0.025 µg
Chrysene	1	0		0.025 µg
Benz(a)anthracene	1	0		0.025 µg
Benzo(b+k)fluoranthene	1	0		0.025 µg
Benzo(a)pyrene	1	0		0.025 µg
Indeno(1,2,3-c,d)pyrene	1	0		0.025 µg
Dibenz(a,h)anthracene	1	0		0.025 µg
Benzo(g,h,i)perylene	1	0		0.025 µg
<u>Volatile Organics</u>				
<u>Field Blank, Fuel Oil</u>				
Formaldehyde	1	0		25 µg/ml
Benzene	1	0		2.5 ppbv
<u>Field Blank, Natural Gas</u>				
Formaldehyde	1	1	704 µg/Nm ³	25 µg/ml
Benzene	1	0		2.5 ppbv

Table F-2
Summary of Quality Control Sample Results

Entrained Particulate Analysis			
<u>Substance</u>	<u>Detection Limit</u> <u>($\mu\text{g}/\text{m}^3$)</u>	<u>Ash Standard,</u> <u>Recovery %</u>	<u>QC Sample</u>
Arsenic	0.1	98	WS 378 Conc 5
Barium	159.5	120	Title 22 #3
Beryllium	0.3	100	WP 287
Cadmium	0.2	121	WP 287
Chromium	3.2	100	WP 287
Cobalt	4.1	111	Host In-house
Copper	0.2	98	WP 287
Lead	1	103	WP 287
Manganese	1.6	91	WP 287
Mercury	4.5	80	WP 287
Molybdenum	8	98	Host In-house
Nickel	63.8	105	WP 287
Selenium	0.3	84	WP 287
Vanadium	16	97	WP 287

Fuel Analysis			
<u>Substance</u>	<u>Detection Limit</u> <u>(mg/kg)</u>	<u>Ash Standard,</u> <u>Recovery %</u>	<u>RPD</u>
Arsenic	1.2	111	12
Beryllium	0.25	108	<1
Cadmium	0.25	85	15
Chromium	0.25	101	15
Copper	0.5	107	3
Lead	1.2	99	<1
Manganese	0.25	103	3
Mercury	0.1	100	16
Nickel	0.25	101	<1
Selenium	1.2	89	4

Table F-3

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean % Recovery</u>	<u>Std. Dev. (% Rec.)</u>
d10 Acenaphthene	5	146	48
d10 Anthracene	5	84	6
d12 Chrysene	5	89	34
d12 Benzo(a)pyrene	5	94	37

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PART II: SITE 104 EMISSIONS REPORT

PRELIMINARY DRAFT REPORT

Test Contractor:

**Carnot, Inc.
15991 Red Hill Avenue, Suite 110
Tustin, California 92680-7388**

3 March 1993

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Section 1

INTRODUCTION

This part of the document summarizes data gathered by Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 104, during a sampling program sponsored by the electric utility. The power plant, a Babcock and Wilcox radiant heat boiler, was tested during both residual fuel oil- and natural gas-firing in March of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The primary emphasis of the sampling effort was to collect valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the plant and sample locations. Section 3 discusses the analytical results for the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data based on traditional QA/QC techniques and engineering calculations. Section 5 presents example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 104

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Barium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Phosphorus	X		
Selenium	X		X
<u>Organic</u>			
Benzene		X	X
Formaldehyde			X
Polycyclic Aromatic Hydrocarbons (15)			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ C ₃ Hydrocarbons		X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section presents a description of the test site, Site 104, and gives the locations of the sampling points.

Facility Information

Site 104 is a steam electric generating unit with a capacity of approximately 350 megawatts (MW). The boiler operated at a minimum of 96% of the full rated load during the test period, and testing was conducted during both 100% oil firing and 100% natural gas firing. During the testing at Site 104, the unit was operating at a relatively consistent load level--between 335 and 342 MW.

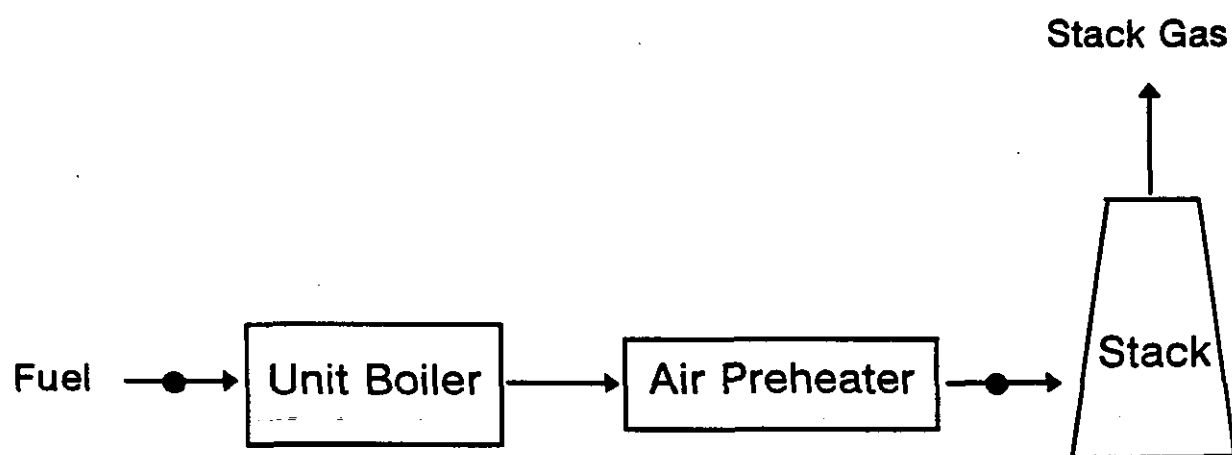
Figure 2-1 shows a process flow diagram of the unit at Site 104. Steam is generated in a Babcock and Wilcox radiant reheat boiler that can be fueled by either natural gas or residual fuel oil. No emission control devices are located downstream of the boiler.

The residual oil fuel at this site has a sulfur content of 0.35%, a higher heating value (HHV) of approximately 18,800 Btu/lb, and an ash content of 0.03 percent. The natural gas fired at Site 104 has a HHV of 22,700 Btu/lb.

Sampling Locations

The fuel to the boiler (oil or natural gas) and the flue gas emitted through the stack were the two streams sampled in this study. Figure 2-1 shows the locations of the sampling points. Brief descriptions of the sampling locations are given below:

- The oil grab samples were collected from the feedlines into the boiler.
- The natural gas analysis was done by a gas chromatograph at a pipeline metering station located at the plant boundary.
- Stack gas samples were collected at existing sample ports located in the duct between the boiler air preheater and the stack. The duct measured 21.6 feet by 15 feet at the sampling location; there were 7 ports per duct. For each isokinetic test, a four-point traverse was made at each sample port, providing a 28-point measurement grid.



● Sampling Locations

Figure 2-1. Process Flow Diagram for Site 104

Section 3

RESULTS

This section summarizes the fuel and emitted gas stream data collected at Site 104 during oil firing. These results were calculated from laboratory and field data reported by Carnot. Only formaldehyde and benzene emissions were measured during the firing of natural gas; metals, PAHs, benzene, and formaldehyde emissions were measured during fuel oil firing.

Appendix A presents the raw analytical data generated by Carnot and their contracting labs during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 104 was sampled in March 1990. Figure 3-1 shows the sequence of tests performed at this site. Samples have been numbered in chronological order. Each fuel type has its own unique set of run numbers. The run numbers are shown in Figure 3-1 and the summary tables.

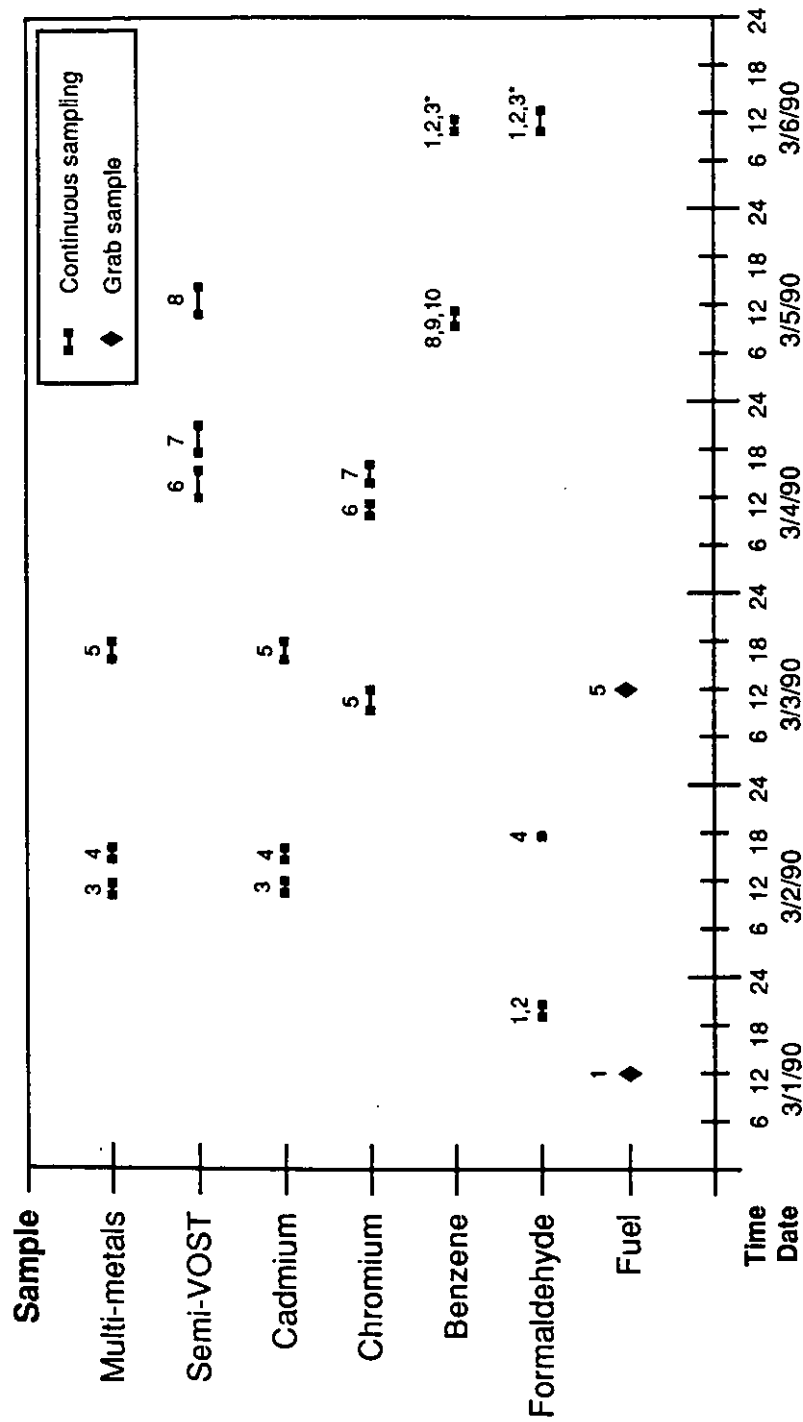
Four collection trains were used to sample the stack gas during oil firing. These trains include a Draft EPA Metals Method train for multi-metals, a CARB Method 424 train for cadmium, a CARB Method 425 train for total and hexavalent chromium, and a semi-VOST (Modified Method 5) train for polynuclear aromatic hydrocarbons (PAHs). Benzene was collected by CARB Method 410A, and formaldehyde was sampled using CARB Method 430 during both natural gas firing and oil firing. Two grab samples of the fuel oil were collected during the five-day test period. An on-line gas chromatograph analysis was performed on the natural gas feed.

Appendix C presents the details of the analytical and sampling methods used at this site.

Data Treatment

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

The convention for correcting the data against the blank results in this group of reports was to use the reagent blank analysis results when they were available. If a reagent blank analysis was not performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no correcting for blank values was done.



* Natural Gas firing.

Figure 3-1. Summary of March 1990 Flue Gas Stream and Fuel Sampling Schedules, including run numbers for Site 104

Blank Corrections

At Site 104, metals, cadmium by CARB 424, PAHs, formaldehyde, and chromium by CARB 425 were corrected for the reagent blank result, and hexavalent chromium was corrected for the field blank result.

The individual metals run measurements for both the solid and liquid phases were corrected for the reagent blank analyses. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration was flagged with a "B." When the blank correction resulted in a value less than the detection limit, the concentration was presented as ND(DL), meaning that the concentration was below the detection limit (DL), which is presented in parentheses. The test contractor has defined the term "detection limit" as three to five times the instrument detection limit.

Total Concentrations

The solid- and vapor-phase concentrations are both considered when determining the total gas stream concentration. The absence of detectable concentrations in either phase requires that conventions be established for calculating total values. For each substance, there are three possible combinations of solid- and vapor-phase concentrations in the emitted gas stream:

- Case 1: The concentrations in both phases are above the detection limits.
- Case 2: The concentrations in both phases are below the detection limits.
- Case 3: The concentration in one phase is above the detection limit, and the concentration in the other phase is below the detection limit.

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

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

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

As in the solid phase = $8.8 \mu\text{g}/\text{Nm}^3$
As in the vapor phase = $2.9 \mu\text{g}/\text{Nm}^3$
Total As in the stack gas = $11.7 \mu\text{g}/\text{Nm}^3$

Results

Case 2: The total concentration is considered to be the solid-phase detection limit.

For example, the selenium (Se) concentration in the stack gas is calculated as follows for Run 4:

Se in the solid phase = ND(3.5) $\mu\text{g}/\text{Nm}^3$
Se in the vapor phase = ND(2.2) $\mu\text{g}/\text{Nm}^3$
Total Se in the stack gas = ND(3.5) $\mu\text{g}/\text{Nm}^3$

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

For example, the beryllium (Be) concentration in the stack gas is calculated as follows for Run 5:

Total Be in the solid phase = 0.32 $\mu\text{g}/\text{Nm}^3$
Total Be in the vapor phase = ND(0.05) $\mu\text{g}/\text{Nm}^3$
Total Be in the stack gas = 0.32 $\mu\text{g}/\text{Nm}^3$

In historical data and previous FCEM data, mercury has existed primarily in the vapor phase. For Case 2, then, the total concentration in the gas stream is considered to be the vapor-phase detection limit. For Cases 1 and 3, the conventions are the same as those described above.

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

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all values are above the detection limit, the arithmetic mean concentration is calculated using the reported quantities.
- For results that include values both above and below the detection limit, one-half of the DL is used for values below the detection limit to calculate the arithmetic mean. For example:

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

By this convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8, which is less than the largest detection limit; therefore, the reported mean becomes ND(4).

<u>Analytical Values</u>	<u>Mean Value</u>
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the two residual oil fuel analyses. Only chloride, chromium, manganese, nickel, and phosphorus were detected in the samples. A mean concentration was calculated for each reported substance, along with the 95% confidence interval about the mean. The confidence interval is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean nickel concentration in the oil is 23 ± 13 mg/L (between 10 and 36 mg/L), according to the two results shown in Table 3-1]. Calculation of the confidence interval is discussed in Section 5.

Natural gas fuel was analyzed for C_1 through C_5 hydrocarbons, nitrogen, carbon dioxide, and benzene. Benzene was detected at 210 ppmv. The results for the natural gas fuel analysis are provided in Appendix D, Table D-1.

Stack Gas

Tables 3-2a, 3-2b, and 3-2c present concentration data for the emitted gas at Site 104. The probe and nozzle rinse and filter portions (solid phase) from the multi-metals train were analyzed separately from the impinger solutions (vapor phase). The solid and vapor phase analytical results, corrected for reagent blank values, are presented in Tables 3-2a and 3-2b, respectively. The hexavalent chromium concentration was corrected for the field blank analysis, since a reagent blank was not analyzed. The three measured concentrations for each phase are presented, as well as the mean and the 95% confidence interval (CI) associated with the mean.

The reagent blank corrections were fairly significant in some cases. Appendix A presents the results of the blank analyses, as well as the test results for each run.

The total concentrations from each run were averaged (according to the conventions outlined previously) to obtain an overall mean concentration for each measured substance.

Table 3-1
Oil Composition Data for Site 104

	<u>Run 1</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^a</u>
Sample Date	3/1/90	3/3/90		
Mass Flow Rate (lb/hr)	--	--	172,700 ^b	8,800
Volumetric Flow Rate (L/hr)			84,100 ^b	4,300
Ash (%)	0.04	0.02	0.03	0.13
Sulfur (%)	0.31	0.39	0.35	0.57
Higher Heating Value (Btu/lb)	18,790	18,740	18,770	320
Specific Gravity	0.931	0.932	0.9315	0.0064
<u>Elements (mg/L)</u>				
Arsenic	ND(1.1) ^c	ND(1.1)	ND(1.1)	--
Beryllium	ND(0.2)	ND(0.2)	ND(0.2)	--
Cadmium	ND(0.2)	ND(0.2)	ND(0.2)	--
Chloride	130	130	130	0
Chromium	0.28	0.36	0.32	0.51
Chromium, hexavalent	ND(0.5)	ND(0.5)	ND(0.5)	--
Copper	ND(0.4)	ND(0.4)	ND(0.4)	--
Lead	ND(1.1)	ND(1.1)	ND(1.1)	--
Manganese	0.21	1.1	0.66	5.7
Mercury	ND(0.1)	ND(0.1)	ND(0.1)	--
Nickel	22	24	23	13
Phosphorus (mg/kg)	7.9	8.8	8.4	5.7
Selenium	ND(1.1)	ND(1.1)	ND(1.1)	--

^aCI = Confidence interval.

^bFlow rate is an average of five measurements taken over a five-day period at or near full load.

^cND indicates that the concentration is below the detection limit; the detection limit is shown in parentheses.

Table 3-2a

**Stack Gas Composition Data at Site 104
Residual Oil Firing - Solid Phase ($\mu\text{g}/\text{Nm}^3$)**

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^a</u>
Sample Date	3/2/90	3/2/90	3/3/90		
Stream Flow Rate (Nm^3/hr)	1,020,000	1,090,000	1,070,000	1,060,000	89,000
Arsenic ^b	8.8 B ^e	3.8	7.7	6.8	6.5
Beryllium ^b	0.32 ^c	ND(0.05) ^{c,d}	0.36 ^c	0.23	0.45
Cadmium ^b	0.57 ^c	0.48 ^c	ND(0.33) ^c	0.40	0.53
Copper ^b	8.5	8.2	0.77 ^c B	5.6	11
Lead ^b	ND(2.5) B	ND(2.4)	4.3 B	ND(2.5)	4.4
Manganese ^b	27	3.7	13	14	29
Mercury ^b	ND(12) ^c	ND(1.5) ^c	ND(1.1) ^c	ND(15)	--
Nickel ^b	753	20	664	479	994
Selenium ^b	ND(3.5) B	ND(3.5) B	ND(4.9) B	ND(4.9)	--
Sample Date	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
	3/3/90	3/4/90	3/4/90		
Stream Flow Rate (Nm^3/hr)	1,040,000	1,050,000	1,040,000	1,045,000	15,000
Chromium, hexavalent ^f	ND(0.3) B	-- ^g	ND(0.2) B	ND(0.3)	--

^aCI = Confidence interval.

^bA reagent blank analysis was performed and used to correct the sample results.

^cA blank correction is not applied, since the substance was not detected in the blank sample.

^dND indicates that the concentration are below the detection limit, which is shown in parentheses.

^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^fA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.

^gSolid and vapor phases were combined before analysis.

Results

Table 3-2b

Stack Gas Composition Vapor Phase Data at Site 104
Residual Oil Firing ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Sample Date</u>	3/2/90	3/2/90	3/3/90		
Stream Flow Rate (Nm^3/hr)	1,020,000	1,090,000	1,070,000	1,060,000	89,000
Arsenic ^b	2.9	1.3	2.8	2.3	2.2
Beryllium ^b	ND(0.05) ^{c,d}	ND(0.05) ^d	ND(0.05) ^d	ND(0.05)	--
Cadmium ^b	0.18 ^d	0.65 ^d	0.72 ^d	0.52	0.72
Copper ^b	5.5	3.3	2.1	3.7	4.3
Lead ^b	ND(0.2) B ^e	ND(0.2) B	ND(0.2) B	ND(0.2)	--
Manganese ^b	23 ^d	6.8 ^d	-- ^f	15	101
Mercury ^b	ND(31) ^d	ND(30) ^d	ND(36) ^d	ND(36)	--
Nickel ^b	2.1	0.73 B	74	26	104
Selenium ^b	ND(2.2) ^d	ND(2.1) ^d	ND(2.3) ^d	ND(2.3)	--
<u>Sample Date</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
	3/13/90	3/4/90	3/4/90		
Stream Flow Rate (Nm^3/hr)	1,040,000	1,050,000	1,040,000	1,045,000	15,000
Chromium, hexavalent ^g	ND(0.3) B	-- ^h	ND(0.6) B	ND(0.6)	--

^aCI = Confidence Interval.^bA reagent blank analysis was performed and used to correct the sample results.^cND indicates that the concentration is below the detection limit which is shown in parentheses.^dA blank correction is not applied, since the substance was not detected in the blank sample.^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.^fImpinger was contaminated with KMnO_4 .^gA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.^hSolid and vapor phases were combined before analysis.

Table 3-2c
Stack Gas Composition Data at Site 104
Residual Oil Firing - Combined Phases ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Elements</u>					
Sample Date	3/2/90	3/2/90	3/3/90		
Stream Flow Rate (Nm^3/hr)	1,020,000	1,090,000	1,070,000	1,060,000	89,000
Arsenic ^b	12	5.1	10	9.0	9
Beryllium ^b	0.32 ^c	ND(0.05) ^{c,d}	0.36 ^b	0.23	0.45
Cadmium ^b	0.76 ^c	1.12 ^c	0.72 ^e	0.87	0.56
Copper ^b	14	11	2.9 ^e	9.5	14
Lead ^b	ND(2.5)	ND(2.4)	4.3 ^B	ND(2.5)	--
Manganese ^b	49	11	-- ^f	30	250
Mercury ^b	ND(31) ^c	ND(30) ^c	ND(36) ^c	ND(36)	--
Nickel ^b	755	21	738	505	1,041
Selenium ^b	ND(3.5)	ND(3.5)	ND(4.9)	ND(4.9)	1.5
Stream Flow Rate (Nm^3/hr)	1,100,000	1,070,000	1,080,000	1,080,000	37,000
Cadmium ^g	1.5 ^c	0.73 ^c	ND(0.4) ^c	0.79	1.6
<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>			
Sample Date	3/3/90	3/4/90	3/4/90		
Stream Flow Rate (Nm^3/hr)	1,040,000	1,050,000	1,040,000	1,045,000	15,000
Chromium ^b	4.9 ^B	7.3	4.6	5.6	4
Chromium, hexavalent ^h	ND(0.3) ^B	ND(0.8) ^B	ND(0.2) ^B	ND(0.8)	--

Table 3-2c (Continued)

<u>Substance</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Mean</u>	<u>95%CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons^b</u>					
Sample Date	3/4/90	3/4/90	3/5/90		
Stream Flow Rate (Nm ³ /hr)	1,040,000	1,160,000	1,160,000	1,120,000	169,000
Acenaphthene	0.16 B	0.24 B	ND(0.012) B	0.14	0.3
Acenaphthylene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Anthracene	ND(0.014)	ND(0.012) B	ND(0.012) B	ND(0.014)	--
Benz(a)anthracene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Benzo(a)pyrene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Benzo(b+k)fluoranthene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Benzo(g,h,i)perylene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Chrysene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Dibenz(a,h)anthracene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Fluoranthene	ND(0.014) B	ND(0.012) B	ND(0.012) B	ND(0.014)	--
Fluorene	0.014 B	0.03	0.019 B	0.018	0.030
Indeno(1,2,3-c,d)perylene	ND(0.014)	ND(0.012)	ND(0.012)	ND(0.014)	--
Naphthalene	4.9 B	3.4 B	8.8 B	5.7	7
Phenanthrene	0.016 B	0.019 B	ND(0.012) B	0.014	0.020
Pyrene	0.015 ^c	ND(0.012)	ND(0.012) ^c	ND(0.012)	--

^aCI = Confidence interval.^bA reagent blank analysis was performed and used to correct the sample results.^cA blank correction is not applied, since the substance was not detected in the blank sample.^dND indicates that the concentration is below the detection limit, which is shown in parentheses.^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.^fImpinger was contaminated with KMnO₄, so a total concentration is not presented.^gSampled by CARB Method 424.^hA field blank analysis was performed.

Table 3-2c presents the total concentrations measured for each run, as well as the mean and 95% CI associated with the total value. The sampling methods cited for total chromium and PAHs indicate that the solid and vapor fractions were collected; however, the fractions were not analyzed separately. For these substances, the results are presented only as a total value. Several of the PAHs were not detected in the stack gas at a detection limit of $0.01 \mu\text{g}/\text{Nm}^3$.

Table 3-3 compares volatile organic emissions from the same boiler fired by two different fuels--residual oil and natural gas. Benzene was not detected while firing either fuel. When the boiler was fired by natural gas, a relatively high formaldehyde level in the reagent blank resulted in only one blank-corrected formaldehyde concentration being above the detection limit. Formaldehyde was detected in two of the samples during the oil-firing test.

Appendix D, Table D-2, presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperatures, and the degree of isokinetic sampling.

Table 3-4 presents the average unit-energy-based emission factors expressed as pounds of substance emitted per 10^{12} Btu put into the boiler. The emission factors were calculated from the total mean stack gas concentrations shown in Tables 3-2c and 3-3. Section 5 contains an example calculation of this factor.

Table 3-3

**Volatile Organic Stack Emissions at Site 104
Residual Oil and Natural Gas Firing**

<u>Volatile Organic Compounds</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Residual Oil Firing</u>					
Stack Flow Rate: 1,160,000 Nm ³ /hr					
Benzene (μg/Nm ³)	ND(3.5) ^b	ND(3.5)	ND(3.5)	ND(3.5)	--
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 4</u>		
Stack Flow Rate: (Nm ³ /hr)	957,000	957,000	1,080,000	998,000	176,000
Formaldehyde ^c (μg/Nm ³)	447	295	ND(8) B ^d	249	559
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
<u>Natural Gas Firing</u>					
Stack Flow Rate: 1,130,000 Nm ³ /hr					
Benzene (μg/Nm ³)	ND(3.5)	ND(3.5)	ND(3.5)	ND(3.5)	--
Formaldehyde ^c (μg/Nm ³)	ND(9) B	ND(9) B	80 B	30	109

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit, which is shown in parentheses.

^cA reagent blank analysis was performed and used to correct the sample results.

^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-4
Stack Gas Emission Factors at Site 104
(lb/10¹² Btu)

Substance	Residual Oil Firing	
	Mean	95% CI ^a
<u>Elements</u>		
Arsenic	6.5	6.4
Beryllium	0.17	0.33
Cadmium	0.62	0.39
Chromium	3	2.6
Chromium, hexavalent	ND(0.06) ^b	--
Copper	6.8	11
Lead	ND(1.6)	--
Manganese	22	173
Mercury	ND(12)	--
Nickel	364	763
Selenium	ND(3.5)	--
<u>Polynuclear Aromatic Hydrocarbons</u>		
Acenaphthene	0.1	0.23
Acenaphthylene	ND(0.01)	--
Anthracene	ND(0.01)	--
Benz(a)anthracene	ND(0.01)	--
Benzo(a)pyrene	ND(0.01)	--
Benzo(b+k)fluoranthene	ND(0.01)	--
Benzo(g,h,i)perylene	ND(0.01)	--
Chrysene	ND(0.01)	--
Dibenz(a,h)anthracene	ND(0.01)	--
Fluoranthene	ND(0.01)	--
Fluorene	0.014	0.02
Indeno(1,2,3-c,d)perylene	ND(0.01)	--
Naphthalene	4.3	5
Phenanthrene	0.011	0.01
Pyrene	ND(0.01)	--
<u>Volatile Organic Compounds</u>		
Benzene	ND(2.5)	--
Formaldehyde	169	381
	Natural Gas Firing	
<u>Volatile Organic Compounds</u>	Mean	95% CI ^a
Benzene	ND(2.3)	--
Formaldehyde	25	-- ^c

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Btu), which is shown in parentheses.

^cInsufficient fuel gas flow rate data to calculate CI.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 104, two methods were used to evaluate data quality. First, and most important, was evaluation of the traditional QA/QC protocol for the sampling and analytical procedures used at Site 104, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 104 QA/QC data are compared to FCEM project objectives for similar QA/QC procedures. The second data assessment tool involves calculating material balances around the entire plant for various substances. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute a significant amount to the overall inlet or outlet mass rate.

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during the sampling and analysis process. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, evaluated using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. The QA/QC measures commonly used as part of the FCEM data assessment protocol, and the characteristic information obtained are summarized in Table 4-1. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data, but limits the ability to measure the various components of measurement error.

As indicated in the table, different QC checks provide different types of information, particularly pertaining to the source of inaccuracy, imprecision, and blank effects. As part of the FCEM project, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Estimates of precision and accuracy are primarily based on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 summarizes the precision and accuracy estimates.

Based on the quality control data evaluated, there is reason to conclude that the data reported are acceptable, except for the following:

- The metals sample for Run 5 was contaminated with KMnO_4 , according to the Carnot report. This indicates that the manganese results for Run 5 are not valid.
- High blank values for several PAHs, metals, and volatiles analytes may indicate suspect results.

A discussion of the precision, and accuracy is presented below for each measurement type, followed by a review stack gas sampling quality control data review, which includes discussions of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias, or persistent positive or negative deviation from the "true" value.

The efficiency of the analytical procedure in the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes and/or other quality assurance measures, as necessary. While spiked samples usually provide a measure of

Table 4-2
Types of Quality Control Data Reported

Analysis	Precision				Accuracy			Blank				
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals ^a	✓					✓						
Ultimate and Proximate ^b	✓											
Phosphorus	✓					✓						
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by ICP ^c	✓		✓			✓			✓			✓
Arsenic by AA ^d	✓								✓			✓
Cadmium ^e	✓		✓			✓			✓			✓
Mercury ^f	✓		✓			✓			✓			✓
Total Chromium by AAS	✓		✓			✓			✓			
Chromium (VI) by IC	✓					✓			✓			
PAH by GC/MS	✓								✓			
Benzene by GC/PID							✓					
Formaldehyde by HPLC			✓	✓								✓

^aIncludes As, Be, Cd, Cr, Cr(VI), Cu, Pb, Hg, Mn, Ni, P, Se, and Zn by EPA Methods 6010/7000.

^bIncluded ash, carbon, hydrogen, nitrogen, oxygen, sulfur, chlorine, and HHV.

^cIncludes Be, Cd, Cu, Pb (front 1/2), Mn, Ni, Se, and Zn.

^dIncludes As, Pb (back 1/2) by graphite furnace AA.

^eBy flame AA.

^fBy cold vapor AA.

*Zn not included in MS/MSD recoveries.

Table 4-3
Summary of Precision and Accuracy Estimates

<u>Measurement Parameter</u>	<u>How Measured</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^a</u>	<u>Accuracy^b</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Fuel Oil	Matrix Duplicate/Spike Analysis				
Arsenic		20% RPD	75-125%	14%	83%
Beryllium		20% RPD	75-125%	<1%	102%
Cadmium		20% RPD	75-125%	5%	76%
Chromium		20% RPD	75-125%	14%	96%
Copper		20% RPD	75-125%	17%	98%
Lead		20% RPD	75-125%	2%	77%
Manganese		20% RPD	75-125%	4%	89%
Mercury		20% RPD	75-125%	24%	102%
Nickel		20% RPD	75-125%	1%	88%
Selenium		20% RPD	75-125%	15%	114%
Metals in Stack Gas - Vapor Phase	Matrix Duplicate/Spike Analysis				
Arsenic (7060)		20% RPD	75-125%	NA	NA
Beryllium		20% RPD	75-125%	<1	82%
Cadmium (7131)		20% RPD	75-125%	NA	NA
Copper		20% RPD	75-125%	4	78%
Lead		20% RPD	75-125%	NA	NA
Manganese		20% RPD	75-125%	4	91%
Mercury		20% RPD	75-125%	<1	97-104%
Nickel		20% RPD	75-125%	3	83%
Selenium		20% RPD	75-125%	<1	88%
Cadmium (7130)		20% RPD	75-125%	<1	96%

Table 4-3 (Continued)

<u>Measurement Parameter</u>	<u>How Measured</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^a</u>	<u>Accuracy^b</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Stack Gas - Solid Phase	Matrix Spike/Duplicate Analysis				
Arsenic		20% RPD	75-125%	27	74%
Beryllium		20% RPD	75-125%	<1	86%
Cadmium		20% RPD	75-125%	<1	77%
Copper		20% RPD	75-125%	2	95%
Lead		20% RPD	75-125%	2	84%
Manganese		20% RPD	75-125%	1	88%
Mercury		20% RPD	75-125%	<1	97%
Nickel		20% RPD	75-125%	<1	99%
Selenium		20% RPD	75-125%	<1	82%
Total Chromium in Stack Gas ^c	Matrix Spike/Duplicate Analysis	20% RPD	75-125%	<1	97%
Hexavalent Chromium in Stack Gas ^c	Matrix Spike/Duplicate Analysis	20% RPD	75-125%	NA	92%
PAHs in Stack Gas	Surrogate Spikes				
d10-Acenaphthene		40% CV	50-150%		54-150 ^d
d10-Anthracene		40% CV	50-150%		56-97
d12-Chrysene		40% CV	50-150%		110-130
d12-Benzo(a)pyrene		40% CV	50-150%		77-98
Fuel Gas	Matrix Spike/Duplicate Analysis				
Composition & HHV				NA	NA
Benzene				NA	NA
Formaldehyde		40% CV	50-150%	26%	86-112%

^aRPD - intended to reflect sampling and analytical variability.
^b% recovery.

^cParticulate and vapor phases combined analyses.

^dPercent recoveries for blank were not included.

CV = Coefficient variation.

accuracy or bias at medium concentration levels, expressed as percent recovery, blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. Table 4-3 gives the precision estimates for metals analyses. For Site 104, precision was estimated using duplicate laboratory analyses. Laboratory duplicate results give an estimate of precision based on laboratory variability alone, and Table 4-3 presents precision objectives for sampling plus analytical variability. Although there was no way to evaluate sampling variability at this site, analytical variability generally seemed to be within the stated objectives for fuel oil and stack gas. The only exception to this was mercury measured in the fuel oil. The relative percent difference (RPD) for the sample and duplicate was 24%, slightly outside the acceptance criteria of 20 percent. The RPD for mercury measurements in the stack gases were well within the acceptance criteria. Therefore, this exception should not be of significant concern.

Measurement data for replicate runs for oil analyses (shown in Table 3-1) show good overall repeatability. In general, the replicate runs show good overall repeatability for trace metal analyses in the stack gas, with the following exceptions:

- Lead had one value (Run 3) a factor of three lower than the other measured parameters. Before being corrected for the blank value, these values measured were well above the detection limit for lead. These values occurred in the front filter and probe/nozzle wash only; the reagent and filter blank values were high for lead.
- Values measured for manganese were not consistent from run to run and differed by orders of magnitude, although all values measured were well above the detection limit. This occurred in both the vapor and particulate sample fractions. However,

analytical notes indicate that the sample from Run 5 was contaminated with KMnO_4 ; therefore, the results for manganese for Run 5 should not be considered valid.

- Nickel values were not consistent from run to run, and the trends observed in the impinger catch measurements were not duplicated in the front filter and probe/nozzle sample fractions. The values were all measured at levels above the detection limit for nickel. Field blank results for this data set were high for both the vapor and particulate fractions.
- Selenium values measured in the particulate fraction were higher during Run 3 than during the other runs; however, the field blank measured for that set was also high.

Precision estimates are best made for samples measured at concentrations similar to average sample concentrations. This is important because the precision of a measurement will change as the concentration in the sample approaches the detection limit for that method. Because of the variability in replicate run data, the analytical duplicates may not always accurately reflect variability for all of the lead, manganese, nickel, and selenium results.

It is not clear whether differences in replicate run concentrations were due to changes in process conditions between test runs or sampling variability. These variations, which indicate the range of concentrations possible in the stream, should be considered when using these data. No data exist to support the conclusion that the measured values reflect anything other than normal process stream variations.

At low levels, measured near the detection limit (e.g., cadmium and beryllium), the absolute difference between replicate values was small, whereas the relative differences were large. This would be expected for measured values that approach zero. The data should not be affected by this.

Accuracy. Accuracy estimates for metals analyses, shown in Table 4-3, are based on matrix spike recovery data. Generally, metal recoveries were within the accuracy objective shown. The only exception was the recovery of arsenic in the particulate stream of the stack gas, where the recovery was 74 percent. This recovery is very close to the minimum acceptance criteria (75%); however, this exception should not be of significant concern.

Blanks. In general, reagent blanks and field blanks were taken for stack gas metals; however, no blanks were taken for fuel oil analyses. Levels measured in the blanks varied from "not detected" to up to hundreds of times the detection limit (for nickel). For the several compounds listed below, field and reagent blank contamination occurred at or near the concentration measured for the following compounds:

- Cadmium;
- Chromium (VI);
- Copper;
- Lead;
- Manganese; and
- Nickel.

High blank values generally indicate bias in the data. At Site 104, one reagent blank and one field blank were taken for the metals. Reagent blanks indicate the blank effects of the reagents used, but they may also indicate blank effects that arise during analysis. Field blanks reflect total sampling and analytical effects. The level of blank contamination for the metals listed above would indicate some bias (high) in the data; however, the number of blanks values measured does not allow this bias to be quantitated.

PAHs

Precision. The only data available to estimate precision for PAH measurements at Site 104 are replicate run analyses. Although replicate runs reflect both sampling and analytical variability (as specified by the precision objectives noted in Table 4-3), they also reflect changes in the process conditions. The data for replicate runs show good overall repeatability. At very low concentrations (near the detection limit) the absolute difference between measured values was small, although the relative difference was large. This is expected as the measured values approach zero. In general, we can conclude that precision objectives for PAHs have been met.

Accuracy. Table 4-3 lists the accuracy estimates for PAHs. Recoveries for PAHs at Site 104 ranged from 54-130%, which is well within specifications, indicating that the data met specifications and can be considered valid.

Blanks. Field blanks showed less than detection limit concentrations for all but phenanthrene and anthracene. For those compounds, the concentrations in the blanks were at least half the concentrations in the sample. This may indicate sampling, analytical, or media contamination, and it could indicate some positive bias in the data for those compounds. However, the quantity of data does not allow a qualitative determination of the contribution of bias in these samples.

Volatile Compounds

Precision. Both benzene and formaldehyde were measured at Site 104. The only data available for evaluating the precision of benzene measurements are replicate run analyses. The results of the replicate run analyses were below the detection limits for all samples measured for Site 104. This indicates consistent results across replicate runs.

The precision of formaldehyde results was estimated by calculating the RPD for a matrix spike/ matrix spike duplicate pair. In this case, the RPD was 26%, which compares favorably with the precision objective of 40% RPD.

Accuracy. No data were generated to evaluate the accuracy of the benzene data; therefore, there is no basis for concluding that the benzene values at Site 104 are invalid.

Matrix spike, matrix spike duplicate results were used to determine the accuracy of the formaldehyde results. This type of spike provides information relating to matrix and other effects. The objectives for formaldehyde recovery are 50-150%, and matrix spike/matrix spike duplicates for Site 104 were 86 and 112%, well within the data quality objectives.

Blanks. No blanks were submitted with the samples analyzed for benzene. The reagent blanks analyzed for formaldehyde showed concentrations close to those found in the samples, which may indicate a positive bias in the formaldehyde data, although this bias cannot be quantitated with available data.

Stack Gas Sampling Quality Control

Sampling quality control was addressed in a summary of the quality assurance program used by Carnot and in a letter of certification from the California Air Resources Board. Also included were calibration records for the dry gas meters, a table outlining the schedule, and procedures used to calibrate these and other equipment, and CEM standard certification sheets.

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location.

Sampling accuracy is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases that may be caused by contamination of the equipment or location or operator errors. Blanks were included for all tests except the CARB 410 (benzenes), which are grab bag samples.

The representativeness of sampling depends on precision and accuracy and also on the characteristics of the sampling locations. The sampling location, on the inlet duct to the stack, was not ideal in terms of undisturbed flow distances upstream and downstream of the ports, but a large enough number (28) of traverse points were used to ensure representativeness. The isokinetic variation is a measure of the operational performance of sampling for particulate matter and can be used to indicate precision, with consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation. Corrections for blank artifacts are discussed in Section 3. Lead, manganese, nickel, and selenium concentrations varied by run; however, other samples gave no indication of process upsets. These concentration variations may reveal the natural range of possible concentrations for these analytes. The QC data presented here give reason for concluding that most of the data are representative. Specific exceptions to this are noted in the preceeding discussions.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011, using the same acidified 2,4-dinitro-phenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 method for semivolatile organic compounds, dioxins, and furans is well established for both sampling and analysis. The EPA multi-metals procedure is still in the evaluation process but is becoming widely accepted and is documented enough to be considered a standard method. This particular test used an in-stack filter system instead of the heated external type described in the method, but the filter holder was Teflon lined and the filter itself was Teflon coated to minimize interferences and contamination. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures, although in this test a sodium bicarbonate solution was used instead of the caustic. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag.

Sampling completeness is mainly a function of generating the requisite number of samples and proper documentation. In particular, the data necessary for calculating the results, including the calibration of the equipment and all pertinent entries on the run data sheets, should be present. Calibration data provided in this report were adequate, and sampling sheets were acceptably filled out. The necessary number of samples were successfully taken and sample custody was transferred properly to the analytical laboratories. One manganese concentration (Run 5) should be considered invalid because of contamination of the sample; however, no other significant data losses were reported. Triplicate runs were performed for stack gas measurements, consistent with the standard FCEM approach. Only two samples of fuel oil and one of natural gas were collected.

Material Balance Results

The streams considered in the material balance for Site 104 were the fuel oil as input and the flue gas as output. Stream flow rates and concentrations, as well as the bias and precision errors associated with these measurements, were entered into a statistical error propagation model to estimate the overall material balance closure. A detailed discussion of the statistical error propagation analysis appears in Appendix E.

Material balance closure is defined as the ratio of outlet to inlet mass. A 100% closure indicates perfect agreement between inlet and outlet mass flow rates. When trace substances are analyzed, closures of between 70% and 130% have been set as a goal for the FCEM project--a range that reflects a typical level of analytical uncertainty. Closures within this range indicate that inlet and outlet stream mass rates are statistically equivalent. Poor closure may indicate measurement problems in one or more of the sample matrices.

The measured oil flow rate was compared with the generating capacity heat input using the oil flow rate, HHV, and an efficiency of 30 percent. The flow rate and generating capacity were in good agreement. Both the oil and stack gas flow rates have small confidence intervals, indicating good precision in their measurements.

Table 4-4 presents the chromium, manganese, and nickel material balance closures and the error propagation analysis results. None of the mean closure values were in the desired range, although the uncertainty term for two of the substances encompass the range. Material balances were not calculated for other elements because the concentrations in the fuel oil were below detection limits. An ash balance could not be performed because particulate loadings were not measured in the stack gas.

Chromium

The material balance closure for chromium, $22 \pm 13\%$, is outside of the desired range. The QA/QC checks for these elements in both the fuel and stack gas show accurate spike recoveries. The results for chromium in the fuel oil (0.28 to 0.36 mg/L) were near the detection limit of 0.2 mg/L.

Manganese

The material balance closure, $57 \pm 190\%$, is nominally outside of the desired range. The impinger for Run 5 was contaminated with KMnO_4 ; therefore, the mean manganese concentration was calculated from the results of the other two test runs. The measured flue gas concentrations of manganese are highly variable, leading to a large 95% CI. The matrix spike recoveries are acceptable for both the solid- and vapor-phase analyses. The spike recovery of manganese in the fuel oil was good (102%).

Table 4-4
Material Balance Closure Results for Site 104

<u>Substance</u>	<u>Mean Closure (%)</u>	<u>95% CI ^a</u>
Chromium	22	13
Manganese	57	190
Nickel	28	58

^aCI = Confidence interval.

Nickel

The nickel material balance closure, $28 \pm 58\%$, is outside of the desired range. Both the solid phase and gas concentrations for Run 4 were an order of magnitude lower than the values for Runs 3 and 5. The spike recoveries were within acceptable limits for the fuel oil and stack gas samples.

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

$$C = \frac{(M - B)}{SV * F} * 35.3 * \frac{520}{492} \quad (5-1)$$

where:

- C = Concentration, $\mu\text{g}/\text{Nm}^3$
- M = Mass measured in the sample, μg
- B = Mass measured in the blank (reagent or field), μg
- SV = Sample volume (at 68°F), dscf
- F = Sample correction factor (see below)
- 35.3 = Conversion of ft^3 to m^3 (standard)
- $\frac{520}{492}$ = Temperature correction for normal conditions, i.e., 32°F (60°F to 32°F)

The sample correction factor depends on the specific analytical procedure where:

- F = 0.95 for the multi-metals train since 5% of the sample was removed for mercury analysis.
- F = 1.0 for mercury, cadmium (by CARB 424), benzene, formaldehyde, and PAHs.

Example Calculations

- $F = 0.5$ for total and hexavalent chromium since one-half of the sample was used for each analysis.

Note that the mercury results were corrected for the sample aliquot in the analytical reports prepared by the lab. All concentrations are presented under normal conditions (32° F, 1 atm).

Unit Energy Calculations

The unit-energy-based emission factors (Table 3-4) were determined from the mass flow rate of a substance being emitted, divided by the fuel heat input to the boiler during testing.

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

E	=	Mean stack emission factor, lb/10 ¹² Btu
g	=	Mean flue gas flow rate, Nm ³ /hr
c	=	Mean total flue gas concentration, μ g/Nm ³
HHV	=	Mean oil higher heating value, Btu/lb
oil	=	Mean oil feed rate, lb/hr
2202.6	=	Mass conversion coefficient, lb/10 ¹² μ g

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

g	=	1,060,000 Nm ³ /hr
c	=	505 μ g/Nm ³
HHV	=	18,770 Btu/lb
oil	=	172,700 lb/hr

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

$$E = \frac{1,060,000 * 505 * 2202.6}{18,770 * 173,000} = 364 \text{ lb}/10^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{h} * 2202.6 \quad (5-3)$$

where:

h = Heat input (estimated by Carnot), Btu/hr

Confidence Interval Calculations

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

CIs for Stream Concentrations

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

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

where:

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

β_r = Bias component

Example Calculations

- t = Student's "t" factor for 97.5 percentile (one-tail) and N-1 degrees of freedom
- S_r = Standard deviation of the individual run measurements
- N = Number of measurements

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

$$\beta_r = \sqrt{\sum (\beta_{pm} * \theta_{Tpm})^2} \quad M=1\text{ton} \quad (5-5)$$

where:

- β_{pm} = Individual bias for each run m
- θ_{pm} = Sensitivity to the run m = 1/N

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Tables 3-2a, 3-2b, and 3-2c, will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Fraction</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>
Arsenic	Solid Phase	8.8	3.8	7.7
Arsenic	Vapor Phase	2.9	1.3	2.8
		<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>
Acenaphthene	Total	0.16	0.24	ND(0.012)

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

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>Standard Deviation</u>
Arsenic	12	5.1	10	9.0	2.6

The 95% confidence interval is calculated by inserting the following values into Equation 5-4:

$$\beta_r = 0 \text{ (no values below the detection limit)}$$

$$t = 4.3$$

$$S_r = 2.6$$

$$N = 3$$

The 95% CI (U_{TOT}) for the total arsenic concentration is $9 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for acenaphthene is calculated the same way. Since the concentration for Run 15 is below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>
β_p	0	0	0.006

The bias component is then calculated from Equation 5-5, using these values. In this example, the sensitivity is 0.33 or 1/3.

$$\beta_r = \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{0}{3}\right)^2 + \left(\frac{0.006}{3}\right)^2}$$

$$= 0.002$$

The standard deviation (S_r) calculated from the three individual acenaphthene concentrations is 0.119. Substituting these values into Equation 5-4,

Example Calculations

$$U_{TOT} = \sqrt{(0.002)^2 + \left(\frac{4.3 * 0.119}{\sqrt{3}}\right)^2}$$
$$= 0.30 \mu\text{g}/\text{Nm}^3$$

CI's for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors and material balance closures were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A
Analytical Data from the Carnot Report

Table A-1 presents the test results for each run, as well as the results of the blank analyses. Blanks were analyzed for metals in both the solid and vapor phase fractions. A field blank and method analysis was performed for PAHs.

Table A-1

**Results of the Sample, Field Blank, and
Reagent Blank Analyses for FCEM Site 104**

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
<u>Oil Firing</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
<u>Individual Sampling Train</u>					
Gas Sample Volume, Nm^3	1.303	1.299	1.298		
Cadmium	2.00	1.00	ND(0.5)	ND(0.5)	ND(0.5)
Gas Sample Volume, Nm^3	1.321	1.303	1.295		
Chromium ⁺⁶ (particulate)	1.72	ND(1.1) *	0.40	3.52	--
Chromium ⁺⁶ (vapor)	ND(0.69)	--	ND(0.73)	3.56	--
Chromium	9.5	12.5	9.0	--	3.0
	<u>Run 3</u>	<u>Run 4</u>	<u>Run 6</u>		
<u>Elements, Multi-metals</u>					
Gas Sample Volume, Nm^3	1.254	1.302	1.232		
<u>Vapor Phase</u>					
Arsenic	3.8	2	3.6	ND(0.28)	0.38
Beryllium	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)
Cadmium	0.36	0.94	0.98	1.1	0.14
Copper	9.1	6.6	4.9	4.6	2.5
Lead	1.7	2.0	1.6	3.1	6.4
Manganese	27	8.4	290 ^b	3.0	ND(0.62)
Mercury ^c	ND(37)	ND(42)	ND(46)	ND(37)	NR(20)
	ND(1.7)	ND(1.2)	ND(1.4)	ND(1.3)	NR(2.0)
Nickel	3.9	2.3	87	31	1.4
Selenium	ND(2.8)	ND(2.8)	ND(2.8)	ND(2.8)	NR(3.1)
<u>Solid Phase</u>					
Arsenic	12.5	6.7	11	5	2
Beryllium	0.38	ND(0.06)	0.42	0.46	ND(0.07)
Cadmium	0.68	0.59	ND(0.41)	1.3	ND(0.41)
Copper	19	19	9.8	18	8.9
Lead	8.3	25	40	36	35
Manganese	36	8.8	19	86	4.2
Mercury	ND(14)	ND(25)	ND(13)	ND(28)	ND(22)
Nickel	900	27	780	900	2.5
Selenium	8.2	ND(3.1)	ND(4.1)	6	14

Table A-1 (Continued)

	<u>Mass Detected (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
<u>PAHs</u>					
Gas Sample Volume, Nm ³	1.83	2.07	2.04		
Naphthalene	30	28	39	13	21
Acenaphthylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Acenaphthene	1.7	1.9	0.28	ND(	1.4
Fluorene	0.074	0.11	0.087	0.089	0.49
Phenanthrene	0.13	0.14	0.1	0.14	0.1
Anthracene	0.091	0.076	0.053	0.068	0.073
Fluoranthene	0.027	0.035	ND(0.025)	0.035	0.026
Pyrene	0.027	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)
Chrysene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benz(a)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(b + k)fluoranthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(a)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Ideno(1,2,3-c,d)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Dibenz(a,h)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(g,h,i)perylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
<u>Volatile Organics</u>					
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 4</u>		
Gas Sample Volume, Nm ³	0.011	0.018	0.019		
Formaldehyde	7.78	0.88	0.87	3.415	2.86
<u>Natural Gas Firing</u>					
<u>Volatile Organics</u>					
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm ³	0.0265	0.0276	0.0247		
Formaldehyde	0.95	2.9	4.84	3.415	2.86
Benzene	ND(1.0)	ND(1.0)	ND(1.0)		

^aParticulate and vapor fractions were combined before analysis. Reported result is total Cr ⁺⁶.

^bImpinger was contaminated by KMnO_4 , according to the Carnot report.

^cTwo impingers analyzed for mercury--the standard multi-metals train impinger and the potassium permanganate impinger.

Appendix B
Individual Stream Concentrations

This appendix presents the results from the Site 104 sampling event in March 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 104 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were corrected from the raw analytical data presented in the Carnot report, which are shown in Appendix A. These concentrations are corrected for the reagent or field blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis and the field blank analysis.

The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration is presented as the detection limit.

The stack (emitted) gas at Site 104 was sampled for cadmium by two different methods--Draft EPA Metals Method and CARB Method 424. The results for the CARB Method 424 test are presented as "Emitted gas, alternate."

Table B-1 Site 104 Stream Concentrations During 011-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3		11.7		5.1
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzo(b,k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Beryllium	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		0.32	<	0.05
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		0.75		1.13
Chromium, hexavalent	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				
Chrysene	Ion chromatography (IC)	ug/nm3				
Copper	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Dibenz(a,h)anthracene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		14		11.5
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Formaldehyde	HPLC, reversed-phase	ug/nm3	447	295	B<	8
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			B<	2.4
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		2.5	B<	10.5
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3		50	<	30
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3		31	<	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		755	B	20.5
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3		3.5	B<	3.5
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		6	B	253
>>>> Emitted gas, alternate <<<<						
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/nm3		1.5		0.77

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.016	B	0.012
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	0.014	B<	0.012
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	10			
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv				1
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.36			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.72			
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	4.9	7.3	4.63	
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3	B<	0.81	B<	0.184
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B			
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	0.014	B<	0.012
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	0.014	0.03	B<
Formaldehyde	HPLC, reversed-phase	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.014	<	0.012
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	B			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	261			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	36			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	4.9	B	8.8
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	738			
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.016	B	0.012
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.015		<	0.012
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	B<			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B	8.6		
>>>> Emitted gas, alternate <<<<						
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	<	0.39		

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run
>>>> Emitted gas <<<<					
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv	<	1	<
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Beryllium	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Chromium, hexavalent	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Chrysene	Ion chromatography (IC)	ug/Nm3			
Copper	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Dibenz(a,h)anthracene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Formaldehyde	HPLC, reversed-phase	ug/Nm3			
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
>>>> Emitted gas, alternate <<<<					
Cadmium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			2.9	1.3
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 0.05	< 0.05
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.18	0.65
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			5.5	3.3
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			8<	0.2
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			23	6.8
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 31	< 30
Nickel	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			2.1	0.73
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 2.2	< 2.1
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			6	9.8
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			8.8	3.8
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.32	< 0.05
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.57	0.48
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			8.5	8.2
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			2.5	2.4
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			< 27	< 3.7
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 12	< 15
Nickel	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			753	19.8
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			3.5	3.5
Zinc	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			8<	8<
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l	< 1.1			
Beryllium	EPA method 6010	mg/l	< 0.2			
Cadmium	EPA method 6010	mg/l	< 0.2			
Carbon	Not specified	wt %	84.27			
Chloride	ASTM D808-87	mg/l	130			
Chromium	EPA method 6010	mg/l	0.28			
Chromium, hexavalent	EPA method 6010	mg/l	< 0.5			
Copper	EPA method 6010	mg/l	< 0.4			
Hydrogen	Not specified	wt %	12.26			
Lead	EPA method 6010	mg/l	< 1.1			
Manganese	EPA method 6010	mg/l	0.21			
Mercury	EPA method 6010	mg/l	< 0.1			
Nickel	EPA method 6010	mg/l	22			

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	2.8			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.72			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	2.12			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	0.2			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	248			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	74			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	<			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	8.6			
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	7.7			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.36			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.77			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	4.3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	12.6			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	664			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	<			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.7			
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Not specified	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Not specified	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run
>>>> Emitted gas, gas phase <<<<					
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
>>>> Emitted gas, solid phase <<<<					
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3			
>>>> Oil <<<<					
Arsenic	EPA method 6010	mg/l			
Beryllium	EPA method 6010	mg/l			
Cadmium	EPA method 6010	mg/l			
Carbon	Not specified	wt %			
Chloride	ASTM D808-87	mg/l			
Chromium	EPA method 6010	mg/l			
Chromium, hexavalent	EPA method 6010	mg/l			
Copper	EPA method 6010	mg/l			
Hydrogen	Not specified	wt %			
Lead	EPA method 6010	mg/l			
Manganese	EPA method 6010	mg/l			
Mercury	EPA method 6010	mg/l			
Nickel	EPA method 6010	mg/l			

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Oxygen	Not specified	wt %	1.98			
Phosphorus	EPA method 6010	mg/l	7.36			
Selenium	EPA method 6010	mg/l	<			
Sulfur	ASTM D129-64	wt %	0.31			
Zinc	EPA method 6010	mg/l	0.98			
>>>> Oil, duplicate <<<<						
Arsenic	EPA method 6010	mg/l	<			
Beryllium	EPA method 6010	mg/l	<			
Cadmium	EPA method 6010	mg/l	<			
Carbon	Not specified	wt %	83.9			
Chloride	ASTM D808-87	mg/l	130			
Chromium	EPA method 6010	mg/l	0.36			
Chromium, hexavalent	EPA method 6010	mg/l	<			
Copper	EPA method 6010	mg/l	<			
Hydrogen	Not specified	wt %	11.82			
Lead	EPA method 6010	mg/l	<			
Manganese	EPA method 6010	mg/l	1.1			
Mercury	EPA method 6010	mg/l	<			
Nickel	EPA method 6010	mg/l	24			
Oxygen	Not specified	wt %	3.76			
Phosphorus	EPA method 6010	mg/l	8.2			
Selenium	EPA method 6010	mg/l	<			
Sulfur	ASTM D129-64	wt %	0.39			
Zinc	EPA method 6010	mg/l	0.92			

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				
>>> Oil, duplicate <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Not specified	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Not specified	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				

Table B-1 Site 104 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run	Run
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				
>>>> Oil, duplicate <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Not specified	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Not specified	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				

Table B-2 Site 104 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<						
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv	< 1	< 1	< 1	
Formaldehyde	HPLC, reversed-phase	ug/m ³	B< 9	B< 9	B 80.3	

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Table C-1
Stream Sampling Methods

<u>Sampling Stream</u>	<u>Collection Method</u>	<u>Substance Measured</u>
Stack Gas	Draft EPA Metals Method	Metals
	CARB Method 424	Cadmium
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410A	Benzene
	CARB Method 429	PAH
	CARB Method 430	Formaldehyde
Oil	Grab	Metals

Table C-2

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Inorganic Components Measured in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>FCEM Target Elements by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by GFAAS	
Arsenic	EPA Method 7060
<u>FCEM Target Elements by Flame Atomic Absorption Spectrophotometry (AAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by Flame AAS	
Chromium	EPA Method 7190
Cadmium ^a	
<u>FCEM Target Elements by Cold Vapor Atomic Absorption Spectrophotometry (CVAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by CVAAS	
Mercury	EPA Method 7470
<u>FCEM Target Elements by Inductively Coupled Argon Plasma Emission Spectrometry (ICP-AES)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by ICP-AES	EPA Method 6010
Beryllium	
Cadmium ^b	
Copper	
Lead	
Manganese	
Nickel	
Selenium	
<u>FCEM Target Elements by Ion Chromatography (IC)</u>	
Preparation	
Extraction by Alkaline Solution	CARB Method 425
Analysis by IC	
Hexavalent Chromium	

^aImpinger analyses for multi-metals train; total analyses for CARB 422 train.

^bFilter analyses for CARB 422 train.

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>Benzene</u>	
Sample Collection	
Tedlar Bags	CARB Method 410
Analysis by Gas Chromatography/PhotoIonization Detector (GC/PID)	CARB Method 410
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by High Performance Liquid Chromatography (HPLC)	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>	
Sample Collection	
Modified Method 5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by GC/MS	CARB Method 429
Naphthalene	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Chrysene	
Benz(a)anthracene	
Benzo(b+k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-c,d)pyrene	
Dibenz(a,h)anthracene	
Benzo(g,h,i)perylene	

Table C-4

**Preparation Methods and Chemical Analysis
Methods Applied to Oil for Site 104**

<u>Substance</u>	<u>Method Reference</u>
<u>FCEM Target Elements</u>	
Arsenic	EPA Method 6010, ICP-AES
Beryllium	EPA Method 6010, ICP-AES
Cadmium	EPA Method 6010, ICP-AES
Chloride	ASTM D808-87
Chromium	EPA Method 6010, ICP-AES
Chromium, hexavalent	EPA Method 6010, ICP-AES
Copper	EPA Method 6010, ICP-AES
Lead	EPA Method 6010, ICP-AES
Manganese	EPA Method 6010, ICP-AES
Mercury	EPA Method 6010, ICP-AES
Nickel	EPA Method 6010, ICP-AES
Selenium	EPA Method 6010, ICP-AES

Table C-5

Sampling Periods for Flue Gas and Oil

<u>Stack Gas</u>	<u>3/01/90</u>	<u>3/02/90</u>	<u>3/03/90</u>	<u>3/04/90</u>	<u>3/05/90</u>	<u>3/06/90</u>
Multi-metals		0940 - 1209 1426 - 1643 0934 - 1219 1426 - 1648	1601 - 1810			
Cadmium		0934 - 1219 1426 - 1648	1559 - 1812			
Chromium			0922 - 1156	0944 - 1102 1405 - 1620		
Semi-VOST				0932 - 1300 1502 - 1834	0844 - 1205	
Benzene					0925 - 1105	0940-1115 *
Formaldehyde	1905-1935 1953-2023	1730-1800				1032-1102 * 1110-1140 * 1147-1217 *

OilSample ^bSample ^bNatural Gas

Grab Sample Analysis

on-line

* Natural gas firing.

^b Exact time unknown.

Appendix D
Process Stream Flow Rates

Table D-1
Natural Gas Analysis March 6, 1990

<u>Substance</u>	<u>Volume %</u>
CH ₄	92.702
C ₂ H ₆	4.172
C ₃ H ₈	0.634
C ₄ H ₁₀ -I	0.043
C ₄ H ₁₀ -N	0.053
C ₅ H ₁₂ -I	0.017
C ₅ H ₁₂ -N	0.013
C ₆ H ₆	0.021
CO ₂	1.399
N ₂	0.954

HHV = 1036.0 Btu/scf.

Fuel factor (60°F) = 8,456 dscf/10⁶Btu @ 0% O₂.

Molecular weight = 17.34 lb/lbmole.

Table D-2

**Process Stream Flow Rates, Stack Gas Characterization Data,
Unit Operating Load, and Degree of Isokinetic Sampling**

<u>Stream</u>	<u>Units of Measure</u>				<u>Average</u>
<u>Residual Oil Firing</u>					
<u>Stack Gas</u>					
<u>Benzene</u>		<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>	
Flow Rate	dscfm ^b	719,645	719,645	719,645	719,645
	Nm ³ /hr ^c	1,160,000	1,160,000	1,160,000	1,160,000
<u>Formaldehyde</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 4</u>	
Flow Rate	dscfm ^b	595,108	595,108	671,447	998,000
	Nm ³ /hr ^c	957,000	957,000	1,080,000	
<u>Natural Gas Firing</u>					
<u>Stack Gas</u>					
<u>Benzene</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^b	701,757	701,757	701,757	701,757
	Nm ³ /hr ^c	1,130,000	1,180,000	1,130,000	1,130,000
<u>Formaldehyde</u>		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^b	701,757	701,737	701,757	701,757
	Nm ³ /hr ^c	1,130,000	1,130,000	1,130,000	1,130,000
<u>Oil</u>	lb/hr				173,000 ^a
	L/hr				84,100
<u>Stack Gas</u>					
<u>Multi-Metals</u>		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	
Flow Rate	dscfm ^b	634,443	677,726	665,816	659,329
	Nm ³ /hr ^c	1,020,000	1,107,000	1,070,000	1,060,000
Isokinetic	%	99.75	98.95	95.98	98.23
Moisture	%	9.4	10.2	10.4	10.0
Oxygen	%	5.62	5.52	5.79	5.64
Carbon Dioxide	%	10.73	11.46	11.05	11.08
Stack Temperature	°F	268.7	267.9	266.0	267.5

Table D-2 (Continued)

<u>Stream</u>	<u>Units of Measure</u>	<u>Average</u>			
<u>Chromium</u>					
		<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	647,615 1,040,000	654,493 1,050,000	648,840 1,040,000	650,316 1,045,000
Isokinetic	%	102.95	100.47	100.72	101.38
Moisture	%	10.6	10.4	10.4	10.5
Oxygen	%	5.02	4.7	6.78	5.5
Carbon Dioxide	%	11.91	12.05	10.55	11.5
Stack Temperature	°F	261.7	272.2	274.1	269.3
<u>Cadmium</u>					
		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	683,709 1,100,000	665,168 1,070,000	671,959 1,080,000	673,612 1,080,000
Isokinetic	%	99.15	101.62	97.48	99.42
Moisture	%	10.3	9.9	10.7	10.3
Oxygen	%	5.95	6.52	5.09	5.85
Carbon Dioxide	%	10.5	13.68	11.56	11.91
Stack Temperature	°F	270.6	258.3	266.0	265.0
<u>PAHs</u>					
		<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	647,370 1,040,000	721,805 1,160,000	719,645 1,160,000	696,273 1,120,000
Isokinetic	%	97.20	98.39	95.32	97.0
Moisture	%	9.8	9.8	9.4	9.7
Oxygen	%	5.28	5.62	5.92	5.61
Carbon Dioxide	%	11.62	11.37	10.96	11.3
Stack Temperature	°F	267.3	269.8	276.5	271.2

*Average of five measurements.

^bStandard conditions: 1 atm, 60° F.

^cNormal conditions: 1 atm, 32° F.

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 104 are included here.

Emission Factor Results

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: ARSENIC

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	6.51193598	3.10E-01	6.37E+00	6.37E+00	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	9.03333333	PREC	4.02E+01	7.21E-01	1.52E+01	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	2.99E-01	6.14E-06	1.54E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	9.63E-02	-3.59E-05	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	1.46E-02	-3.59E-05	7.52E+03	5
Oil hhv	BTU/lb	18765	PREC	1.38E-03	-3.46E-04	1.52E+02	2

* $t \times Sr$

** $(Bias \times Sensitivity)^2$ or $(t \times StDev/N^{.5} \times Sensitivity)^2$

*** Bias or $(StDev \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: BERYLLIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.16580206	8.57E-03	3.28E-01	3.28E-01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.23	PREC	1.07E-01	7.21E-01	7.86E-01	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	2.01E-04	1.56E-07	1.57E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	6.24E-05	-9.15E-07	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	9.80E-06	-9.15E-07	7.65E+03	5
Oil hhv	BTU/lb	18765	PREC	9.28E-07	-8.82E-06	1.54E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CADMIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.62476138	2.98E-02	3.85E-01	3.86E-01	4.2	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.86666666	PREC	1.45E-01	7.21E-01	9.16E-01	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	2.58E-03	5.89E-07	1.49E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	8.87E-04	-3.45E-06	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	1.26E-04	-3.45E-06	7.28E+03	5
Oil hhv	BTU/lb	18765	PREC	1.19E-05	-3.32E-05	1.47E+02	2

* $t \times Sr$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: COPPER

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	6.82431667	3.25E-01	1.06E+01	1.06E+01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm^3	9.46666666	PREC	1.11E+02	7.21E-01	2.54E+01	3
Gas Flow 1	Nm^3/hr	1060327.66	PREC	3.38E-01	6.44E-06	1.57E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	1.06E-01	-3.76E-05	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	1.65E-02	-3.76E-05	7.63E+03	5
Oil hhv	BTU/lb	18765	PREC	1.56E-03	-3.63E-04	1.54E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: LEAD

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	1.61476788	2.53E-01	3.20E+00	3.21E+00	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	2.24	PREC	1.02E+01	7.21E-01	7.69E+00	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	1.91E-02	1.52E-06	1.57E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	5.92E-03	-8.91E-06	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	9.30E-04	-8.91E-06	7.65E+03	5
Oil hhv	BTU/lb	18765	PREC	8.80E-05	-8.59E-05	1.54E+02	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: MANGANESE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	21.6263556	1.03E+00	1.73E+02	1.73E+02	12.7	1.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	30	PREC	3.01E+04	7.21E-01	3.40E+02	2
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	2.87E+01	2.04E-05	4.55E+05	3
Oil Flowrate	lb/hr	172649.4	PREC	1.40E+00	-1.19E-04	2.22E+04	5
Oil Flowrate	lb/hr	172649.4	BIAS	1.06E+00	-1.19E-04	8.64E+03	-
Oil hhv	BTU/lb	18765	PREC	1.33E-01	-1.15E-03	4.48E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: MERCURY

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	11.6566056	3.94E+00	2.37E+00	4.59E+00	3.3	2.5

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	16.17	PREC	4.99E+00	7.21E-01	5.37E+00	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	5.79E-01	1.10E-05	1.20E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	3.09E-01	-6.43E-05	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	2.82E-02	-6.43E-05	5.84E+03	5
Oil hhv	BTU/lb	18765	PREC	2.67E-03	-6.20E-04	1.18E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: NICKEL

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	363.803360	1.73E+01	7.63E+02	7.63E+02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	504.666666	PREC	5.81E+05	7.21E-01	1.83E+03	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	9.70E+02	3.43E-04	1.57E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	3.01E+02	-2.01E-03	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	4.72E+01	-2.01E-03	7.66E+03	5
Oil hhv	BTU/lb	18765	PREC	4.47E+00	-1.94E-02	1.55E+02	2

* t x Sr

** (Bias x Sensitivity)² or (t x StDev/N^{.5} x Sensitivity)²

*** Bias or (StDev x t)

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: SELENIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	1.42733947	4.88E-01	6.81E-01	8.38E-01	4.0	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	1.98	PREC	4.50E-01	7.21E-01	1.61E+00	3
Gas Flow 1	Nm ³ /hr	1060327.66	PREC	1.27E-02	1.35E-06	1.45E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	4.63E-03	-7.87E-06	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	6.18E-04	-7.87E-06	7.06E+03	5
Oil hhv	BTU/lb	18765	PREC	5.86E-05	-7.59E-05	1.43E+02	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT SUBSTANCE: CHROMIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	3.99169195	1.90E-01	2.62E+00	2.63E+00	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	5.614	PREC	6.87E+00	7.11E-01	6.38E+00	3
Oil Flowrate	lb/hr	172649.4	BIAS	3.62E-02	-2.20E-05	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	5.70E-03	-2.20E-05	7.67E+03	5
Gas Flow 1	Nm ³ /hr	1045833.66	PREC	3.24E-03	3.82E-06	2.58E+04	3
Oil hhv	BTU/lb	18765	PREC	5.40E-04	-2.12E-04	1.55E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CHROMIUM, HEXAVALENT

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.57308580	6.36E-02	1.80E+00	1.81E+00	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.806	PREC	3.26E+00	7.11E-01	4.40E+00	3
Oil Flowrate	lb/hr	172649.4	BIAS	7.46E-04	-3.16E-06	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	1.18E-04	-3.16E-06	7.70E+03	5
Gas Flow 1	Nm ³ /hr	1045833.66	PREC	6.73E-05	5.48E-07	2.59E+04	3
Oil hhv	BTU/lb	18765	PREC	1.12E-05	-3.05E-05	1.55E+02	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT SUBSTANCE: ACENAPHTHENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.10429428	5.05E-03	2.29E-01	2.29E-01	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.137	PREC	5.22E-02	7.61E-01	5.20E-01	3
Gas Flow 1	Nm ³ /hr	1119742	PREC	2.52E-04	9.31E-08	2.95E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	2.47E-05	-5.75E-07	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	3.81E-06	-5.75E-07	7.59E+03	5
Oil hhv	BTU/lb	18765	PREC	3.61E-07	-5.55E-06	1.53E+02	2

* $t \times Sr$

** $(Bias \times Sensitivity)^2$ or $(t \times StDev/N^{.5} \times Sensitivity)^2$

*** Bias or $(StDev \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: ANTHRACENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01035330	1.83E-03	1.53E-03	2.38E-03	4.2	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	Nm ³ /hr	1119742	PREC	2.31E-06	9.25E-09	2.85E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	2.43E-07	-5.71E-08	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	3.50E-08	-5.71E-08	7.33E+03	5
Oil hhv	BTU/lb	18765	PREC	3.31E-09	-5.51E-07	1.48E+02	2
Tot Conc	ug/Nm ³	0.0136	PREC	0.00E+00	7.61E-01	0.00E+00	3

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: FLUORANTHENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01035330	1.83E-03	1.53E-03	2.38E-03	4.2	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	Nm ³ /hr	1119742	PREC	2.31E-06	9.25E-09	2.85E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	2.43E-07	-5.71E-08	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	3.50E-08	-5.71E-08	7.33E+03	5
Oil hhv	BTU/lb	18765	PREC	3.31E-09	-5.51E-07	1.48E+02	2
Tot Conc	ug/Nm ³	0.0136	PREC	0.00E+00	7.61E-01	0.00E+00	3

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: FLUORENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01370289	1.10E-03	2.07E-02	2.07E-02	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.018	PREC	4.25E-04	7.61E-01	4.69E-02	3
Gas Flow 1	Nm ³ /hr	1119742	PREC	4.21E-06	1.22E-08	2.90E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	4.26E-07	-7.56E-08	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	6.37E-08	-7.56E-08	7.47E+03	5
Oil hhv	BTU/lb	18765	PREC	6.03E-09	-7.29E-07	1.51E+02	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: NAPHTHALENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	4.33925144	2.07E-01	5.20E+00	5.21E+00	4.2	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	5.7	PREC	2.66E+01	7.61E-01	1.17E+01	3
Gas Flow 1	Nm ³ /hr	1119742	PREC	4.09E-01	3.88E-06	2.86E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	4.28E-02	-2.39E-05	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	6.19E-03	-2.39E-05	7.35E+03	5
Oil hhv	BTU/lb	18765	PREC	5.86E-04	-2.31E-04	1.48E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: PHENANTHRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01065781	1.02E-03	1.30E-02	1.31E-02	4.2	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.014	PREC	1.67E-04	7.61E-01	2.94E-02	3
Gas Flow 1	Nm ³ /hr	1119742	PREC	2.47E-06	9.52E-09	2.86E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	2.58E-07	-5.88E-08	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	3.74E-08	-5.88E-08	7.36E+03	5
Oil hhv	BTU/lb	18765	PREC	3.54E-09	-5.67E-07	1.49E+02	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

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UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: PYRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.00936364	1.39E-03	9.13E-03	9.24E-03	4.1	2.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	0.0123	PREC	8.16E-05	7.61E-01	2.05E-02	3
Gas Flow 1	Nm ³ /hr	1119742	PREC	1.83E-06	8.36E-09	2.80E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	1.99E-07	-5.17E-08	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	2.77E-08	-5.17E-08	7.20E+03	5
Oil hhv	BTU/lb	18765	PREC	2.62E-09	-4.98E-07	1.45E+02	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: FORMALDEHYDE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	168.942746	8.07E+00	3.81E+02	3.81E+02	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	ug/Nm ³	249	PREC	1.44E+05	6.78E-01	9.70E+02	3
Gas Flow 1	Nm ³ /hr	997971.666	PREC	8.92E+02	1.69E-04	3.06E+05	3
Oil Flowrate	lb/hr	172649.4	BIAS	6.48E+01	-9.32E-04	8.64E+03	-
Oil Flowrate	lb/hr	172649.4	PREC	9.91E+00	-9.32E-04	7.55E+03	5
Oil hhv	BTU/lb	18765	PREC	9.39E-01	-8.99E-03	1.52E+02	2

* $t \times Sr$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

Appendix E

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
c	chromium % closure	percent	21.84899	1.04E+00	1.33E+01	1.3E+01	3.18E+00	3.0E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) concout	chromium conc out	ug/Nm3	5.6	PREC	1.16E+02	3.90E+00	4.77E+00	3
2) concin	chromium conc in	mg/l	.32	PREC	5.05E+01	-6.06E+01	1.81E+01	2
3) oilflow	oil flowrate in	L/hr	84100	BIAS	1.08E+00	-2.47E-04	4.21E+03	-
4) oilflow	oil flowrate in	L/hr	84100	PREC	9.02E-02	-2.47E-04	2.71E+03	5
5) gasflow	stack gas flowrate	Nm3/hr	1050000	PREC	5.09E-02	2.08E-05	1.88E+04	3
=====								
* PRECISION COMPONENT = t*Srbar								
** (Bp*SIGMAp)^2 FOR BIAS ERRORS; (t*Spbar*SIGMAp)^2 FOR PRECISION ERRORS								
-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** Bp FOR BIAS ERRORS; Sp FOR PRECISION ERRORS								

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
c	manganese % closure	percent	57.29111	2.73E+00	1.86E+02	1.9E+02	4.30E+00	1.7E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) concout	manganese conc out	ug/Nm3	30	PREC	2.46E+04	1.91E+00	1.16E+02	2
2) concin	manganese conc in	mg/l	.66	PREC	9.85E+03	-5.19E+01	2.71E+00	2
3) gasflow	stack gas flowrate	Nm3/hr	1060000	PREC	2.34E+01	5.40E-05	1.55E+05	3
4) oilflow	oil flowrate in	L/hr	84100	BIAS	7.44E+00	-6.49E-04	4.21E+03	-
5) oilflow	oil flowrate in	L/hr	84100	PREC	1.13E+00	-6.49E-04	3.67E+03	5

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_p \cdot SIGMA_p)^2$ FOR BIAS ERRORS; $(t \cdot S_{pbar} \cdot SIGMA_p)^2$ FOR PRECISION ERRORS

-WHERE S_{pbar} =PRECISION INDEX OF THE MEAN, $S_p/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; S_p FOR PRECISION ERRORS

Appendix E

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
c	nickel % closure	percent	27.67409	1.32E+00	5.73E+01	5.7E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) concout	nickel conc out	ug/Nm3	505.0001	PREC	3.25E+03	5.48E-02	1.80E+03	3
2) concin	nickel conc in	mg/l	23	PREC	2.46E+01	-1.15E+00	6.08E+00	2
3) gasflow	stack gas flowrate	Nm3/hr	1060000	PREC	5.45E+00	2.61E-05	1.55E+05	3
4) oilflow	oil flowrate in	L/hr	84100	BIAS	1.74E+00	-3.13E-04	4.21E+03	-
5) oilflow	oil flowrate in	L/hr	84100	PREC	2.65E-01	-3.13E-04	3.67E+03	5

* PRECISION COMPONENT = $t \cdot S_r \cdot \bar{b}$

** $(B_p \cdot \text{SIGMap})^2$ FOR BIAS ERRORS; $(t \cdot S_p \cdot \bar{b} \cdot \text{SIGMap})^2$ FOR PRECISION ERRORS

-WHERE $S_p \cdot \bar{b}$ = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; S_p FOR PRECISION ERRORS

Appendix F

Quality Assurance/Quality Control Data

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Reagent blank and field blank analyses were performed for the metals (solid phase and vapor phase). A field blank was analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

Table F-2 presents matrix spike recovery data for one of the multi-metals stack gas samples. A duplicate analysis for metals was run on one of the flue gas samples. Table F-2 presents the relative percent difference (RPD) between the duplicate analyses for this sample.

Table F-3 presents the matrix spike recovery results for the oil samples. The relative percent difference between the matrix spike and the matrix spike duplicate is also presented. Table F-4 presents the results for the lab spike recoveries for the PAH analyses.

Table F-1
Summary of Blank Sample Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected (μg)</u>	<u>Detection Limit (μg)</u>
PAH				
<u>Method Blank</u>				
Naphthalene	1	1	21	0.025
Acenaphthylene	1	0		0.025
Acenaphthene	1	1	1.4	0.025
Fluorene	1	1	0.049	0.025
Phenanthrene	1	1	0.1	0.025
Anthracene	1	1	0.073	0.025
Fluoranthene	1	1	0.026	0.025
Pyrene	1	0		0.025
Chrysene	1	0		0.025
Benz(a)anthracene	1	0		0.025
Benz(b+k)fluoranthene	1	0		0.025
Benzo(a)pyrene	1	0		0.025
Indeno(1,2,3-c,d)pyrene	1	0		0.025
Dibenz(a,h)anthracene	1	0		0.025
Benzo(g,h,i)perylene	1	0		0.025
<u>Field Blank</u>				
Naphthalene	1	1	13	0.025
Acenaphthylene	1	0		0.025
Acenaphthene	1	0		0.025
Fluorene	1	0		0.025
Phenanthrene	1	1	0.052	0.025
Anthracene	1	1	0.048	0.025
Fluoranthene	1	0		0.025
Pyrene	1	0		0.025
Chrysene	1	0		0.025
Benz(a)anthracene	1	0		0.025
Benz(b+k)fluoranthene	1	0		0.025
Benzo(a)pyrene	1	0		0.025
Indeno(1,2,3-c,d)pyrene	1	0		0.025
Dibenz(a,h)anthracene	1	0		0.025
Benzo(g,h,i)perylene	1	1	0.04	0.025
Volatile Organics				
<u>Method Blank</u>				
Formaldehyde	2	2	2.86, 2.86	0.24
Benzene	0	0		
<u>Field Blank</u>				
Formaldehyde	2	2	3.28, 3.55	0.24
Benzene	0	0		

Table F-1 (Continued)

<u>Method</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Reported (μg)</u>	<u>Detection Limit (μg)</u>
Metals - Solid Phase				
<u>Field Blank</u>				
Arsenic	1	1	5.0	--
Beryllium	1	1	0.46	0.07
Cadmium	1	1	1.3	0.41
Copper	1	1	18	0.8
Lead	1	1	36	3.0
Manganese	1	1	86	--
Mercury	1	0		28
Nickel	1	1	900	0.6
Selenium	1	1	6.0	4.1
<u>Reagent Blank</u>				
Arsenic	1	1	2.0	--
Beryllium	1	0		0.07
Cadmium	1	0		0.41
Copper	1	1	8.9	0.8
Lead	1	1	35	3.0
Manganese	1	1	4.2	--
Mercury	1	0		22
Nickel	1	1	2.5	0.6
Selenium	1	1	14	4.1
Metals - Vapor Phase				
<u>Field Blank</u>				
Arsenic	1	0		0.28
Beryllium	1	0		0.06
Cadmium	1	1	1.1	--
Copper	1	1	4.6	--
Lead	1	1	3.1	--
Manganese	1	1	3.0	0.62
Mercury ^a	1	0		1.3, 37
Nickel	1	1	31	0.6
Selenium	1	0		2.8
<u>Reagent Blank</u>				
Arsenic	1	1	0.38	0.28
Beryllium	1	0		0.06
Cadmium	1	1	0.14	--
Copper	1	1	2.5	--
Lead	1	1	6.4	--
Manganese	1	0		0.62
Mercury ^a	1	0		2.0, 20
Nickel	1	1	1.4	0.6
Selenium	1	0		3.1

Table F-1 (Continued)

<u>Method</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Reported (μg)</u>	<u>Detection Limit (μg)</u>
Chromium				
<u>Field Blank</u>				
Chromium	1	1	1.5	1.25
Chromium, hexavalent (solid)	1	1	1.76	0.0014
Chromium, hexavalent (vapor)	1	1	1.78	0.0014
Lead				
<u>Field Blank</u>				
Cadmium	1	0		0.5
<u>Reagent Blank</u>				
Cadmium	1	0		0.5

^aTwo impinger analyses, including a potassium permanganate impinger.

Table F-2
Summary of Quality Control Results for Stack Gas

<u>Substance</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
<u>Stack Gas - Solid Phase</u>		
Arsenic	74	27
Beryllium	86	<1
Cadmium	77	<1
Copper	95	<2
Lead	84	2
Manganese	88	1
Mercury	97	<1
Nickel	99	<1
Selenium	82	<1
<u>Stack Gas - Vapor Phase</u>		
Beryllium	82	<1
Copper	78	4
Manganese	91	4
Mercury*	97, 104	<1, <1
Nickel	83	3
Selenium	88	<1
<u>Stack Gas - Total</u>		
Chromium	97	<1
Chromium, hexavalent	96	--
Cadmium	96	<1

*Results from both impingers.

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-3
Summary of Quality Control Results for Fuel Oil

<u>Substance</u>	<u>Detection Limit (mg/L)</u>	<u>Matrix Spike Recovery %</u>	<u>Matrix Spike Duplicate RPD ^a</u>
Arsenic	1.2	83	14
Beryllium	0.2	102	<1
Cadmium	0.2	76	5
Chromium	0.2	96	14
Copper	--	98	17
Lead	1.2	77	2
Manganese	--	89	4
Mercury	0.1	102	24
Nickel	--	88	1
Phosphorus	2.5 mg/kg	84	2
Selenium	1.2	114	15

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-4

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean Spike Recovery (%)</u>	<u>Std. Dev. (% Rec.)</u>
d10 Acenaphthene	8	98	35
d10 Anthracene	8	70	26
d12 Chrysene	8	122	18
d12 Benzo(a)pyrene	8	74	28

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PART III: SITE 105

PRELIMINARY DRAFT REPORT

Test Contractor:

**Carnot, Inc.
15991 Red Hill Avenue, Suite 110
Tustin, California 92680-7388**

3 March 1993

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Section 1

INTRODUCTION

This section of the document summarizes data gathered by Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 105, during a sampling program sponsored by the electric utility company. The power plant, a Babcock and Wilcox supercritical boiler, was tested during both residual fuel oil- and natural gas-firing in February of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The primary emphasis of the sampling effort was collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the plant and sample locations. Section 3 discusses the results of the chemical analyses of the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data using traditional QA/QC techniques and engineering calculations. Section 5 explains example calculations. The appendices contain raw data, stream concentrations, sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 105

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Selenium	X		X
<u>Organic</u>			
Benzene		X	X
Formaldehyde			X
Polycyclic Aromatic Hydrocarbons			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ -C ₅ Hydrocarbons		X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section describes Site 105 and its sampling locations.

Facility Information

Site 105 is equipped with a Babcock and Wilcox supercritical boiler with a rated capacity of 5.10×10^6 lb/hr steam flow rate. The unit's electrical output is rated at 750 MW. Design steam conditions are 3830 psig with 1005° F of superheat and a 1005° F reheat temperature. The unit burns either fuel oil or natural gas. Testing was conducted during 100% oil firing and 100% natural gas operation. The operating load was at least 96% during all sampling.

Flue Gas Treatment Facilities

Flue gases are discharged to the atmosphere by means of a stack. Two parallel (north and south) ducts convey flue gas from the boiler to the stack. No pollution control devices are used.

Sampling Locations

Figure 2-1 shows where the fuel oil feed, natural gas feed, and flue gas streams at Site 105 were sampled. The procedures for collecting samples, pretreating samples, and conducting chemical analyses are discussed in Appendix C. Brief descriptions of the sampling methods appear below:

- Two fuel oil grab samples were taken from the boiler feed lines. Natural gas samples were analyzed by an online gas chromatograph; 17 samples were analyzed for natural gas composition on the day of testing.
- Stack gas samples were collected at sampling ports located on each of the two ducts between the boiler air preheater and the stack. Each duct had four sample ports. A five-point traverse was made at each sample port, providing a 20-point measurement grid on each duct. Testing was performed isokinetically for metals and PAH compounds.

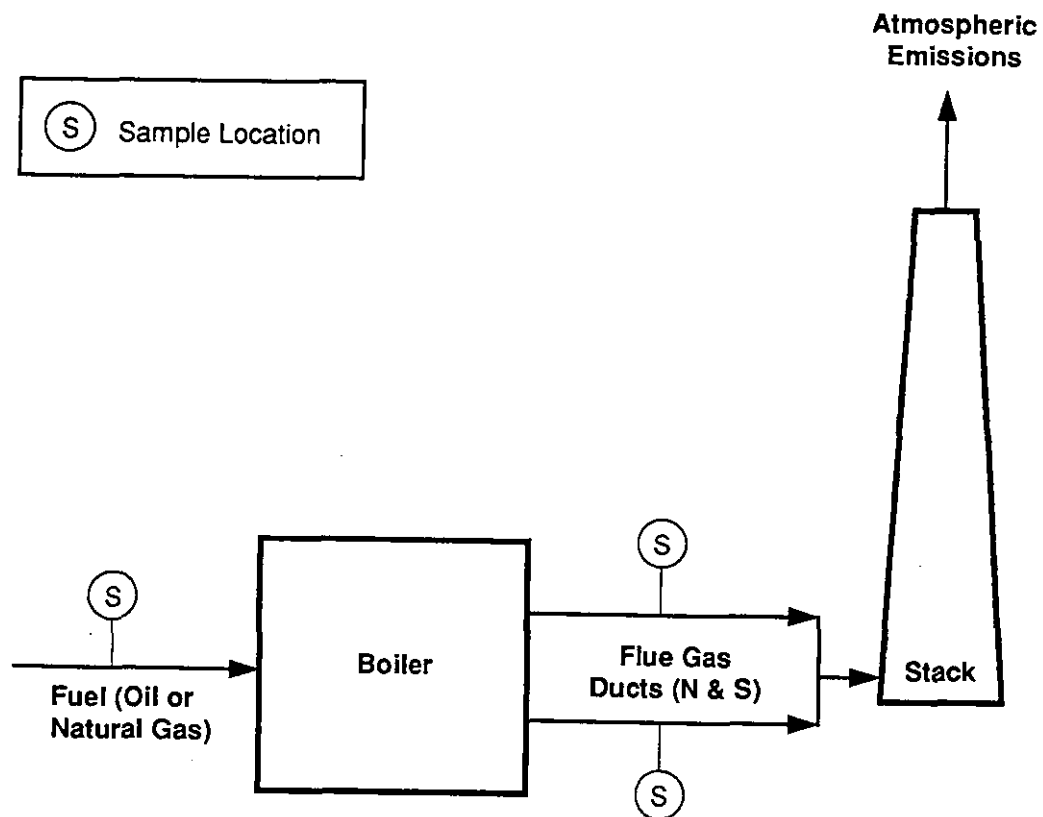


Figure 2-1. Process Flow Diagram, Site 105

Section 3

RESULTS

This section discusses the results of the sampling of Site 105. Appendix A presents analytical data generated by Carnot and their contracted labs. Stream concentrations calculated by Radian Corporation from the data in the Carnot report can be found in Appendix B. Appendix C presents the details of the analytical and sampling methods used at this site. Example calculations of the results discussed in this section appear in Section 5.

Sampling Schedule

Carnot personnel conducted sampling at Site 105 from February 12 to February 18, 1990. Figure 3-1 presents a timeline of the different sampling runs, which have been grouped by time period into "runs." The run numbers shown in Figure 3-1 correspond to those on the summary tables. Samples have been numbered in chronological order and each fuel type has its own unique set of run numbers.

Data Treatment

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

Blank Corrections

At Site 105, the metals, total chromium by CARB 425, and formaldehyde were corrected for the reagent blank result; PAHs were corrected for the field blank results. No blank analysis was performed for the hexavalent chromium by CARB 425. The individual metals run measurements for both phases were corrected for the reagent blank analytical result. The convention for using blank results to correct the data in these reports was to use the reagent blank results when they were available. If a reagent blank analysis was not performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no blank correcting was done. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration was flagged with a "B" on the summary tables.

When the blank correction resulted in a value less than the detection limit, the concentration is presented as ND(DL), meaning that the concentration is below the detection limit (DL), which is presented in parentheses. The test contractor has defined the term "detection limit" as three to ten times the instrument detection limit, depending on the analytical laboratory that performed the analysis.

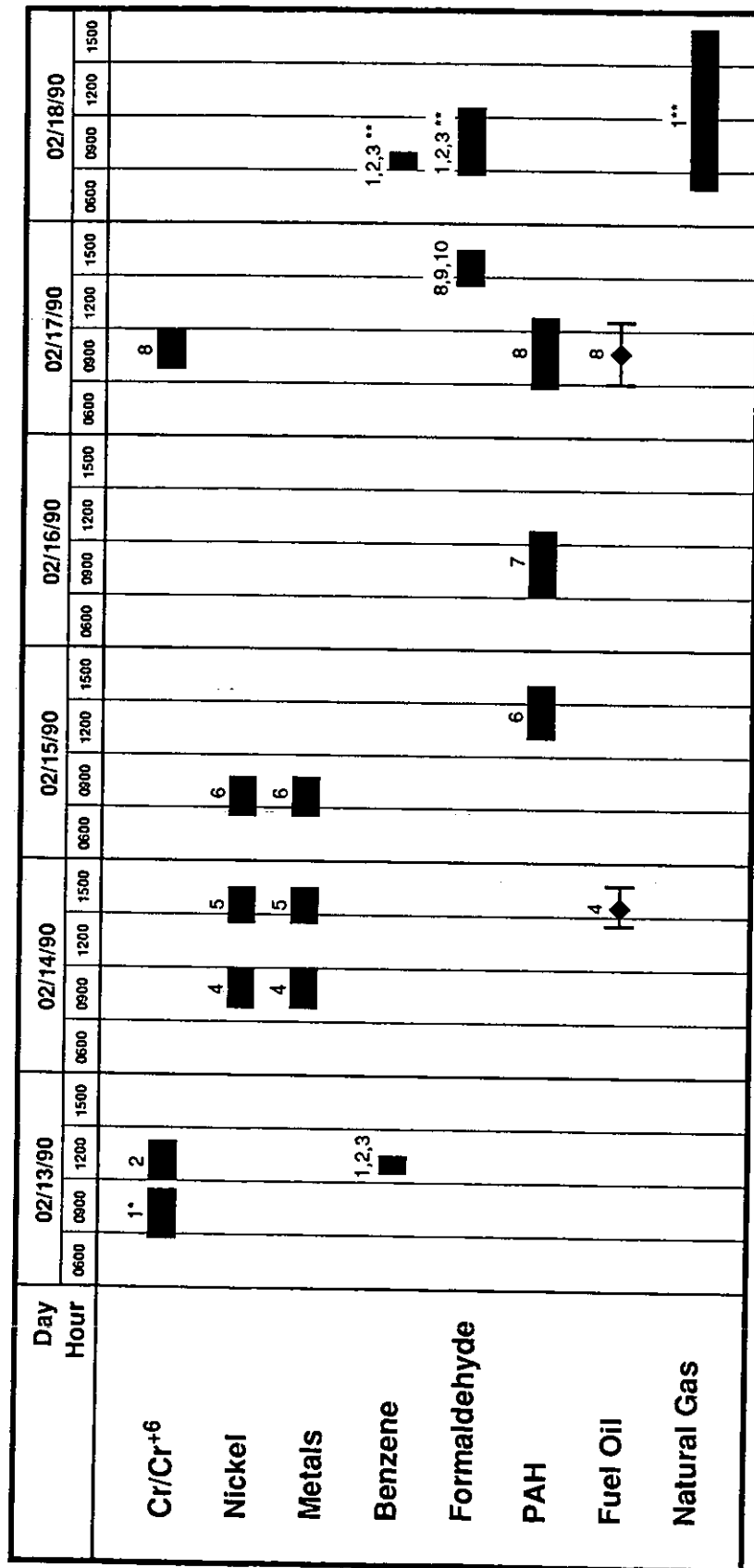


Figure 3-1. Sampling Timeline for FCEM Site 105

Total Concentrations

The solid and vapor phase concentrations were both considered when determining the total gas stream concentration. The absence of detectable concentrations greater than the DL in either (or both) phase requires that conventions be established for calculating total values. For each substance, there are three possible combinations of solid- and vapor-phase concentrations in the emitted gas stream:

- Case 1: The concentrations in both phases are above the detection limits.
- Case 2: The concentrations in both phases are below the detection limits.
- Case 3: The concentration in one phase is above the detection limit and the concentration in the other phase is below the detection limit.

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

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

For example, the total cadmium (Cd) concentration in the stack gas is calculated as follows for Run 5.

$$\text{Cd in the solid phase} = 0.93 \mu\text{g}/\text{Nm}^3$$

$$\text{Cd in the vapor phase} = 0.24 \mu\text{g}/\text{Nm}^3$$

$$\text{Total Cd in the stack gas} = 1.2 \mu\text{g}/\text{Nm}^3$$

- Case 2: The total concentration is considered to be the solid phase detection limit.

For example, the total beryllium (Be) concentration in the stack gas is calculated as follows for Run 5.

$$\text{Be in the solid phase} = \text{ND}(0.05) \mu\text{g}/\text{Nm}^3$$

$$\text{Be in the vapor phase} = \text{ND}(0.03) \mu\text{g}/\text{Nm}^3$$

$$\text{Total Be in the stack gas} = \text{ND}(0.05) \mu\text{g}/\text{Nm}^3$$

Results

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

For example, the total selenium (Se) concentration in the stack gas is calculated as follows for Run 5.

Se in the solid phase = $8.2 \mu\text{g}/\text{Nm}^3$

Se in the vapor phase = $\text{ND}(1.7) \mu\text{g}/\text{Nm}^3$

Total Se in the stack gas = $8.2 \mu\text{g}/\text{Nm}^3$

In historical data and previous FCEM data, mercury has been shown to exist primarily in the vapor phase. For Case 2, then, the total concentration in the gas stream is considered to be the vapor phase detection limit. For Cases 1 and 3, the conventions are the same as those described above.

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

Average Concentrations

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

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

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

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

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the fuel oil sample analyses. The two sample runs correspond to the sample dates shown in Figure 3-1. Fuel oil was analyzed for the same set of metals as the exhaust gas. In addition, sulfur and phosphorus also were analyzed in the oil. Measured fuel oil flow rates are presented in Appendix D, Table D-1. Natural gas fuel was analyzed for C_1 through C_5 hydrocarbons, nitrogen, and carbon dioxide. Benzene ($C_6 H_6$) was detected at 160 ppmv. Additional analytical results for the natural gas fuel are provided in Appendix D, Table D-2.

For each substance, a mean has been calculated, along with the 95% confidence interval about the mean. The number reported as a confidence interval is the range about the mean, i.e., the confidence interval for sulfur in the oil is reported to be 0.19 percent. This means that it is 95% certain that the true mean sulfur value is 0.37 ± 0.19 percent. The calculation of confidence intervals is discussed in Section 5.

Stack Gas

Tables 3-2a, 3-2b, 3-2c, and 3-2d present the stack gas concentrations of elements, benzene, formaldehydes, and polynuclear aromatic hydrocarbon PAHs compounds. The trace element data are presented for both the solid and vapor fractions. To obtain element solid phase concentrations, the particulate filter and probe, and nozzle rinse fractions were combined and analyzed. Gas phase concentrations were obtained by analyzing impinger catches. Table 3-3 presents the data on a unit-energy basis (emission factor).

The concentrations in each duct were not expected to be significantly different since they are generated from the same boiler. As shown in Tables 3-2a, b, c, and d, concentration is independent of sampling location. Therefore, the results from all runs have been averaged to obtain one mean for each substance.

Appendix D, Table D-3, presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperatures, and the degree of isokinesis during sampling.

Table 3-1
Site 105 Fuel Oil Analysis

	<u>Run 4</u>	<u>Run 8</u>	<u>Mean</u>	<u>95% CI</u>
<u>Sample Date</u>	2/14/90	2/17/90		
Mass Flow Rate (lb/hr)	-	-	338,700 ^a	1,800
Volumetric Flow Rate (L/hr)	-	-	164,530 ^a	870
<u>Elements (mg/L)</u>				
Arsenic	ND(1.1) ^b	ND(1.1)	ND(1.1)	
Beryllium	ND(0.22)	ND(0.22)	ND(0.22)	
Cadmium	ND(0.22)	ND(0.22)	ND(0.22)	
Chloride	799	630	715	1100
Chromium	0.26	0.28	0.27	0.13
Chromium (VI)	ND(0.50)	ND(0.50)	ND(0.50)	
Copper	ND(0.43)	ND(0.43)	ND(0.43)	
Lead	ND(1.1)	ND(1.1)	ND(1.1)	
Mercury	ND(0.10)	ND(0.10)	ND(0.10)	
Manganese	ND(0.43)	ND(0.43)	ND(0.43)	
Nickel	24	22	23	13
Phosphorus	7.7	8.4	8.1	4.1
Selenium	ND(1.0)	ND(1.0)	ND(1.0)	
Zinc	0.68	0.82	0.75	0.9
Ash (wt%)	0.491	0.016	0.25	3.0
Sulfur (wt %)	0.38	0.35	0.37	0.19
Higher Heating Value (Btu/lb)	18691	18593	18960	620

CI = Confidence interval.

^aFlow rate is an average of six values taken over a four-day period.

^bND indicates the substance was not detected in the sample; the detection limit is shown in parentheses.

Table 3-2a

Stack Gas Composition Data at Site 105
Residual Oil Firing

Solid Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Elements^a</u>	<u>Run 4</u> <u>N Duct</u>	<u>Run 5</u> <u>S Duct</u>	<u>Run 6</u> <u>N Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date	2/14/90	2/14/90	2/15/90		
Stack Gas Flow Rate (Nm^3/hr) ^b	1,020,000	1,130,000	1,010,000	1,050,000	170,000
Arsenic	6.1	2.9	6.0	5.0	4.6
Beryllium	ND(0.03) ^c	ND(0.05)	ND(0.05)	ND(0.05)	
Cadmium	0.72 ^d	0.93 ^d	0.49 ^d	0.71	0.54
Copper	6.0	12	15	11	11
Lead	2.3 B ^e	4.9 B ^e	7.4 B ^e	4.9	6.2
Manganese	4.7	5.5	4.6	4.9	1.2
Mercury	ND(0.80) ^d	ND(1.4) ^d	ND(2.2) ^d	ND(2.2)	
Nickel	720	670	730	700	73
Selenium	3.0 B ^e	8.2	0.47 B ^e	3.9	9.7

CI = Confidence interval.

^aA reagent blank analysis was performed and used to correct the sample results.

^bFlow for the sampled duct only.

^cND indicates the concentration is below the detection limit (shown in parentheses).

^dA blank correction is not applied since the substance was not detected in the blank sample.

^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-2b

**Stack Gas Composition Data at Site 105
Residual Oil Firing**

Vapor Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Elements^a</u>	<u>Run 4</u> <u>N Duct</u>	<u>Run 5</u> <u>S Duct</u>	<u>Run 6</u> <u>N Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date	2/14/90	2/14/90	2/15/90		
Stack Gas Flow Rate (Nm^3/hr) ^b	1,020,000	1,130,000	1,010,000	1,050,000	170,000
Arsenic	0.45 °	0.68 °	0.80 °	0.64	0.45
Beryllium	ND(0.02) °	ND(0.03) °	ND(0.05) °	ND(0.05)	--
Cadmium	0.41	0.24	0.094	0.25	0.40
Copper	2.1	4.9	2.0 B°	3.0	4.1
Lead	0.95	19	1.8	7.2	25
Manganese	0.38 °	0.86 °	0.67 °	0.64	0.60
Mercury	ND(5.3) °	ND(5.8) °	ND(6.6) °	ND(6.6)	--
Nickel	13 °	1.1 °	18 °	11	22
Selenium	ND(1.2) °	ND(1.7) °	ND(1.8) °	ND(1.8)	--

CI = Confidence interval.

^aA reagent blank analysis was performed and used to correct the sample results.

^bFlow for sampled gas duct only.

^cA blank correction is not applied since the substance was not detected in the blank sample.

^dND indicates that the concentration is below the detection limit which is shown in parentheses.

^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-2c

**Stack Gas Composition Data at Site 105
Residual Oil Firing**

Combined Phases ($\mu\text{g}/\text{Nm}^3$)

<u>Elements^a</u>	<u>Run 4</u> <u>N Duct</u>	<u>Run 5</u> <u>S Duct</u>	<u>Run 6</u> <u>N Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date	2/14/90	2/14/90	2/15/90		
Stack Gas Flow Rate (Nm^3/hr) ^b	1,020,000	1,130,000	1,010,000	1,050,000	170,000
Arsenic	6.60	3.6	6.8	5.7	4.5
Beryllium	ND(0.03) ^c	ND(0.05)	ND(0.05)	ND(0.05)	
Cadmium	1.1	1.2	0.59	0.96	0.80
Copper	8.2	17	17	14	13
Lead	3.3 B ^d	24 B ^d	9.2 B ^d	12	26
Manganese	5.1	6.3	5.3	5.6	1.7
Mercury	ND(5.3) ^c	ND(5.8) ^c	ND(6.6) ^c	ND(6.6)	
Nickel	730	670	740	710	95
Selenium	3.0	8.2	0.47 B ^d	3.9	9.8

Table 3-2c
(Continued)

<u>Substances by CARB 425</u>		<u>Run 1</u> <u>N Duct</u>	<u>Run 2</u> <u>S Duct</u>	<u>Run 8</u> <u>S Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date		2/13/90	2/13/90	2/17/90		
Stack Gas Flow Rate (Nm ³ /hr) ^b		1,050,000	1,010,000	1,000,000	1,020,000	66,000
Chromium (VI) ^c		0.59	ND(0.4)	ND(0.6)	ND(0.6)	-
Chromium (Total) ^a		1.9	3.1	3.7	2.9	2.3
<u>Polynuclear Aromatic Hydrocarbons^a</u>		<u>Run 6</u> <u>S Duct</u>	<u>Run 7</u> <u>N Duct</u>	<u>Run 8</u> <u>N Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date		2/15/90	2/16/90	2/17/90		
Stack Gas Flow Rate (Nm ³ /hr) ^b		1,080,000	960,000	930,000	990,000	20,000
Acenaphthene		ND(0.009) B ^d	ND(0.009) B ^d	ND(0.010)	ND(0.010)	-
Acenaphthylene		ND(0.009)	ND(0.009)	ND(0.010)	ND(0.010)	
Anthracene		ND(0.009) B ^d	ND(0.009) B ^d	ND(0.010)	ND(0.010)	
Benz(a)anthracene		ND(0.009) ^e	ND(0.009) ^e	0.11 ^e	0.040	0.15
Benzo(a)pyrene		ND(0.009) ^e	ND(0.009) ^e	ND(0.010) ^e	ND(0.010)	

Table 3-2c

(Continued)

	Run 6 S Duct	Run 7 N Duct	Run 8 N Duct	Mean	95% CI
Benzo(b+k)fluoranthene	ND(0.009) ^c	ND(0.009) ^c	0.056 ^c	0.022	0.074
Benzo(g,h,i)perylene	ND(0.009) ^c	ND(0.009) ^c	0.034 ^c	0.014	0.042
Chrysene	ND(0.009) ^c	ND(0.009) ^c	0.015 ^c	ND(0.009)	
Dibenz(a,h)anthracene	ND(0.009) ^c	ND(0.009) ^c	0.010 ^c	ND(0.009)	
Fluoranthene	0.023	0.015 B ^d	0.15	0.061	0.18
Fluorene	ND(0.009)	ND(0.009) B ^d	0.075	0.028	0.10
Indeno(1,2,3-c,d)pyrene	ND(0.009)	ND(0.009)	0.029	0.014	0.035
Naphthalene	26	28	ND(0.010) B ^d	18	39
Phenanthrene	0.078	0.054	0.24	0.12	0.24
Pyrene	ND(0.009) B ^d	ND(0.009) B ^d	0.089	0.033	0.12

CI = Confidence interval.

^aA reagent blank analysis was performed and used to correct the sample results.^bFlow for sampled duct only.^cND indicates the concentration is below the detection limit (shown in parentheses).^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.^eA blank correction is not applied since the substance was not detected in the blank sample.^fNo blank analysis was performed.^gA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.

Table 3-2d
Stack Gas Composition Data at Site 105

<u>Oil-Fired Operation</u>		<u>Units</u>	<u>Run 1</u> <u>S Duct</u>	<u>Run 2</u> <u>S Duct</u>	<u>Run 3</u> <u>N Duct</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date			2/14/90	2/14/90	2/14/90		
Stack Gas Flow ^a		Nm ³ /hr	--	--	--	2,066,000	--
Benzene		μg/Nm ³	ND(3.5) ^b	ND(3.5)	ND(3.5)	ND(3.5)	--
Sample Date			Run 8 N Duct	Run 9 N Duct	Run 10 S Duct	<u>Mean</u>	<u>95% CI</u>
Stack Gas Flow ^a		Nm ³ /hr	2/17/90	2/17/90	2/17/90		
Formaldehyde ^d		μg/Nm ³	931,000	931,000	995,000	952,000	92,000
			1300 ^c	840 ^c	400 ^c		
<u>Gas-Fired Operation</u>		<u>Units</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>95% CI</u>
Sample Date			2/18/90	2/18/90	2/18/90		
Stack Gas Flow ^a		Nm ³ /hr	--	--	--	2,068,000	--
Benzene		μg/Nm ³	ND(14)	ND(14)	ND(14)	ND(14)	
Sample Date			Run 8 N Duct	Run 9 N Duct	Run 10 S Duct	<u>Mean</u>	<u>95% CI</u>
Stack Gas Flow ^a		Nm ³ /hr	2/17/90	2/17/90	2/17/90		
Formaldehyde ^d		μg/Nm ³	1,065,000	1,065,000	1,002,000	1,044,000	90,000
			580 ^c	990 ^c	990 ^c	860	590

^aFlow is for both ducts.

^bND indicates the concentration is below the detection limit.

^cFlow is for the sampled duct only.

^dA reagent blank analysis was performed and used to correct the sample results.

^eA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-3
Stack Gas Emission Factors

<u>Elements</u>	<u>Emission Factor</u> <u>(lb/10¹² BTU)</u>	<u>95% CI</u>
Arsenic	4.1	3.2
Beryllium	ND(0.36) ^a	--
Cadmium	0.69	0.58
Chromium	2.1	1.7
Chromium (VI)	ND(0.42)	--
Copper	10	9.4
Lead	9	19
Manganese	4.0	1.1
Mercury	ND(4.7)	--
Nickel	510	58
Selenium	2.8	7.2
Zinc	100	100
<u>PAH</u>		
Acenaphthene	ND(0.007)	--
Acenaphthylene	ND(0.007)	--
Anthracene	ND(0.007)	--
Benz(a)anthracene	0.03	0.11
Benzo(a)pyrene	ND(0.007)	--
Benzo(b+k)fluoranthene	0.016	0.054
Benzo(g,h,i)perylene	0.010	0.030
Chrysene	ND(0.006)	--
Dibenz(a,h)anthracene	ND(0.006)	--
Fluoranthene	0.04	0.13
Fluorene	0.020	0.074
Indeno(1,2,3-c,d)pyrene	0.010	0.025
Napthalene	13	29
Phenanthrene	0.09	0.18
Pyrene	0.023	0.089
<u>VOC Oil-Fired</u>		
Benzene	ND(2.5)	--
Formaldehyde	620	850
<u>VOC Gas-Fired</u>		
Benzene	ND(1.0)	--
Formaldehyde ^b	600	--

^aND indicates the concentration is below the detection limit (expressed in lb/10¹² Btu), which is shown in parentheses.

^bInsufficient fuel flow rate data to calculate as 95% confidence interval.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 105, two methods were used to evaluate data quality. First, and most important, was evaluation of the traditional QA/QC protocol for sampling and analytical procedures used at Site 105, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 105 QA/QC data are compared with FCEM project objectives. The second data evaluation tool involves calculating material balances for various substances around the entire plant. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute significantly to the overall inlet or outlet mass rate (e.g., coal, bottom ash, collected fly ash, etc.).

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during sampling and analysis. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. The QA/QC measures commonly used as part of the FCEM data assessment protocol, and the characteristic information obtained are summarized in Table 4-1. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data, but does limit the ability to measure the various components of measurement error.

As shown in the table, different QC checks provide different types of information, particularly pertaining to the sources of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Estimates of precision and accuracy are based primarily on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 presents a summary of precision and accuracy estimates.

Based on the quality control data evaluated, and recognizing the limitations in data quality reflected by relatively large confidence intervals for the average emission estimates and the error associated with high blanks for some species, there is reason to conclude that the data reported are valid. Not enough information is available to differentiate each component of variability, but excessive analytical variability or bias generally is not indicated. The uncertainty is in large part a natural consequence of the low levels measured, confounded by uncertainty about the estimates of the blanks and process variation.

A discussion of precision and accuracy is presented below for each measurement type, followed by a stack gas sampling quality control data review, which includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias or persistent positive or negative deviation from the "true" value.

The efficiency of the analytical procedure in the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes or other quality assurance measures, as necessary. While spiked samples usually provide a measure of

Table 4-2

Types of Quality Control Data Reported

Analysis	Precision				Accuracy				Blank				
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Other	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>													
ICP Metals	✓		✓			✓							
Ultimate and Proximate		✓											
<u>Fuel - Natural Gas</u>													
Composition & HHV	✓												
<u>Stack Gas - Natural Gas Fuel</u>													
Benzene	✓												
Formaldehyde	✓			✓		✓			✓ (Field Spikes)	✓		✓	
<u>Stack Gas - Fuel Oil</u>													
Metals (ICP)	✓		✓			✓				✓			✓
As (GFAAS)	✓		✓						✓ (Field Spike)	✓			✓
Pb (FAAS)	✓		✓						✓ (Field Spike)	✓			✓
Hg (CVAAS)	✓		✓			✓				✓			✓
Cr(VI) IC			✓			✓				✓			
Cr(total) AAS			✓			✓							✓
Benzene GC/PID	✓												
Formaldehyde HPLC	✓			✓		✓			✓ (Field Spike)	✓		✓	
PAH GC/MS	✓												

Table 4-3
Summary of Precision and Accuracy Estimates

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spike				
Arsenic		20% RPD	75-125%	10%	83
Beryllium		20% RPD	75-125%	<1% ^d	88
Cadmium		20% RPD	75-125%	<1%	88
Chromium (total)		20% RPD	75-125%	2%	83
Chromium (VI)		20% RPD	75-125%	NM	88
Copper		20% RPD	75-125%	<1%	88
Lead		20% RPD	75-125%	9%	76
Mercury		20% RPD	75-125%	6%	102
Manganese		20% RPD	75-125%	9%	85
Nickel		20% RPD	75-125%	10%	94
Selenium		20% RPD	75-125%	3%	98
Phosphorus		20% RPD	75-125%	2%	84
Metals in Stack Gas (Vapor Fraction)	Precision - Duplicate Analysis Accuracy - Matrix Spike				
Arsenic		20% RPD	75-125%	NC	NC ^e
Beryllium		20% RPD	75-125%	<1% ^d	77
Cadmium		20% RPD	75-125%	6	108
Copper		20% RPD	75-125%	5	80
Lead		20% RPD	75-125%	NC	NC ^e
Manganese		20% RPD	75-125%	<1% ^d	76
Mercury		20% RPD	75-125%	<1% ^d	98, 101
Nickel		20% RPD	75-125%	<1% ^d	69
Selenium		20% RPD	75-125%	<1% ^d	97

Table 4-3 (Continued)

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Stack Gas (Particulate Fraction)	Precision - Duplicate Analysis Accuracy - Matrix Spike				
Arsenic		20% RPD	75-125%	28	74
Beryllium		20% RPD	75-125%	<1 ^d	77
Cadmium		20% RPD	75-125%	5	69
Copper		20% RPD	75-125%	4	89
Lead		20% RPD	75-125%	5	87
Manganese		20% RPD	75-125%	4	78
Mercury		20% RPD	75-125%	<1 ^d	99
Nickel		20% RPD	75-125%	3	97
Selenium		20% RPD	75-125%	4	70
Chromium (Combined Value)		20% RPD	75-125%	23	104
PAHs in Stack Gas	Precision and Accuracy - Surrogate Spikes				
d10-Acenaphthene		35% CV	50-150%	7	32-36
d10-anthracene		35% CV	50-150%	11	50-62
d12-Chrysene		35% CV	50-150%	6	98-110
d12-Benzo(a)pyrene		35% CV	50-150%	28	36-54 ^f

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicate, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) between the duplicate results.

^cAccuracy is expressed as the range of recoveries expected for individual analysis results.

^dAll samples were "not detected".

^eMethod of standard additions used.

^fBased on only two results. No recovery value was reported for d12-benzo(a)pyrene in Run 9.

accuracy or bias at medium concentration levels, expressed as percent recovery, blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. The precision estimates for metals analyses at Site 105 are shown in Table 4-3. For this site, precision was estimated using analytical duplicates. Laboratory duplicate results give an estimate of precision based on laboratory variability alone; Table 4-3 presents precision objectives for sampling and analytical variability. There was no way to evaluate sampling variability at this site independent of variability in the process streams. However, analytical variability generally seemed to be within the stated objectives (20% RPD) for both fuel oil and stack gas. The only exceptions to this were:

- Arsenic in the particulate fraction of the stack gas (28% RPD); and
- Total chromium in the stack gas, combined particulate and vapor fraction (23% RPD).

In both cases, the RPD values were only slightly higher than the stated objectives. These exceptions should not have any major effect on the usability of the data.

Measurement data for replicate runs (Shown in Table A-1) showed good overall repeatability, except for nickel and lead in the vapor phase of the stack gas. The nickel value for Run 5 was an order of magnitude lower than in the other two runs. The quantity of nickel in the vapor phase is small when compared with the total concentration of nickel in the stack gas. Therefore, the deviation in the nickel concentrations for Run 5 may not affect overall data quality. For lead, the concentration in the vapor phase of the stack gas was approximately 10 times higher than the concentration in Runs 4 or 6. The source of the variation cannot be determined.

Accuracy. Accuracy estimates for metals analyses are shown in Table 4-3. These estimates are based on matrix spike recovery data, which show that recoveries for fuel oil, stack gas-vapor phase, and stack gas-particulate phase were generally within acceptance criteria. The only exceptions are nickel recovery in the stack gas vapor fraction (69% RPD), and cadmium recovery (69%) and zinc recovery (69%) in the stack gas particulate fraction. These exceptions should not be of significant concern.

Blanks. Blank results can be found in Table A-1. At Site 105, both reagent blanks and field blanks were analyzed for stack gas metals; no blanks were analyzed for fuel oil at this site. In the vapor phase of the stack gas, the field blanks were near the concentration of the samples measured during runs 4, 5, and 6 for the metals listed below:

- Cadmium;
- Copper;
- Lead; and
- Manganese

In most of these cases, a lower level of contamination was noted in the reagent blank, which indicates that there may have been multiple sources of contamination. In addition, blank values measured at these high levels make the Run 4, 5, and 6 concentrations for these metals highly suspect.

In the particulate phase of the stack gas, high blank values were found for beryllium (both field and reagent blank values), although the concentrations for the samples from Runs 4, 5, and 6 were measured below the detection limit. The blanks for the following metals had contamination at or near the levels measured in the actual samples:

- Lead (field blank and reagent blank);
- Manganese (field blank - reagent blank showed about half the concentration); and
- Selenium (reagent blank - field blank was not detected).

The high concentration of contamination in the blanks associated with these samples indicates that the measured values for these metals for Runs 4, 5, and 6 are suspect. In addition, the following metals showed blank contamination levels that were about half the concentration in the samples:

- Arsenic;
- Cadmium; and
- Copper.

The levels of contaminant in these blanks indicate that the results may be biased high; however, the information provided does not allow a calculation of bias.

PAHs

Precision. The precision estimates for Site 105 PAH analyses are summarized in Table 4-3. No duplicate sample or analysis data were available, so precision estimates are based on the deviation of surrogate recovery values in the three replicate test runs. These data show good precision for analysis of the four surrogate compounds, ranging from 6 to 28 %CV, all within the 35% objective.

The total variability for PAH analyses observed in the replicate test runs was relatively large compared with the concentrations measured, which were mostly below or near the detection limits, although there was an order of magnitude difference between the concentrations of some compounds measured in one test run versus another. The effect of these differences is reflected in confidence intervals greater than or equal to the mean values (shown in Table 3-2c).

Accuracy. The accuracy estimates for PAH analyses (shown in Table 4-3) are expressed as the range of surrogate recovery values for the three replicate test runs. Recoveries for two of the four surrogate compounds are low (32-36% and 36-54%), compared with the 50-150% objective. Recoveries for the other two surrogates (50-62% and 98-110%) are within the objective. These indicators suggest reliable analyses, with quantitation of some compounds possibly influenced by sample matrix effects.

Blanks. Eleven of the 15 polycyclic aromatic compounds analyzed were detected in the stack gas stream during oil firing: benz(a)anthracene, benzo(b+k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene. Of these, only fluoranthene and phenanthrene were detected in all three PAH runs. Naphthalene was detected in two runs and the remaining seven compounds were detected only once. A reagent blank analysis was not performed for these compounds; therefore, the field blanks results were used to correct the measured concentrations. For about half of these PAH compounds, the field blank levels were high, compared to the stack gas measurements (sometimes in excess of 100% of the measured concentration); these concentrations are marked with a "B" flag in Table 3-2c. Appendix A contains the blank results and raw reported values. The high levels of PAHs in the field blank make some of the PAH measurements suspect, but the lack of a reagent blank result makes it difficult to determine the cause of the high blank results.

Formaldehyde

Precision. The precision estimates for formaldehyde analyses (shown in Table 4-3) are based on matrix spike duplicate results. The relative percent difference for the duplicate spike recovery results is 12%, well within the 40% objective. No precision data were available for benzene.

Accuracy. The accuracy estimate for formaldehyde, expressed in terms of matrix spike recoveries, ranged from 98-112%, well within the 50-150% recovery objective. No recovery data were available for benzene.

Blanks. The concentrations presented for formaldehyde in the flue gas (for both oil and natural gas firing) are not corrected for the blank result. No formaldehyde was detected in the reagent blank. The benzene results are also uncorrected because no blank data were available.

Stack Gas Sampling Quality Control

Sampling quality control was addressed in a summary of the quality assurance program used by Carnot and in a letter of certification from the California Air Resources Board. Also documented were calibration records for the dry gas meters and a table outlining the schedule and procedures used for calibrating these and other equipment, and CEM standard certification sheets.

The precision of the sampling can be estimated by comparing results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location.

The accuracy of the sampling is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases that may be caused by contamination of the equipment or location, or operator errors. Blanks were included for all tests except the CARB 410 (benzene), which were grab bag samples.

The representativeness of the sampling depends on the precision and accuracy and also on the characteristics of the sampling locations. The sampling location, on the inlet ducts to the stack, was not ideal in terms of undisturbed flow distances upstream and downstream of the ports, at least from the diagrams provided (the dimensions, other than the cross-section of the duct, were not specified). In addition, although a large number of traverse points were used on both ducts together (40), administrative approval was given to sample only one for each test run, thus reducing the number by half. Because of this, the number of points should probably have been increased to the maximum required (24) for each duct. However, any bias caused by this was most likely minimal. The isokinetic variation is a measure of the operational performance of the sampling for particulate matter. It can be used to indicate precision and has consequences for representativeness. All of the sampling runs met the acceptance

criteria for isokinetic variation. Based on adherence to the approved stack gas sampling methods, discussed below, the samples collected should be considered representative. There are, however, significant variabilities in results for certain analytes from run to run. This has resulted in low confidence in the estimate of the average emissions for these compounds. Although corrected for, blank artifacts also contribute to the overall variability and uncertainty in the results, particularly in cases where the blank result is as large as the sample result. Although there might be some concern about collecting only three samples to characterize the two flue gas ducts, any disagreement between north and south duct sample results does not appear to be profound.

The comparability of sampling depends upon the representativeness of the samples and on the use of consistently applied standard methods. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011, using the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 method for semivolatile organic compounds, dioxins, and furans is well established both for sampling and analysis. The EPA multimetals procedure is still in the evaluation process, but is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container which is evacuated to fill a bag. Overall, there is no reason to conclude that the data reported would not be comparable with data from similar studies, although adherence to more formal and rigorous quality assurance protocols would enhance any such comparisons.

The completeness of the sampling is mainly a function of generating the requisite number of samples and proper documentation. In particular, the data necessary for calculating the results, including the calibration of the equipment and all pertinent entries on the run data sheets, should be present. Calibration data provided in this report were adequate, and sampling sheets were acceptably filled out, although impinger exit temperatures were not always present, and in the case of the PAH runs, condenser exit temperatures were substituted for them. The necessary number of samples were successfully taken and sample custody was transferred properly to the analytical laboratories. No data losses were noted.

Material Balance Results

At Site 105, the overall plant mass balance was simplified to one inlet (fuel oil) and one outlet (stack gas) stream. The composition measured in one flue gas duct was assumed to be the same in the other duct. Stream flow and concentration distributions (average and standard deviation) were entered into a statistical error propagation model to estimate the confidence intervals for the material balance closures. A detailed discussion of the statistical error propagation analysis appears in Appendix E. Appendix F contains detailed QA/QC data.

Closure is defined as the ratio of outlet to inlet mass flow rates. A 100% closure indicates perfect agreement between the outlet and inlet mass flow rates. When trace substances are analyzed, a closure of between 70% and 130% has been set as a goal for the FCEM project. This range reflects the typical level of analytical uncertainty and, therefore, allows the investigator to interpret the inlet and outlet stream component mass flow rates as being statistically equivalent. Poor closure values indicate an analytical or sampling problem with one or more types of sample matrices, excessive process variability, problems collecting representative samples, or a combination of these situations.

The measured oil flow rate was compared with the unit generating capacity by calculating a heat input using the oil flow rate, HHV, and an efficiency of 30 percent. The flow rate and generating capacity were in good agreement. Both oil and flue gas flow rates have small confidence intervals, indicating good precision in their measurements.

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

A number of trace elements were detected in the stack gas but not the fuel oil. Only chromium and nickel were detected in both the fuel oil and stack gas streams. As shown in Table 4-4, the closure for each of these compounds was outside the target range.

Chromium

The material balance closure, $14 \pm 11\%$, is outside the desirable range. The reagent blank level for the flue gas stream analysis was about one-fifth of the mean measured concentration. No blank data were available for the fuel oil stream. The spike recoveries for both streams were reasonable: 104% for the stack gas stream and 84% for the fuel oil.

Nickel

The material balance closure, $39 \pm 9\%$, is also below the desirable range. The broad confidence interval suggests that variability in the data could account for the poor result. Reagent blank concentrations for the flue gas stream analyses were small compared with the mean concentration. Spike recoveries in the gas stream were 69% for vapor-phase Ni and 97% for solid-phase Ni. In the fuel oil, the spike recovery was 94 percent.

Table 4-4
Material Balance Closure Results for Site 105

<u>Substance</u>	<u>Mean Closure (%)</u>	<u>95% CI ^a</u>
Chromium	14	11
Nickel	39	9

^aCI = Confidence interval.

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

$$C = \frac{(M - B)}{SV * F} * 35.3 * \frac{520}{492} \quad (5-1)$$

where:

- C = Concentration, $\mu\text{g}/\text{Nm}^3$
- M = Mass measured in the sample, μg
- B = Mass measured in the blank (reagent or field), μg
- SV = Sample volume (at 60° F), dscf
- F = Sample correction factor (see below)
- 35.3 = Conversion of ft^3 to m^3
- $\frac{520}{492}$ = Temperature correction for normal conditions, i.e., 32° F (60° F to 32° F)

The sample correction factor depends on the specific analytical procedure where:

- F = 0.95 for the multi-metals train since 5% of the sample was removed for mercury analysis.;
- F = 1.0 for mercury, benzene, formaldehyde, and PAHs; and

Example Calculations

- $F = 0.5$ for total and hexavalent chromium since one-half of the sample was used for each analysis.

Note that the mercury results were corrected for the sample aliquot in the analytical reports prepared by the lab. All concentrations are presented at normal conditions (32° F, 1 atm).

Unit Energy Calculations

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

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

$$E = \frac{(g_N + g_S) * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

E	=	Mean stack emission factor, lb/10 ¹² Btu
g_N	=	Mean flue gas flow rate, Nm ³ /hr (North Duct)
g_S	=	Mean flue gas flow rate, Nm ³ /hr (South Duct)
c	=	Mean total flue gas concentration, μ g/Nm ³
HHV	=	Mean oil higher heating value, Btu/lb
oil	=	Mean oil feed rate, lb/hr
2202.6	=	Unit conversion coefficient, lb/10 ¹² μ g

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

g_N	=	1,001,200 Nm ³ /hr
g_S	=	1,083,500 Nm ³ /hr
c	=	710 μ g/Nm ³
HHV	=	18,960 Btu/lb

$$\text{oil} = 338,700 \text{ lb/hr}$$

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

$$E = \frac{(1,001,200 + 1,083,500) * 710 * 2202.6}{18,960 * 338,700} = 510 \text{ lb}/10^2 \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{(g_N + g_S) * c}{h} * 2202.6 \quad (5-3)$$

where:

$$h = \text{Heat input (estimated by Carnot as 6,588 MMBtu/hr)}$$

Confidence Interval Calculations

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

CIs for Stream Concentrations

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

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

where:

$$U_{TOT} = 95\% \text{ CI for the total mean}$$

$$\beta_r = \text{Bias component}$$

Example Calculations

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

S_r = Standard deviation of the individual run measurements

N = Number of measurements

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

$$\beta_r = \sqrt{\sum_{i=1}^{N_i} (\beta_p * \theta_p)^2} \quad (5-5)$$

where:

β_{pi} = Bias for each run i

θ_{pi} = Sensitivity to run i = $1/N$

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Tables 3-2a, 3-2b, and 3-2c, will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Fraction</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>
Nickel	Solid Phase	720	670	730
Nickel	Vapor Phase	13	1.1	18
		<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>
Pyrene	Total	ND(0.009)	ND(0.009)	0.089

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

<u>Substance</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>Standard Deviation</u>
Nickel	730	670	740	710	38

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

$$\begin{aligned}\beta_r &= 0 \text{ (no values below the detection limit)} \\ t &= 4.3 \\ S_t &= 38 \\ N &= 3\end{aligned}$$

The 95% CI (U_{TOT}) for the total nickel concentration is $95 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for pyrene is calculated the same way. Since the concentrations for Runs 6 and 7 are below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>
β_p	0.0045	0.0045	0

The bias component is then calculated from Equation 5-5, using these values. In this example, the sensitivity is 0.33 or $1/3$.

$$\begin{aligned}\beta_r &= \sqrt{\left(\frac{0.0045}{3}\right)^2 + \left(\frac{0.0045}{3}\right)^2 + \left(\frac{0}{3}\right)^2} \\ &= 0.0021\end{aligned}$$

The standard deviation (S_t) calculated from the three individual pyrene concentrations is 0.049. Substituting these values into Equation 5-4,

$$\begin{aligned}U_{TOT} &= \sqrt{(0.0021)^2 + \left(\frac{4.3 * 0.049}{\sqrt{3}}\right)^2} \\ &= 0.12 \mu\text{g}/\text{Nm}^3\end{aligned}$$

CI's for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors and material balance closures were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A

Analytical Data from the Carnot Report

Table A-1
Results of the Sample, Field Blank, and Reagent Blank Analyses for
Site 105 Oil-Fired Test

<u>Substance</u>	<u>Mass Measured in Sample (μg)</u>				<u>Reagent Blank (μg)</u>	<u>Field Blank (μg)</u>
	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 6</u>		
<u>Volume, Nm³</u>	2.21	1.71	1.58			
<u>Vapor Phase (Oil-Firing)</u>						
As	0.94	1.1	1.2		ND(0.32)	ND(0.28)
Be	ND(0.05)	ND(0.05)	ND(0.05)		ND(0.06)	ND(0.06)
Cd	0.97	0.49	0.25		0.11	0.37
Cu	7.5	11	6.0		3.0	15
Pb	3.0	31	3.7		1.0	3.4
Mn	0.8	1.4	1.0		ND(0.65)	1.3
Hg (standard impinger)	ND(6.3)	ND(5.7)	ND(5.4)		ND(1.7)	ND(4.1)
(KMnO ₄ impinger)	ND(4.8)	ND(3.7)	ND(4.4)		ND(2.0)	ND(4.5)
Ni	29	1.8	27		ND(0.65)	5.9
Se	ND(2.7)	ND(2.7)	ND(2.7)		ND(3.2)	ND(2.8)
Zn	11	8.0	11		1.4	16
<u>Solid Phase (Oil-Firing)</u>						
As	15	6.7	11		2.0	5.0

Table A-1
(Continued)

Substance	Mass Measured in Sample (μg)				Reagent Blank (μg)	Field Blank (μg)
	Run 4	Run 5	Run 6	Run 8		
Be	ND(0.07)	ND(0.07)	ND(0.07)		0.18	0.09
Cd	1.5	1.5	0.74		ND(0.32)	0.64
Cu	21	28	30		8.3	11
Pb	47	50	53		42	45
Mn	16	15	13		6.1	14
Hg	ND(1.7)	ND(2.3)	ND(3.3)		ND(2.3)	ND(1.4)
Ni	1500	1100	1100		4.9	41
Se	14	21	8.4		7.7	ND(3.5)
Zn	180	100	260		20	23
Volume, Nm ³	Run 1 2.38	Run 2 2.29	Run 8 1.56			
Vapor Phase (Oil-Firing)						
Cr(VI)		ND(0.45)				
Solid Phase (Oil-Firing)						
Cr(VI)		0.12				

Table A-1
(Continued)

Substance	Mass Measured in Sample (μg)			Reagent Blank (μg)	Field Blank (μg)
	Run 1	Run 2	Run 8		
Combined Phase (Oil-Firing)					
Cr(VI) Comb	0.70		ND(0.50)		
Cr Comb	2.6	3.9	3.1	0.4	
Volume, Nm ³					
Nickel (CARB 433)					
Volume, Nm ³					
Acenaphthene					
Acenaphthylene					
Anthracene					
Benz(a)anthracene					
Benzo(a)pyrene					
Benzo(b + k)fluoranthene					

Table A-1
(Continued)

Substance	Mass Measured in Sample (µg)				Reagent Blank (µg)	Field Blank (µg)
	Run 6	Run 7	Run 8	Run 10		
Benzo(g,h,i)perylene	ND(0.025)	ND(0.025)	0.085		ND(0.025)	ND(0.025)
Chrysene	ND(0.025)	ND(0.025)	0.04		ND(0.025)	ND(0.025)
Dibenz(a,h)anthracene	ND(0.025)	ND(0.025)	0.028		ND(0.025)	ND(0.025)
Fluoranthene	0.12	0.095	0.43		0.054	
Fluorene	ND(0.025)	0.14	0.32		0.12	
Indeno(1,2,3-c,d)pyrene	ND(0.025)	ND(0.025)	0.076		ND(0.025)	
Naphthalene	95	97	22		22	
Phenanthrene	0.29	0.22	0.69		0.071	
Pyrene	0.079	0.078	0.32		0.082	
Volume, Nm ³	Run 8 0.027	Run 9 0.043	Run 10 0.048			
Formaldehyde	36.2	36.1	19.7		ND(0.89)	16.2

Table A-2
Results of the Sample, Field Blank, and Reagent Blank Analyses for
Site 105 Gas-Fired Tests

<u>Substance</u>	<u>Mass Measured in Sample (μg)</u>			<u>Reagent Blank (μg)</u>	<u>Field Blank (μg)</u>
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Volume, Nm ³	0.068	0.049	0.036		
Formaldehyde	36.2	36.1	19.7	ND(0.89)	16.2

Appendix B
Stream Composition Data

This appendix presents the results from the Site 105 sampling event in February 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 105 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented in the Carnot report, which are shown in Appendix A. These concentrations were corrected for the reagent or field blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis and the field blank analysis. The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration is presented as the detection limit.

The stack (emitted) gas at Site 105 was sampled for nickel by two different methods--Draft EPA Metals Method and CARB Method 433. The results for the CARB Method 433 test are presented as "Emitted gas, alternate." The CARB 433 results were not used in any calculations presented in the body of the report.

Table B-1 Site 105 Stream Concentrations During 011-Fired Tests

Substance	Method	Unit	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				6.6
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv	<	<	<	
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	1	1	1	
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				< 0.03
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				1.1
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS)	ug/nm3	1.9	3.1		
Chrysene	Ion chromatography (IC)	ug/nm3	0.59	< 0.4		
Copper	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				8.2
Dibenz(a,h)anthracene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Formaldehyde	HPLC, reversed-phase	ug/nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				3.3
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				5.1
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3				< 5.3
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				730
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				3
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				80
>>>> Emitted gas, alternate <<<<						
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/nm3				910

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B<	B<	B<
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	<
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B<	B<	B<
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	3.6	6.8		
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	0.11
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv				
Benzof(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	<
Benzo(b,k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	0.056
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	0.034
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	<		
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.05	0.05		
Chromium	Inductively coupled argon plasma emission spectrophotometry (AAS)	ug/Nm3	1.2	0.59		3.7
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS)	ug/Nm3				0.6
Chrysene	Ion chromatography (IC)	ug/Nm3		<	<	0.015
Copper	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	17	17		
Dibenz(a,h)anthracene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		<	<	0.01
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		0.023	B	0.15
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B<	B<	0.075
Formaldehyde	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		<	<	1300
Indeno(1,2,3-c,d)pyrene	HPLC, reversed-phase	ug/Nm3		<	<	0.029
Lead	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	24	B		
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	6.3	5.3		
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	5.8	6.6		
Naphthalene	Atomic absorption spectrophotometry, cold vapor (CVAAAS)	ug/Nm3		26	28	B<
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	670	740		0.01
Phenanthrene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		0.078	0.054	0.24
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B<	B<	0.089
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	8.2	B		
Zinc	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	53	160		
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Emitted gas, alternate <<<<						
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	960	840		

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run
>>>> Emitted gas <<<<					
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv			
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Chromium	Atomic absorption spectrophotometry (AAS)	ug/Nm3			
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3			
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Formaldehyde	HPLC, reversed-phase	ug/Nm3	840	400	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
>>>> Emitted gas, alternate <<<<					
Nickel	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3			

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				0.45
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				< 0.02
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				0.41
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				2.1
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				0.95
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				0.38
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				5.3
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				13
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				1.2
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				4.5
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				6.1
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				< 0.03
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				0.72
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				6
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				2.3
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				4.7
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				< 0.8
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				720
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				3
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				76
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				1.1
Beryllium	EPA method 6010	mg/l				< 0.22
Cadmium	EPA method 6010	mg/l				< 0.22
Carbon	Not specified	wt %				84.97
Chloride	ASTM D808-87	mg/l				799
Chromium	EPA method 6010	mg/l				0.26
Chromium, hexavalent	EPA method 6010	mg/l				< 0.5
Copper	EPA method 6010	mg/l				< 0.43
Hydrogen	Not specified	wt %				12.47
Lead	EPA method 6010	mg/l				< 1.1
Manganese	EPA method 6010	mg/l				< 0.43
Mercury	EPA method 6010	mg/l				< 0.1
Nickel	EPA method 6010	mg/l				24

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	0.68	0.8		
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	0.05		
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.24	0.094		
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	4.9	8		
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	19	1.8		
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.86	0.67		
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<	6.6		
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	1.1	18		
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	<	1.8		
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	4	6.4		
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	2.9	6		
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	0.05		
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.93	0.49		
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	12	15		
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	4.9	7.4		
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	5.5	4.6		
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<	2.2		
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	670	730		
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	8.2	0.47		
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	49	160		
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Not specified	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Not specified	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run
>>>> Emitted gas, gas phase <<<<					
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
>>>> Emitted gas, solid phase <<<<					
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
Selenium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			
>>>> Oil <<<<					
Arsenic	EPA method 6010	mg/l			
Beryllium	EPA method 6010	mg/l			
Cadmium	EPA method 6010	mg/l			
Carbon	Not specified	wt %			
Chloride	ASTM D808-87	mg/l			
Chromium	EPA method 6010	mg/l			
Chromium, hexavalent	EPA method 6010	mg/l			
Copper	EPA method 6010	mg/l			
Hydrogen	Not specified	wt %			
Lead	EPA method 6010	mg/l			
Manganese	EPA method 6010	mg/l			
Mercury	EPA method 6010	mg/l			
Nickel	EPA method 6010	mg/l			

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Oxygen	Not specified	wt %				1.95
Phosphorus	EPA method 6010	mg/l				7.73
Selenium	EPA method 6010	mg/l				<
Sulfur	ASTM D129-64	wt %				1
Zinc	EPA method 6010	mg/l				0.38
>>> Oil, duplicate <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Not specified	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Not specified	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Oxygen	Not specified	wt %				
Phosphorus	EPA method 6010	mg/l				
Selenium	EPA method 6010	mg/l				
Sulfur	ASTM D129-64	wt %				
Zinc	EPA method 6010	mg/l				
>>> Oil, duplicate <<<<						
Arsenic	EPA method 6010	mg/l				1.1
Beryllium	EPA method 6010	mg/l				< 0.22
Cadmium	EPA method 6010	mg/l				< 0.22
Carbon	Not specified	wt %				84.3
Chloride	ASTM D808-87	mg/l				630
Chromium	EPA method 6010	mg/l				0.28
Chromium, hexavalent	EPA method 6010	mg/l				< 0.5
Copper	EPA method 6010	mg/l				< 0.43
Hydrogen	Not specified	wt %				12.83
Lead	EPA method 6010	mg/l				< 1.1
Manganese	EPA method 6010	mg/l				< 0.43
Mercury	EPA method 6010	mg/l				< 0.1
Nickel	EPA method 6010	mg/l				22
Oxygen	Not specified	wt %				2.27
Phosphorus	EPA method 6010	mg/l				8.38
Selenium	EPA method 6010	mg/l				1
Sulfur	ASTM D129-64	wt %				< 0.35
Zinc	EPA method 6010	mg/l				0.82

Table B-1 Site 105 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run
Oxygen	Not specified	wt %			
Phosphorus	EPA method 6010	mg/l			
Selenium	EPA method 6010	mg/l			
Sulfur	ASTM D129-64	wt %			
Zinc	EPA method 6010	mg/l			
>>>> Oil, duplicate <<<<					
Arsenic	EPA method 6010	mg/l			
Beryllium	EPA method 6010	mg/l			
Cadmium	EPA method 6010	mg/l			
Carbon	Not specified	wt %			
Chloride	ASTM D808-87	mg/l			
Chromium	EPA method 6010	mg/l			
Chromium, hexavalent	EPA method 6010	mg/l			
Copper	EPA method 6010	mg/l			
Hydrogen	Not specified	wt %			
Lead	EPA method 6010	mg/l			
Manganese	EPA method 6010	mg/l			
Mercury	EPA method 6010	mg/l			
Nickel	EPA method 6010	mg/l			
Oxygen	Not specified	wt %			
Phosphorus	EPA method 6010	mg/l			
Selenium	EPA method 6010	mg/l			
Sulfur	ASTM D129-64	wt %			
Zinc	EPA method 6010	mg/l			

Table B-2 Site 105 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<						
Benzene	Gas chromatography-mass spectroscopy (GC-MS)	ppbv	<	<	<	4
Formaldehyde	HPLC, reversed-phase	ug/Mn3	580	990	990	990

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Appendix C summarizes the sampling and analytical methods used at Site 105. The following text describes these procedures. The text is paraphrased from Carnot report CR-71109-2046. Table C-1 summarizes the methods by sample stream. Table C-2 presents the sampling periods for gas streams. Table C-3 summarizes sampling and analytical methods by analyte group.

Sampling and Analytical Procedures

All tests were performed with the boiler operating at 96% or more of full load. The boiler was operated under normal control settings throughout the test program. Continuous soot blowing was in effect while firing oil. Details of process conditions during testing can be found in Appendix D.

Sampling Locations

Measurements were performed at the existing sample ports located in each of the two ducts between the boiler air preheater and the stack. Each duct measured 16-1/2 feet by 20-1/2 feet at the sampling location, and there were 4 sample ports per duct. For each isokinetic test, a five-point traverse was made at each sample port, providing a 20-point measurement grid on each duct. The concentrations measured in one duct were assumed to be the same for the other duct.

CO₂ and O₂ Measurements

CO₂ and O₂ were measured using Carnot's Continuous Emissions Monitor (CEM) system. The system meets EPA requirements. A portable O₂ sensor was used to perform a 28 point O₂ traverse in conjunction with each isokinetic test. CO₂ was measured at a fixed point in the north duct at a location 1/2 duct diameter upstream of the sampling plane.

Table C-1
Summary of Sampling and Analytical Methods

<u>Analyte</u>	<u>Reference Method</u>	<u>Analytical Method</u>	<u>Analytical DL</u>	<u># Duplicates Notes</u>
<u>Exhaust Gas</u>				
PAH	CARB 429	GC/MS	17 ng/m ³	3
Formaldehyde	CARB 430	HPLC	13 ppb	3 Each Fuel
Benzene	CARB 410A	GC/PID	1-4 ppb	3 Each Fuel
Cr (Total)	CARB 425	AAS	0.3 µg/m ³	3
Cr(VI)	CARB 425	Ion Chromatography	0.6 µg/m ³	3
Metals	Draft EPA	(see Table C-2)	(see Table A-2)	3
Nickel	CARB 433	Flame AAS	0.5 µg/m ³	3
O ₂	EPA 3A	Electrochem Cell	0.5%	In Conjunction ^a
CO ₂	EPA 3A	Nondispersive IR	0.5%	In Conjunction ^a
Velty/Moisture	EPA 1,2,4	Pitot Trav, Grav.		In Conjunction ^{a,b}
<u>Fuel Oil</u>				
Metals	EPA 6010			2
Sulfur	ASTM D129-64			2
Chlorides	ASTM D808-87			2

^aO₂, CO₂, H₂O, and velocity tests were performed in conjunction with all isokinetic tests.

^bVelocity and moisture tests also performed on natural gas fuel.

Table C-2
Summary of Metals Analytical Methods

<u>Metal</u>	<u>Analytical Method</u>	<u>DL (ug/m³)^a</u>
Be	ICP	0.06
Cr	Graphite Furnace AA	0.30
As	Graphite Furnace AA	0.30
Cd	ICP	0.10
Cu	ICP	0.70
Pb	Graphite Furnace AA	3.20
Mn	ICP	0.60
Hg	Cold Vapor AA	13
Ni	ICP	0.60
Se	Graphite Furnace AA	3.40
Zn	ICP	0.60

^aAssumes a 1.9 Nm³ sample.

Table C-3
Summary of Gas Stream Sampling Runs
(Flue Gas)

<u>Date</u>	<u>Metals</u>	<u>Nickel</u>	<u>Cr(VI)</u>	<u>Benzene</u>	<u>Formald</u>	<u>PAH</u>	<u>Velc/ Moist</u>
2/13/90			0839-1132	1232-1252			
			1202-1415	1256-1312			
				1314-1334			
2/14/90	0944-1200	0944-1200					
	1424-1634	1424-1634					
2/15/90	0830-1040	0830-1040				1259-1609	
2/16/90						0909-1231	
2/17/90			0941-1154		1429-1459	0848-1239	
					1510-1540		
					1557-1627		
2/18/90				0903-0913	1040-1110		0856-0925
				0919-0929	1120-1150		0957-1027
				1004-1009	1205-1235		

Velocity and Moisture

Velocity and moisture were determined in conjunction with all isokinetic tests according to EPA Methods 1, 2, and 4. Non-isokinetic point tests were performed during separate velocity traverses. The average duct velocity is applied to the single point test.

Metals Analysis

Reagent and field blanks were analyzed for all trace metals. A mandatory check for matrix effects was performed for each metal, except hexavalent chromium, by spiking one sample.

If the recovery was less than $\pm 25\%$ of nominal, all samples were analyzed using the method of standard additions. A duplicate analysis was performed for each metal. Acceptable criteria for agreement between duplicates was ± 10 percent. Because of matrix effects for some metals, 0% recovery was reported for graphite furnace measurements. The following criteria were then established for this test series:

- For GFAAS results with recoveries of less than $\pm 25\%$ of nominal were samples analyzed using the method of standard additions;
- Where GFAAS showed no response to standard additions, ICP was used; and
- Where GFAAS detection limits were higher than ICP, ICP was used.

Triplicate samples were collected for metals analysis; two samples at the north duct and one sample at the south duct.

Metals Sampling

Samples for metals analysis were collected by three separate sample trains are discussed in the following paragraphs.

Multi-Metals Train

Samples to be analyzed for arsenic, beryllium, cadmium, copper, lead, manganese, mercury, nickel, selenium and zinc were collected using an EPA draft metals method titled "Methodology for the Determination of Metals Emissions in Exhaust Gases from Stationary Source Combustion Processes." The sample train is of the same configuration as a CARB Method 5 train, with the following exceptions:

- The probe is Teflon® to eliminate metal contamination of the sample;
- The filter is Teflon® coated fiberglass to minimize interferences;
- The first two impingers contain dilute nitric acid and hydrogen peroxide to collect any volatile metals which pass through the filter; and
- The third impinger contains an acidified potassium permanganate solution to collect any mercury that is not collected in the nitric acid impingers.

Analyses for these metals was performed by ICP, graphite furnace and cold vapor atomic adsorption, depending upon the metal. Decomposition of each sample fraction is described in the EPA draft method. Whenever possible, decomposed sample portions were concentrated and combined, with regard to preventing loss of volatile metals, to achieve the lowest detection limits possible for these samples. Five percent of the decomposed probe wash/filter extract and 5% of the nitric acid/peroxide impinger catch was removed for mercury analysis. The remaining 95% of these sample portions was concentrated to a total volume of 50 mL and analyzed for metals. The probe wash/filter portions and the impinger catch portions were analyzed separately. The KMnO₄ impinger portion was analyzed for mercury only.

Chromium and Nickel Trains

CARB Method 425 was used for total and hexavalent chromium. In order to achieve a low detection limit, a separate sample train was used. Ion chromatography was chosen as the analytical method, which provides lower detection limits than the colorimetric method. A separate train was run for nickel using CARB 433. The was performed at the request of CARB for inclusion in the CARB Metals Validation Study.

PAH

PAH samples were collected according to the sampling procedures of CARB Method 429, also known as the semi-VOST or "Modified Method 5." Table 3-5 summarizes the pertinent information for these tests. In this procedure, a sample is collected isokinetically and passed through a heated Method 5 filter followed by and XAD-2 sorbent module in a water cooled jacket. The sorbent module is followed by an impinger train to collect moisture an any semivolatile species that might pass through the resin. GC/MS with selected ion monitoring was used to analyze PAH. The procedure provides the lowest detection limits possible for these samples. A full field blank as collected and analyzed for PAH. For a field blank, a separate sample train was assembled, transported, leak checked, rinsed, and recovered in the same was as the sample train. This provided a blank value not only for the analytical procedures but also for the reagents, filter, and any possible contamination introduced by sample handling.

VOC

Samples for benzene were collected in Tedlar bags and analyzed by GC/MS. Formaldehyde samples were collected nonisokinetically according to CARB Method 430 using midget impingers in acidic 2,4-dinitrophenylhydrazine solution. The analysis for formaldehyde was performed using reverse-phase HPLC. A field blank and field spike were also submitted for analysis.

Fuel Analysis

Duplicate samples of fuel oil were analyzed for metals using EPA Method 6010, sulfur using ASTM Method D129-64, and chlorides using ASTM Method D808-87. Gas fuel analysis was obtained from the plant.

Appendix D
Process Data

Table D-1
Fuel Oil Flow Rates

<u>Date</u>	<u>Time</u>	<u>Average Flow Rate</u> <u>gal/hr @ 60° F</u>	<u>Average</u> <u>MMBtu/hr</u>
2/13	0830/1618	43,672	6,428
2/14	1430/1610	43,658	6,413
2/15	0842/1101	43,790	6,425
2/15	1318/1553	44,162	6,445
2/16	0929/1328	43,590	6,500
2/17	0856/1225	43,672	6,416

Table D-2

**Natural Gas Analysis February 18, 1990
Average of 17 Samples (0756 - 1655)**

Species	Vol % *
CH ₄	92.467
C ₂ H ₆	4.531
C ₃ H ₈	0.729
C ₄ H ₁₀ -I	0.05
C ₄ H ₁₀ -N	0.58
C ₅ H ₁₂ -I	0.018
C ₅ H ₁₂ -N	0.014
C ₆ H ₆	0.016
CO ₂	1.227
N ₂	0.892

Molecular weight = 17.67.

HHV = 1042.5 Btu/scf.

Fuel Factor (60°F) = 8,599 dscf/10⁶ Btu @ 0% O₂.

*Analyses performed by on-line GC.

Table D-3
Process Condition Data

Oil-Fired Operation		Process Condition Data										
Date	Time	Test	Run	Duct	Flue Gas (10 ³ Nm ³ /hr)	Load (MW)	(MMBtu/hr)	O ₂ (%)	CO ₂ (%)	H ₂ O (%)	% Isokinetic	Temperature (°F)
2/13	0839/1132	Cr	1	N	1052	727	6428	5.12	11.78	9.4	94.07	255.4
2/13	1202/1415	Cr	2	S	1014	727	6428	5.13	11.72	10.1	101.9	255.6
2/13	1232/1252	Benzene	1	S	-	727	6428	-	-	-	-	-
2/13	1256/1312	Benzene	2	S	-	727	6428	-	-	-	-	-
2/13	1314/1334	Benzene	3	N	-	727	6428	-	-	-	-	-
2/14	0949/1200	Ni	4	S	1152	717	6413	-	11.92	9.2	97.57	241.1
2/14	0944/1200	Multi-Metals	4	N	1016	717	6413	4.96	11.92	10.2	96.19	254.1
2/14	1424/1634	Ni	5	N	1035	725	6413	5.03	11.88	9.5	98.58	261.6
2/14	1424/1634	Multi-Metals	5	S	1129	725	6413	-	11.88	9.2	97.14	244.6
2/15	0830/1040	Ni	6	S	1128	723	6425	5.23	11.70	9.3	97.29	246.1
2/15	0830/1040	Multi-Metals	6	N	1011	723	6425	4.83	11.99	10.1	99.99	257.7
2/15	1259/1609	PAH	6	S	1083	726	6445	5.07	11.82	9.3	95.65	239.9
2/16	0909/1231	PAH	7	N	963	730	6500	5.11	11.69	10.1	100.63	266.2
2/17	0848/1239	PAH	8	N	931	729	6416	5.24	11.63	9.4	98.88	268.5
2/17	0941/1154	Cr	8	S	996	729	6416	4.88	12.09	9.7	100.62	257.9
2/17	1429/1459	Formaldehyde	8	N	931	729	6416	-	-	-	-	267.3
2/17	1510/1540	Formaldehyde	9	N	931	729	6416	-	-	-	-	234.6
2/17	1557/1627	Formaldehyde	10	S	995	729	6416	-	-	-	-	238.7

Table D--3
(Continued)

Process Condition Data												
Gas-Fired Operation												
Date	Time	Test	Run	Duct	Flue Gas (10 ³ Nm ³ /hr)	Load (MW)	(MMBtu/hr)	O ₂ (%)	CO ₂ (%)	H ₂ O (%)	% Isokinetic	Temperature (°F)
2/18	0903/0913	Benzene	1	S	-	728	6588	-	-	-	-	-
2/18	0919/0929	Benzene	2	S	-	728	6588	-	-	-	-	-
2/18	1004/1009	Benzene	3	N	-	728	6588	-	-	-	-	-
2/18	1040/1110	Formaldehyde	1	N	1065	728	6588	-	-	-	-	228.4
2/18	1120/1150	Formaldehyde	2	N	1065	728	6588	-	-	-	-	202.3
2/18	1205/1235	Formaldehyde	3	S	1002	728	6588	-	-	-	-	248.8

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 105 are included here.

Emission Factor and Mass Balance Results

XXXXXXXXXXXXXXXXXXXX

X

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UNCERTAINTY CONTRIBUTOR					

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
CLOSURE	Zinc out/in MB	%	157.7021	7.52E+00	2.49E+02	2.5E+02	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) CO	outlet conc	ug/Nm^3	94	PREC	5.84E+04	1.68E+00	2.50E+02	3
2) CI	inlet conc	mg/L	.75	PREC	3.36E+03	-1.92E+02	4.26E-01	2
3) G2	duct 2 flow	Nm^3/hr	1083511	PREC	7.48E+01	7.56E-05	2.80E+05	6
4) VOL	fuel vol flowr	gal/hr	43740	BIAS	5.65E+01	-3.43E-03	2.19E+03	-
5) G1	duct 1 flow	Nm^3/hr	1001200	PREC	3.66E+01	7.56E-05	1.96E+05	6
6) VOL	fuel vol flowr	gal/hr	43740	PREC	1.76E+00	-3.43E-03	9.47E+02	6

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Appendix E

	X					
	X					
	X					
C	X					
O	X					
N	X					
N	X					
O	X					
T	X					
R	X					
R	X					
M	X					
I	X					
A	X	X				
B	X	X				
L	X	X				
U	X	X				
I	X	X				
T	X	X				
Z	X	X				
I	X	X				
E	X	X				
O	X	X				
D	X	X				
N	X	X				
S	X	X				
*	X	X				
*	X	X				
	X	X	X	X		

		1	2	3	4	5	6		
		UNCERTAINTY CONTRIBUTOR							
OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM	
CLOSURE	Nickel out/in MB	%	38.842	1.85E+00	9.04E+00	9.2E+00	4.30E+00	2.5E+00	

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) C1	inlet conc	mg/L	23	PREC	4.82E+01	-1.62E+00	6.07E+00	2
2) C0	outlet conc	ug/Nm^3	710	PREC	2.67E+01	5.47E-02	1.64E+02	3
3) G2	duct 2 flow	Nm^3/hr	1083511	PREC	4.54E+00	1.86E-05	2.80E+05	6
4) VOL	fuel vol flowr	gal/hr	43740	BIAS	3.43E+00	-8.46E-04	2.19E+03	-
5) G1	duct 1 flow	Nm^3/hr	1001200	PREC	2.22E+00	1.86E-05	1.96E+05	6
6) VOL	fuel vol flowr	gal/hr	43740	PREC	1.07E-01	-8.46E-04	9.47E+02	6

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ =PRECISION INDEX OF THE MEAN, $Sp/(NUMBER \ OF \ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

[illegible]

1	2	3	4	5	6
				UNCERTAINTY CONTRIBUTOR	

OUTPUT VARIABLE			AVERAGE	ABSOLUTE BIAS	ABSOLUTE PRECISION	ABSOLUTE TOTAL	STUDENT	DEGREES OF
NAME	DESCRIPTION	UNITS	VALUE	COMPONENT	COMPONENT*	UNC	t	FREEDOM
CLOSURE	Chromium out/in MB	%	13.51466	6.44E-01	1.10E+01	1.1E+01	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAP)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) CO	outlet conc	ug/Nm^3	2.9	PREC	1.16E+02	4.66E+00	4.00E+00	3
2) CI	inlet conc	mg/L	.27	PREC	4.23E+00	-4.83E+01	6.02E-02	2
3) G2	duct 2 flow	Nm^3/hr	1083511	PREC	5.50E-01	6.48E-06	2.80E+05	6
4) VOL	fuel vol flowr	gal/hr	43740	BIAS	4.15E-01	-2.94E-04	2.19E+03	-
5) G1	duct 1 flow	Nm^3/hr	1001200	PREC	2.68E-01	6.48E-06	1.96E+05	6
6) VOL	fuel vol flowr	gal/hr	43740	PREC	1.29E-02	-2.94E-04	9.47E+02	6

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

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: ARSENIC

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	4.07644520	1.94E-01	3.23E+00	3.23E+00	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	5.7	PREC	1.03E+01	7.15E-01	7.79E+00	3
Gas Flow 2	dscm/hr	1083500	PREC	4.99E-02	0.00000195	2.80E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	3.75E-02	-1.15E-05	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	2.44E-02	1.96E-06	1.96E+05	6
Fuel Flowrate	lb/hr	338697	PREC	1.21E-03	-1.15E-05	7.44E+03	6
Fuel Oil	BTU/lb	18957	PREC	1.37E-05	-2.15E-04	2.43E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: BERYLLIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.03575829	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	1.72E-08	ERR	6
Tot Conc	mg/Nm ³	0.05	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-1.89E-06	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000001	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-1.01E-07	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	2.89E-06	-1.01E-07	1.69E+04	-

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CADMIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.68655919	3.26E-02	5.75E-01	5.76E-01	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.96	PREC	3.28E-01	7.15E-01	1.39E+00	3
Gas Flow 2	dscm/hr	1083500	PREC	1.42E-03	0.00000032	2.80E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.06E-03	-1.93E-06	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	6.95E-04	3.29E-07	1.96E+05	6
Fuel Flowrate	lb/hr	338697	PREC	3.45E-05	-1.93E-06	7.45E+03	6
Fuel Oil	BTU/lb	18957	PREC	3.90E-07	-3.62E-05	2.44E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CHROMIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	2.07398089	9.86E-02	1.65E+00	1.65E+00	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	2.9	PREC	2.70E+00	7.15E-01	3.98E+00	3
Gas Flow 2	dscm/hr	1083500	PREC	1.29E-02	0.00000099	2.80E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	9.72E-03	-5.83E-06	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	6.31E-03	9.95E-07	1.96E+05	6
Fuel Flowrate	lb/hr	338697	PREC	3.14E-04	-5.83E-06	7.44E+03	6
Fuel Oil	BTU/lb	18957	PREC	3.54E-06	-1.09E-04	2.43E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CHROMIUM(VI)

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.42909949	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	2.06E-07	ERR	6
Tot Conc	mg/Nm ³	0.6	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-2.26E-05	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000020	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-1.21E-06	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	4.16E-04	-1.21E-06	1.69E+04	-

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: COPPER

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	10.0123215	4.76E-01	9.37E+00	9.38E+00	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	14	PREC	8.73E+01	7.15E-01	2.26E+01	3
Gas Flow 2	dscm/hr	1083500	PREC	3.05E-01	0.00000480	2.82E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	2.26E-01	-2.82E-05	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.49E-01	4.80E-06	1.97E+05	6
Fuel Flowrate	lb/hr	338697	PREC	7.40E-03	-2.82E-05	7.48E+03	6
Fuel Oil	BTU/lb	18957	PREC	8.35E-05	-5.28E-04	2.45E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: LEAD

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	8.58198991	4.08E-01	1.89E+01	1.90E+01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	12	PREC	3.59E+02	7.15E-01	4.59E+01	3
Gas Flow 2	dscm/hr	1083500	PREC	2.30E-01	0.00000411	2.85E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.66E-01	-2.41E-05	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.12E-01	4.12E-06	1.99E+05	6
Fuel Flowrate	lb/hr	338697	PREC	5.58E-03	-2.41E-05	7.58E+03	6
Fuel Oil	BTU/lb	18957	PREC	6.30E-05	-4.53E-04	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: MANGANESE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	4.00492862	1.90E-01	1.11E+00	1.12E+00	3.8	2.2

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	5.6	PREC	1.17E+00	7.15E-01	2.62E+00	3
Gas Flow 2	dscm/hr	1083500	PREC	3.81E-02	0.00000192	2.49E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	3.62E-02	-1.13E-05	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.86E-02	1.92E-06	1.74E+05	6
Fuel Flowrate	lb/hr	338697	PREC	9.25E-04	-1.13E-05	6.62E+03	6
Fuel Oil	BTU/lb	18957	PREC	1.04E-05	-2.11E-04	2.16E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: MERCURY

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	4.72009445	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	2.26E-06	ERR	6
Tot Conc	mg/Nm ³	6.6	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-2.49E-04	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000226	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-1.33E-05	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	5.03E-02	-1.33E-05	1.69E+04	-

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: NICKEL

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	507.767736	2.41E+01	5.26E+01	5.79E+01	3.0	3.1

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	710	PREC	2.21E+03	7.15E-01	1.14E+02	3
Fuel Flowrate	lb/hr	338697	BIAS	5.82E+02	-1.43E-03	1.69E+04	-
Gas Flow 2	dscm/hr	1083500	PREC	3.71E+02	0.00024356	1.94E+05	6
Gas Flow 1	dscm/hr	1001200	PREC	1.81E+02	2.44E-04	1.35E+05	6
Fuel Flowrate	lb/hr	338697	PREC	9.01E+00	-1.43E-03	5.15E+03	6
Fuel Oil	BTU/lb	18957	PREC	1.02E-01	-2.68E-02	1.68E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: SELENIUM

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	2.78914672	1.33E-01	7.15E+00	7.15E+00	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	3.9	PREC	5.10E+01	7.15E-01	1.73E+01	3
Gas Flow 2	dscm/hr	1083500	PREC	2.43E-02	0.00000133	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.76E-02	-7.84E-06	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.19E-02	1.34E-06	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	5.90E-04	-7.84E-06	7.59E+03	6
Fuel Oil	BTU/lb	18957	PREC	6.67E-06	-1.47E-04	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: ZINC

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	100.123215	4.76E+00	1.03E+02	1.03E+02	4.3	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	140	PREC	1.05E+04	7.15E-01	2.48E+02	3
Gas Flow 2	dscm/hr	1083500	PREC	3.06E+01	0.00004802	2.82E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	2.26E+01	-2.82E-04	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.50E+01	4.80E-05	1.97E+05	6
Fuel Flowrate	lb/hr	338697	PREC	7.44E-01	-2.82E-04	7.50E+03	6
Fuel Oil	BTU/lb	18957	PREC	8.40E-03	-5.28E-03	2.45E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
 SUBSTANCE: BENZENE (OIL FIRING)

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	2.50308039	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	1.20E-06	ERR	6
Tot Conc	mg/Nm ³	3.5	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-1.32E-04	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000120	ERR	6
Fuel Flowrate lb/hr		338697	PREC	ERR	-7.04E-06	ERR	6
Fuel Flowrate lb/hr		338697	BIAS	1.42E-02	-7.04E-06	-1.69E+04	-

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: FORMALDEHYDE (OIL FIRING)

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	615.042610	2.92E+01	8.48E+02	8.48E+02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	860	PREC	7.17E+05	7.15E-01	2.05E+03	3
Gas Flow 2	dscm/hr	1083500	PREC	1.17E+03	0.00029502	2.84E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	8.54E+02	-1.73E-03	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	5.72E+02	2.95E-04	1.98E+05	6
Fuel Flowrate	lb/hr	338697	PREC	2.84E+01	-1.73E-03	7.55E+03	6
Fuel Oil	BTU/lb	18957	PREC	3.21E-01	-3.24E-02	2.47E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: ACENAPHTHENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.00715165	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.43E-09	ERR	6
Tot Conc	mg/Nm ³	0.01	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.77E-07	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-2.01E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	1.16E-07	-2.01E-08	1.69E+04	-

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
 SUBSTANCE: ACENAPHTHYLENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.00715165	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.43E-09	ERR	6
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.77E-07	ERR	2
Tot Conc	mg/Nm ³	0.01	PREC	ERR	ERR	ERR	3
Fuel Flowrate	lb/hr	338697	PREC	ERR	-2.01E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	1.16E-07	-2.01E-08	1.69E+04	-

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: ANTHRACENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.00715165	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.01	PREC	ERR	ERR	ERR	3
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.77E-07	ERR	2
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.43E-09	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-2.01E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	1.16E-07	-2.01E-08	1.69E+04	-

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
 SUBSTANCE: BENZ(A)ANTHRACENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.02860663	1.61E-03	1.11E-01	1.11E-01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.04	PREC	1.22E-02	7.15E-01	2.68E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	2.57E-06	0.00000001	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.85E-06	-8.04E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.25E-06	1.37E-08	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	6.23E-08	-8.04E-08	7.60E+03	6
Fuel Oil	BTU/lb	18957	PREC	7.03E-10	-1.51E-06	2.49E+01	2

* $t \times Sr$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: BENZO(A)PYRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.00715165	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.43E-09	ERR	6
Tot Conc	mg/Nm ³	0.01	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.77E-07	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-2.01E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	1.16E-07	-2.01E-08	1.69E+04	-

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: BENZO(B+K)FLUORANTHENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01573364	1.14E-03	5.44E-02	5.44E-02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.022	PREC	2.96E-03	7.15E-01	1.32E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	7.76E-07	0.00000000	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	5.59E-07	-4.42E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	3.79E-07	7.55E-09	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	1.88E-08	-4.42E-08	7.60E+03	6
Fuel Oil	BTU/lb	18957	PREC	2.13E-10	-8.30E-07	2.49E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: BENZO(G,H,I)PERYLENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01001232	9.89E-04	3.08E-02	3.08E-02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.014	PREC	9.49E-04	7.15E-01	7.46E-02	3
Gas Flow 2	dscm/hr	1083500	PREC	3.14E-07	0.00000000	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	2.26E-07	-2.82E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.53E-07	4.80E-09	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	7.62E-09	-2.82E-08	7.59E+03	6
Fuel Oil	BTU/lb	18957	PREC	8.60E-11	-5.28E-07	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: CHRYSENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	1b/MMBtu	0.00643649	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.09E-09	ERR	6
Tot Conc	mg/Nm ³	0.009	PREC	ERR	ERR	ERR	3
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.39E-07	ERR	2
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Fuel Flowrate	lb/hr	338697	PREC	ERR	-1.81E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	9.36E-08	-1.81E-08	1.69E+04	-

* $t \times Sr$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: DIBENZ(A,H)ANTHRACENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	1b/MMBtu	0.00643649	ERR	ERR	ERR	ERR	ERR

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Gas Flow 2	dscm/hr	1083500	PREC	ERR	0.00000000	ERR	6
Gas Flow 1	dscm/hr	1001200	PREC	ERR	3.09E-09	ERR	6
Fuel Oil	BTU/lb	18957	PREC	ERR	-3.39E-07	ERR	2
Tot Conc	mg/Nm ³	0.009	PREC	ERR	ERR	ERR	3
Fuel Flowrate	lb/hr	338697	PREC	ERR	-1.81E-08	ERR	6
Fuel Flowrate	lb/hr	338697	BIAS	9.36E-08	-1.81E-08	1.69E+04	-

* $t \times Sr$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: FLUORANTHENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.04362511	2.07E-03	1.31E-01	1.31E-01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.061	PREC	1.72E-02	7.15E-01	3.18E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	5.96E-06	0.00000002	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	4.30E-06	-1.23E-07	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	2.91E-06	2.09E-08	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	1.45E-07	-1.23E-07	7.59E+03	6
Fuel Oil	BTU/lb	18957	PREC	1.63E-09	-2.30E-06	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT
SUBSTANCE: FLUORENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.02002464	1.29E-03	7.44E-02	7.44E-02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Mm ³	0.028	PREC	5.53E-03	7.15E-01	1.80E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	1.26E-06	0.00000000	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	9.06E-07	-5.63E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	6.14E-07	9.61E-09	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	3.05E-08	-5.63E-08	7.60E+03	6
Fuel Oil	BTU/lb	18957	PREC	3.44E-10	-1.06E-06	2.49E+01	2

* $t \times S_r$

** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$

*** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: INDENO(1,2,3-C,D)PYRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.01001232	9.89E-04	2.54E-02	2.54E-02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.014	PREC	6.43E-04	7.15E-01	6.14E-02	3
Gas Flow 2	dscm/hr	1083500	PREC	3.13E-07	0.00000000	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	2.26E-07	-2.82E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.53E-07	4.80E-09	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	7.61E-09	-2.82E-08	7.59E+03	6
Fuel Oil	BTU/lb	18957	PREC	8.59E-11	-5.28E-07	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: NAPHTHALENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	12.8729848	6.12E-01	2.90E+01	2.90E+01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	18	PREC	8.39E+02	7.15E-01	7.01E+01	3
Gas Flow 2	dscm/hr	1083500	PREC	5.17E-01	0.00000617	2.85E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	3.74E-01	-3.62E-05	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	2.53E-01	6.17E-06	1.99E+05	6
Fuel Flowrate	lb/hr	338697	PREC	1.26E-02	-3.62E-05	7.58E+03	6
Fuel Oil	BTU/lb	18957	PREC	1.42E-04	-6.79E-04	2.48E+01	2

* $t \times Sr$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: PHENANTHRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.08581989	4.08E-03	1.77E-01	1.77E-01	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.12	PREC	3.14E-02	7.15E-01	4.29E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	2.30E-05	0.00000004	2.85E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.66E-05	-2.41E-07	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	1.12E-05	4.12E-08	1.99E+05	6
Fuel Flowrate	lb/hr	338697	PREC	5.58E-07	-2.41E-07	7.58E+03	6
Fuel Oil	BTU/lb	18957	PREC	6.30E-09	-4.53E-06	2.48E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

UNCERTAINTY CONTRIBUTOR REPORT

SUBSTANCE: PYRENE

OUTPUT VARIABLE	UNITS	AVG VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNCERTAINTY	STUDENT t FACTOR	DEGREES OF FREEDOM
E-Factor	lb/MMBtu	0.02360047	1.42E-03	8.89E-02	8.89E-02	4.4	2.0

INPUT VARIABLE	UNITS	AVG VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTN **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
Tot Conc	mg/Nm ³	0.033	PREC	7.89E-03	7.15E-01	2.15E-01	3
Gas Flow 2	dscm/hr	1083500	PREC	1.75E-06	0.00000001	2.86E+05	6
Fuel Flowrate	lb/hr	338697	BIAS	1.26E-06	-6.64E-08	1.69E+04	-
Gas Flow 1	dscm/hr	1001200	PREC	8.53E-07	1.13E-08	2.00E+05	6
Fuel Flowrate	lb/hr	338697	PREC	4.24E-08	-6.64E-08	7.60E+03	6
Fuel Oil	BTU/lb	18957	PREC	4.78E-10	-1.24E-06	2.49E+01	2

* $t \times S_r$ ** $(\text{Bias} \times \text{Sensitivity})^2$ or $(t \times \text{StDev}/N^{.5} \times \text{Sensitivity})^2$ *** Bias or $(\text{StDev} \times t)$

Material Balance Closure Results

Uncertainty Contributor Report Substance: Formaldehyde (Gas Firing)

OUTPUT		AVERAGE		ABSOLUTE		ABSOLUTE		ABSOLUTE		ABSOLUTE		STUDENT		DEGREES	
VARIABLE		VALUE		BIAS		PRECISION		TOTAL		UNC		t		OF	
NAME	DESCRIPTION	UNITS	VALUE	COMPONENT	TYPE	COMPONENT*	UNC	STUDENT	OF	FREEDOM					
e	Emission Factor	lb	285.2055	0.00E+00	1.98E+02	2.0E+02	4.30E+00	2.1E+00							
=====															
INPUT		AVERAGE		ERROR		ABSOLUTE		ABSOLUTE		ABSOLUTE		ABSOLUTE		NUMBER	
VARIABLE		VALUE		TYPE		CONTRIBUTION		SENSITIVITY		ERROR OF		INPUT***		SAMPLES	
NAME	DESCRIPTION	UNITS	VALUE	PREC	PREC	PREC	PREC	PREC	PREC	PREC	PREC	PREC	PREC	PREC	PREC
1) stack	stack gas concentrat	ug/Nm3	853.3	PREC	PREC	3.87E+04	3.34E-01	1.02E+03	3						
2) gasflow	stack gas flowrate	Nm3/hr	1044000	PREC	PREC	6.09E+02	2.73E-04	1.57E+05	3						

* PRECISION COMPONENT = t*Spbar

** (Bp*SIGMA)^2 FOR BIAS ERRORS; (t*Spbar*SIGMA)^2 FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Appendix F
Quality Assurance/Quality Control

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented, as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Reagent blank and field blank analyses were performed for the metals (solid and vapor phase). A field blank consisting of a complete semi-VOST sampling train was analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

Table F-2 presents matrix spike recovery data performed for one of the multi-metals stack gas samples. A duplicate analysis was run on one of the flue gas samples for metals. Table F-2 presents the relative percent difference (RPD) between the duplicate analyses for this sample.

Table F-3 presents the matrix spike recovery results for the oil samples. The relative percent difference between the matrix spike and the matrix spike duplicate is also presented. Table F-4 presents the results for the lab spike recoveries for the PAH analyses.

Table F-1
Summary of QA/QC Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected, μg</u>	<u>Detection Limits</u>
PAHs				
<u>Field Blank</u>				
Naphthalene	1	1	22	0.025 μg
Acenaphthylene	1	0		0.025 μg
Acenaphthene	1	1	0.48	0.025 μg
Fluorene	1	1	0.12	0.025 μg
Phenanthrene	1	1	0.071	0.025 μg
Anthracene	1	1	0.061	0.025 μg
Fluoranthene	1	1	0.054	0.025 μg
Pyrene	1	1	0.082	0.025 μg
Chrysene	1	0		0.025 μg
Benz(a)anthracene	1	0		0.025 μg
Benzo(b+k)fluoranthene	1	0		0.025 μg
Benzo(a)pyrene	1	0		0.025 μg
Indeno(1,2,3-c,d)pyrene	1	0		0.025 μg
Dibenz(a,h)anthracene	1	0		0.025 μg
Benzo(g,h,i)perylene	1	0		0.025 μg
Volatile Organics				
<u>Method Blank</u>				
Formaldehyde	1	0		0.89 mL
Benzene	0	0		
<u>Field Blank</u>				
Formaldehyde	1	1	16.2	0.48 $\mu\text{g/mL}$
Benzene	0	0		
Metals - Solid Phase				
<u>Field Blank</u>				
Arsenic	1	1	5.0	--
Beryllium	1	1	0.09	0.07 μg
Cadmium	1	1	0.64	0.32 μg
Copper	1	1	11	0.70 μg
Lead	1	1	45	3.0 μg
Manganese	1	1	14	0.60 μg
Mercury	1	0		1.4 μg
Nickel	1	1	41	0.6 μg
Selenium	1	0		3.5 μg
<u>Reagent Blank</u>				
Arsenic	1	1	2.0	--
Beryllium	1	1	0.18	0.07 μg
Cadmium	1	0		0.32 μg
Copper	1	1	8.3	0.70 μg
Lead	1	1	42	3.0 μg
Manganese	1	1	6.1	0.60 μg
Mercury	1	0		2.3 μg
Nickel	1	1	4.9	0.6 μg
Selenium	1	1	7.7	3.5 μg

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected, μg</u>	<u>Detection Limits</u>
Metals - Vapor Phase				
<u>Field Blank</u>				
Arsenic	1	0		0.28 μg
Beryllium	1	0		0.06 μg
Cadmium	1	1	0.37	0.11 μg
Copper	1	1	15	0.55 μg
Lead	1	1	3.4	--
Manganese	1	1	1.3	0.65 μg
Mercury*	2	0		4.5 μg
Nickel	1	1	5.9	0.65 μg
Selenium	1	0		2.8 μg
<u>Reagent Blank</u>				
Arsenic	1	0		0.32 μg
Beryllium	1	0		0.06 μg
Cadmium	1	1	0.11	0.11 μg
Copper	1	1	3.0	0.55 μg
Lead	1	1	1.0	--
Manganese	1	0		0.65 μg
Mercury*	2	0		2.0 μg
Nickel	1	0		0.65 μg
Selenium	1	0		3.2 μg
Chromium				
<u>Field Blank</u>				
Chromium	0	0		--
Chromium, hexavalent	0	0		0.0014 $\mu\text{g/mL}$
<u>Reagent Blank</u>				
Chromium	1	1	0.4	0.03 μg
Chromium, hexavalent	1	0		0.0014 $\mu\text{g/mL}$
Nickel - CARB 433				
<u>Field Blank</u>				
Nickel	1	1	28	0.50 μg
<u>Reagent Blank</u>				
Nickel	1	1	6.0	0.50 μg

*Includes blanks for permanganate impinger.

Table F-2
Summary of Quality Control Results for Stack Gas

<u>Substance</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
<u>Stack Gas - Solid Phase</u>		
Arsenic	74	27
Beryllium	77	<1
Cadmium	69	5
Copper	89	4
Lead	87	5
Manganese	78	4
Mercury	99	<1
Nickel	97	3
Selenium	70	4
<u>Stack Gas - Vapor Phase</u>		
Arsenic	--	--
Beryllium	77	<1
Cadmium	108	6
Copper	80	5
Lead	--	--
Manganese	76	<1
Mercury ^b	101,98	<1, <1
Nickel	69	<1
Selenium	97	<1
<u>Stack Gas - Total</u>		
Chromium	104	23
Chromium, hexavalent	--	--
Formaldehyde	1-5	--

$$RPD = \left[\frac{A - B}{\left(\frac{A + B}{2} \right)} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

^b Results from both sets of impingers.

Table F-3
Summary of Quality Control Results for Fuel Oil

<u>Substance</u>	<u>Detection Limit (mg/L)</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD *</u>
Arsenic	1.1	83	10
Beryllium	0.22	88	<1
Cadmium	0.22	88	<1
Chromium	--	84	2
Chromium, hexavalent	0.50	--	--
Copper	0.43	88	<1
Lead	1.1	76	9
Manganese	0.43	85	9
Mercury	0.10	102	6
Nickel	--	94	10
Selenium	1.0	98	3

$$RPD = \left[\frac{A - B}{\left(\frac{A + B}{2} \right)} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-4

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean Spike Recovery (%)</u>
d10 Acenaphthylene	4	33
d10 Anthracene	4	60
d12 Chrysene	4	107
d12 Benzo(a)pyrene	4	50

PART IV: SITE 106

PRELIMINARY DRAFT REPORT

Test Contractor:

**Carnot, Inc.
15991 Red Hill Avenue, Suite 110
Tustin, California 92680-7388**

3 March 1993

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Section 1

INTRODUCTION

This part of the document summarizes data gathered by Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 106, during a sampling program sponsored by the electric utility. The power plant was tested during both residual fuel oil and natural gas firing in March of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The primary emphasis of the sampling effort was collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the power plant and sample locations. Section 3 discusses the results of the chemical analyses of the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data using traditional QA/QC techniques and engineering calculations. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 106

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Selenium	X		X
<u>Organic</u>			
Benzene			X
Formaldehyde			X
Polynuclear Aromatic Hydrocarbons (15)			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ -C ₄ Hydrocarbons		X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section provides a description of the test site, Site 106, and gives the locations of the sampling points.

Facility Information

At this site, a steam electric generating unit with a capacity of approximately 480 megawatts (MW) was tested. The boiler was operated at a minimum of 97% of the full rated load during the test period. Testing was conducted during both 100% oil firing and 100% natural gas firing. During the testing at Site 106, the unit was operating at a very consistent load level -- between 465 MW and 476 MW.

Figure 2-1 is a process flow diagram of the unit at Site 106. Steam is generated in a boiler fueled by either natural gas or residual fuel oil. No emission control devices are located downstream of the boiler.

The residual oil fuel at this site has a sulfur content of 0.15%, a higher heating value (HHV) of approximately 19,000 Btu/lb, and an ash content of 0.02 percent. The natural gas fired at Site 106 has a HHV of 20,400 Btu/lb.

Sampling Locations

The fuel to the boiler (oil or natural gas) and the flue gas emitted through the stack were the two streams sampled in this study. Figure 2-1 shows the locations of the sampling points. Brief descriptions of the sampling locations are given below:

- The oil grab samples were collected from the feedlines into the boiler.
- The natural gas analysis was done at a header feeding the boiler.
- Stack gas samples were collected from ports located in each of the two air preheater exit ducts. Three metals samples were collected from both ducts, for a total of six runs. For the remaining substances (chromium and PAHs), two tests were performed in one duct and one test was performed in the other duct, to obtain three sample sets for each substance.

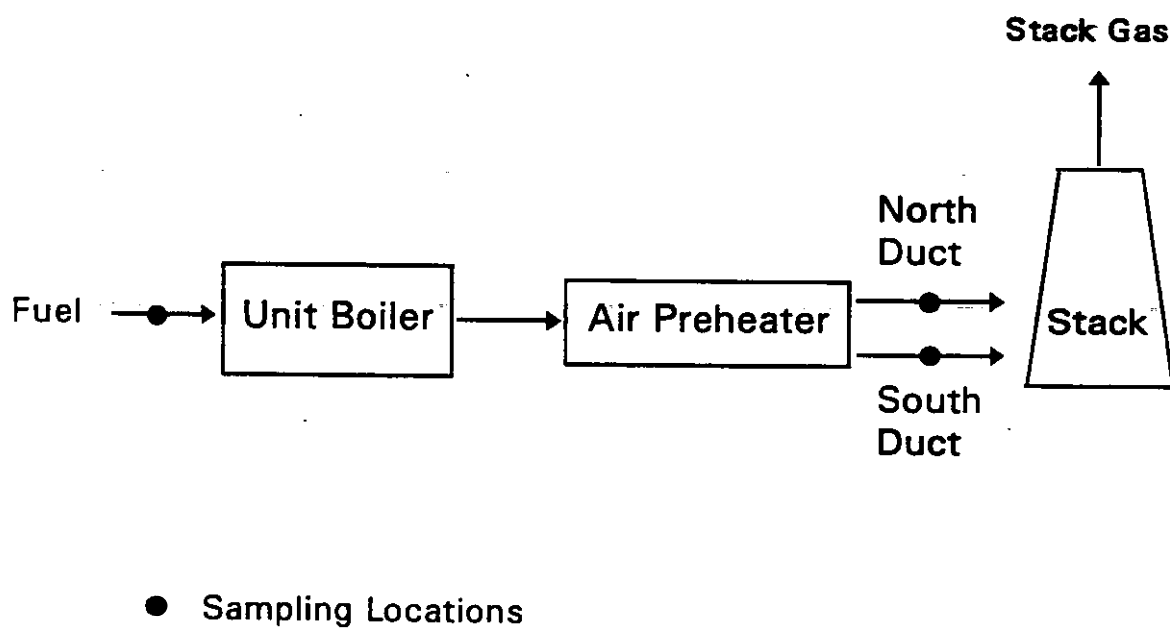


Figure 2-1. Process Flow Diagram for Site 106

Section 3

RESULTS

This section summarizes the fuel and emitted gas stream data collected at Site 106 during oil firing. These results were calculated from laboratory and field data reported by Carnot. Only formaldehyde and benzene emissions were measured during the firing of natural gas; metals, PAHs, benzene, and formaldehyde emissions were measured during fuel oil firing.

Appendix A summarizes the raw analytical data generated by Carnot and their contracting labs during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 106 was sampled in March 1990. Figure 3-1 shows the sequence of tests performed at this site. Samples are numbered in chronologic order. Each fuel type has its own unique set of run numbers. The run numbers appear in Figure 3-1 and the summary tables.

Three collection trains were used to sample the stack gas during oil firing. These trains include a Draft EPA Metals Method train for multi-metals, a CARB Method 425 train for total and hexavalent chromium, and a semi-VOST (Modified Method 5) train for polynuclear aromatic hydrocarbons (PAHs). Benzene was collected by CARB Method 410A, and formaldehyde was sampled using CARB Method 430 for the comparison of emissions produced during natural gas firing and oil firing. Only a single grab sample of the fuel oil was collected during the four-day test period. One hydrocarbon analysis was performed on the natural gas feed.

Appendix C describes the analytical and sampling methods used at this site.

Data Treatment

Several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

Blank Corrections

The convention for using blanks to correct the data in this group of reports was to use the reagent blank results when they were available. If a reagent blank analysis was not

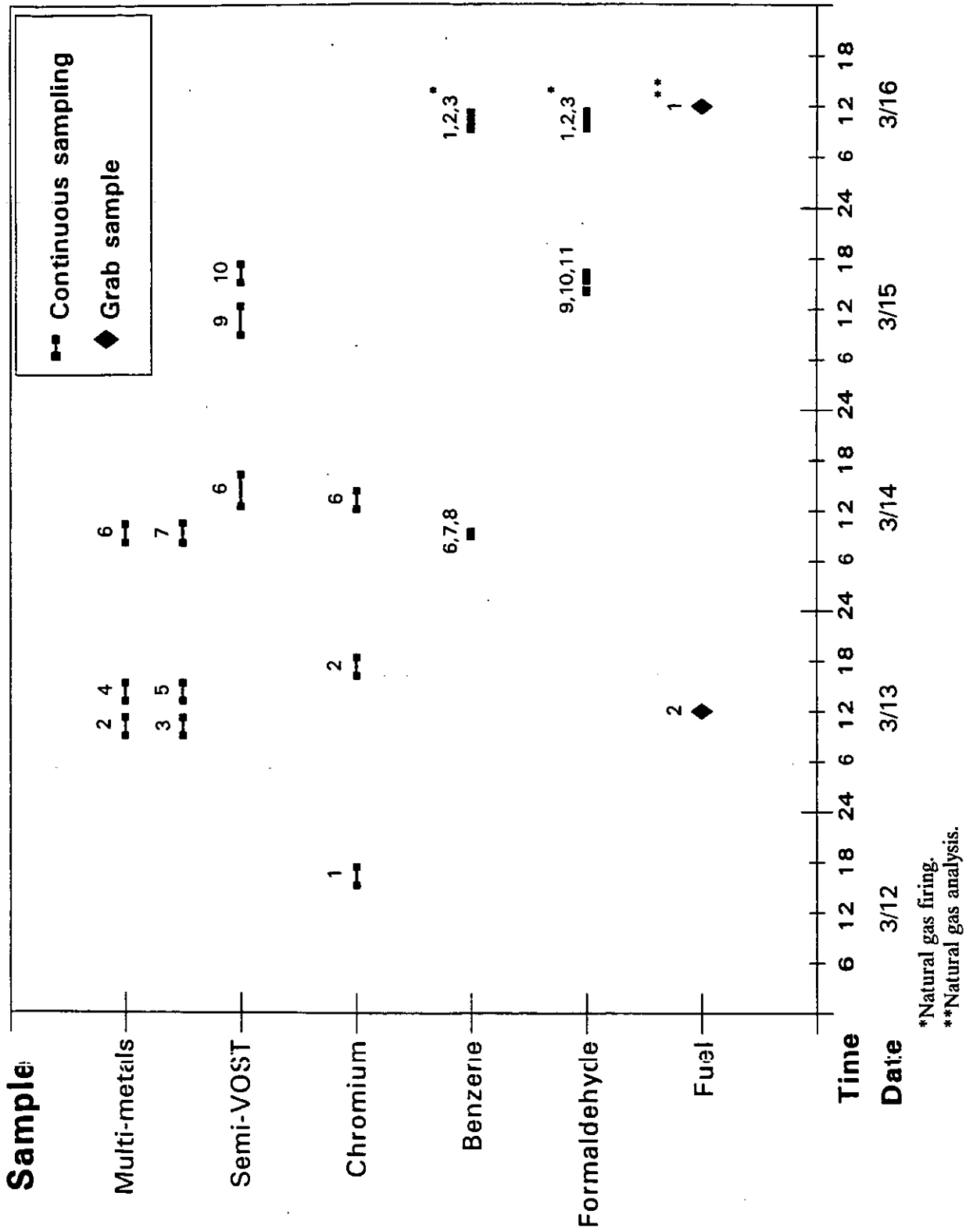


Figure 3-1. Summary of March 1990 Flue Gas Stream and Fuel Sampling Schedule for Site 106, Including Run Numbers

performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no corrections were made.

At Site 106, the reagent blank results were used to correct individual metal run measurements for both the solid and vapor phases. A reagent blank analysis was also done for formaldehyde; only a field blank analysis was performed for PAHs. If the reagent blank was not analyzed, the measurement was corrected for the field blank analysis. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration is flagged with a "B". When the blank correction resulted in a value less than the detection limit given by the analyzing laboratory for each substance, the concentration is presented as ND(DL), which means that the concentration is below the detection limit (DL), which is given in parentheses. The test contractor has defined the term "detection limit" as three to ten times the instrument detection limit, depending on the laboratory that performed the analysis.

Total Concentrations

The solid and vapor phase concentrations are both considered when determining the total gas stream concentration. The absence of detectable concentrations in either phase requires that conventions be established for calculating total values. For each substance, there are three possible combinations of solid and vapor phase concentrations in the emitted gas stream:

- Case 1: The concentrations in both phases are above the detection limits.
- Case 2: The concentrations in both phases are below the detection limits.
- Case 3: The concentration in one phase is above the detection limit, and the concentration in the other phase is below the detection limit.

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

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

For example, the total arsenic (As) concentration in the stack gas is calculated as follows for Run 7:

As in the solid phase = $91.3 \mu\text{g}/\text{Nm}^3$

As in the vapor phase = $0.85 \mu\text{g}/\text{Nm}^3$

Total As in the stack gas = $92.2 \mu\text{g}/\text{Nm}^3$

Case 2: The total concentration is considered to be the solid phase detection limit.

For example, the total beryllium (Be) concentration in the stack gas is calculated as follows for Run 4:

Be in the solid phase = $\text{ND}(0.07) \mu\text{g}/\text{Nm}^3$

Be in the vapor phase = $\text{ND}(0.04) \mu\text{g}/\text{Nm}^3$

Total Be in the stack gas = $\text{ND}(0.07) \mu\text{g}/\text{Nm}^3$

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

For example, the total cadmium (Cd) concentration in the stack gas is calculated as follows for Run 2:

Cd in the solid phase = $\text{ND}(0.9) \mu\text{g}/\text{Nm}^3$

Cd in the vapor phase = $1.42 \mu\text{g}/\text{Nm}^3$

Total Cd in the stack gas = $1.42 \mu\text{g}/\text{Nm}^3$

In historical and previous FCEM data, mercury has been shown to exist primarily in the vapor phase. For Case 2, then, the total concentration in the gas stream is considered to be the vapor-phase detection limit. For Cases 1 and 3 the conventions are the same as those described above.

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

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all values are above the detection limit, the arithmetic mean concentration is calculated using the reported quantities.
- For results that include values both above and below the detection limit, one-half of the DL is used for values below the detection limit to calculate the mean. For example:

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

By our convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8. This is less than the largest detection limit, so the reported mean becomes ND(4).

Analytical Values	Mean Value
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the residual oil fuel analysis. Only a few of the target substances were identified in the oil sample, typically at very low levels.

Natural gas was analyzed for C_1 through C_4 hydrocarbons, nitrogen, oxygen, and carbon dioxide. Appendix D, Table D-1 contains the results of these analyses.

Stack Gas

Tables 3-2a, 3-2b, and 3-3c present concentration data for the emitted gas at Site 106. The probe and nozzle rinse and filter portions (solid phase) from the multi-metals train were analyzed separately from the impinger solutions (vapor phase). The solid and vapor phase analytical results, corrected for reagent blank values, are presented in Tables 3-2a and 3-2b, respectively. The six measured concentrations for each phase are presented, as well as the mean and the 95% confidence interval (CI) associated with the mean. The confidence interval is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean solid phase nickel concentration in the stack gas is $354 \pm 84 \mu\text{g}/\text{Nm}^3$ (between 270 and $438 \mu\text{g}/\text{Nm}^3$), based on the six results shown in Table 3-2a]. Calculation of the confidence interval is discussed in Section 5.

The reagent blank corrections were fairly significant in some cases. Appendix A presents the results of the blank analyses, as well as the test results for each run.

The concentrations in each duct are not expected to be significantly different since they are generated from the same boiler. As can be seen in Tables 3-2a, 3-2b, 3-2c, and 3-3, concentration is independent of sampling location; therefore, the total concentrations from each run were averaged (according to the conventions outlined previously) to obtain an overall mean concentration of each measured substance.

Table 3-2c presents the total concentrations measured for each run, as well as the mean and 95% CI associated with the total value. The sampling methods cited for total

Table 3-1
Oil Composition Data for Site 106

	<u>Run 2</u>
Sample Date	3/13/90
Mass Flow Rate (lb/hr)	235,890 ^a
Volumetric Flow Rate (L/hr)	112,000 ^a
<u>Elements (mg/L)</u>	
Arsenic	ND(1.1) ^b
Beryllium	ND(0.22)
Cadmium	ND(0.22)
Chloride	150
Chromium	0.41
Chromium, hexavalent	ND(0.5)
Copper	2.9
Lead	ND(1.1)
Manganese	0.23
Mercury	ND(0.1)
Nickel	6.7
Selenium	ND(1)
Ash (%)	0.02
Sulfur (%)	0.15
Higher Heating Value (Btu/lb)	19,035

^aFlow rate is an average of 18 measurements taken over a five-day period at or near full load.

^bND indicates that the concentration is below the detection limit, which is shown in parentheses.

Table 3-2a

Stack Gas Composition Data at Site 106

Residual Oil Firing

Solid Phase ($\mu\text{g}/\text{Nm}^3$)

Substance *	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	95% CI ^b
Duct	North	South	North	South	North	South		
Sample Date	3/13/90	3/13/90	3/13/90	3/13/90	3/14/90	3/14/90		
Stream Flow Rate ^c (Nm ³ /hr)	1,619,000	2,018,000	2,005,000	2,038,000	2,026,000	2,045,000	1,959,000	175,000
Arsenic	12.6	9.05	16.5	14.6	15.8	91.3	26.6	33
Beryllium	0.095	B ^d	ND(0.07) ^e	0.137	0.14	0.071	0.153	0.15
Cadmium	ND(0.9) ^f	ND(0.7) ^f	ND(0.6) ^f	ND(0.6) ^f	ND(0.6) ^f	ND(0.6) ^f	ND(0.9)	--
Copper	2.4	26.1	12.2	13.3	13.1	9.6	12.8	8
Lead	20.9	33.8	26.0	22.6	19.1	12.8	22.5	7
Manganese	52.4	20.1	6.9	6.4	15.0	6.6	17.9	19
Mercury	ND(0.9) ^f	ND(0.7) ^f	ND(0.7) ^f	ND(0.6) ^f	ND(0.7) ^f	ND(0.7) ^f	ND(0.9)	--
Nickel	370 ^f	331 ^f	415 ^f	376 ^f	424 ^f	206 ^f	354	84
Selenium	4.74	0.37	10.1	1.44	3.53	1.49	3.61	4

*A reagent blank analysis was performed and used to correct the sample results.

^bCI = Confidence interval.

^cThis is the total unit stack flow rate (i.e., two times the individual duct measurement).

^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^eND indicates that the concentration is below the detection limit, which is shown in parentheses.

^fA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-2b

Stack Gas Composition Data at Site 106 Residual Oil Firing

Vapor Phase ($\mu\text{g}/\text{Nm}^3$)

Substance ^a	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	95% CI ^b
Duct	North	South	North	South	North	South		
Sample Date	3/13/90	3/13/90	3/13/90	3/13/90	3/14/90	3/14/90		
Stream Flow Rate ^c (Nm^3/hr)	1,619,000	2,018,000	2,005,000	2,038,000	2,026,000	2,045,000	1,959,000	175,000
Arsenic	ND(2) ^d B ^e	ND(2)	0.15 B	ND(2)	1.06	0.85	ND(2)	0.5
Beryllium	ND(0.06) ^f	ND(0.04) ^f	ND(0.04) ^f	ND(0.04) ^f	ND(0.04) ^f	ND(0.04) ^f	ND(0.04)	—
Cadmium	1.42 ^f	1.25 ^f	2.67 ^f	0.68 ^f	0.85 ^f	ND(0.2) ^f	1.16	0.9
Copper	ND(0.6) B	6.33	ND(0.4) B	ND(0.4) B	2.54 B	ND(0.4) B	1.63	3
Lead	4.45 ^f	2.21 ^f	9.64 ^f	13.7 ^f	4.17 ^f	4.27 ^f	6.41	5
Manganese	33.4	— ^g	7.56	— ^g	3.18	54.9	24.8	38
Mercury	ND(5) ^f	ND(4) ^f	ND(3) ^f	ND(3) ^f	ND(3) ^f	ND(3) ^f	ND(5)	—
Nickel	122	9.0	14.2	7.66	4.73	106	43.9	57
Selenium	3.89 ^f	ND(2) ^f	ND(2) ^f	ND(2) ^f	ND(2) ^f	ND(2) ^f	ND(2)	1

^aA reagent blank analysis was performed and used to correct the sample results.

^bCI = Confidence interval.

^cThis is the total unit stack flow rate (i.e., two times the individual duct measurements).

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^fA blank correction is not applied since the substance was not detected in the blank sample.

^gNitric acid impinger was contaminated by backup of KMnO_4 mercury impinger solution.

Table 3-2c

**Stack Gas Composition Data at Site 106
Residual Oil Firing**

Combined Phases ($\mu\text{g}/\text{Nm}^3$)

Substance		Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	95% CI ^a
Elements ^b									
Duct		North	South	North	South	North	South		
Sample Date		3/13/90	3/13/90	3/13/90	3/13/90	3/14/90	3/14/90		
Stream Flow Rate (Nm^3/hr) ^c		1,619,000	2,018,000	2,005,000	2,038,000	2,026,000	2,045,000	1,959,000	175,000
Arsenic		12.6	9.05	16.7	14.6	16.9	92.2	27.0	34
Beryllium		0.095 B ^d	0.44	ND(0.07) ^e B	0.137 B	0.14 B	0.071 B	0.153	0.2
Cadmium		1.42 ^f	1.25 ^f	2.67 ^f	0.68 ^f	0.85 ^f	ND(0.6) ^f	1.20	0.9
Copper		2.4 B	32.4	12.2 B	13.3	15.6	9.6 B	14.3	10
Lead		25.4	36.0	35.6	36.3	23.3	17.1 B	29.0	9
Manganese		85.8	-- ^g	14.5	-- ^g	18.2	61.5	45.0	55
Mercury		ND(5) ^f	ND(4) ^f	ND(3) ^f	ND(3) ^f	ND(3) ^f	ND(3) ^f	ND(5)	--
Nickel		492	340	429	384	429	312	398	69
Selenium		8.63 B	0.37 B	10.1	1.44 B	3.53 B	1.49 B	4.26	4

Substance		Run 1	Run 2	Run 6
Elements ^b				
Duct		South	North	North
Sample Date		3/12/90	3/13/90	3/14/90
Stream Flow Rate (Nm^3/hr) ^c		1,954,000	1,860,000	2,025,000
Chromium ^b		6.74 ^f	5.93 ^f	10.1 ^f
Chromium, hexavalent ^b		1.04 ^f	1.33 ^f	9.47 ^f

1,946,000 87,000
10.9 19.7
3.95 5

Results

Table 3-2c (Continued)

	Run 6	Run 9	Run 10	Mean	95% CI ^a
Polynuclear Aromatic Hydrocarbons ^a					
Duct	South	North	South		
Sample Date	3/14/90	3/15/90	3/15/90		
Stream Flow Rate (Nm ³ /hr) ^c	2,090,000	1,848,000	2,102,000	2,013,000	150,000
Acenaphthene	1.08 ^f	0.81 ^f	0.13 ^f	0.67	1
Acenaphthylene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Anthracene	0.014 B	ND(0.01) B	ND(0.01) B	ND(0.01)	0.006
Benzo(a)anthracene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Benzo(a)pyrene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Benzo(b + k)fluoranthene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Benzo(g,h,i)perylene	ND(0.012) B	ND(0.012) B	ND(0.01) B	ND(0.012)	-
Chrysene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Dibenzo(a,h)anthracene	ND(0.012)	ND(0.012)	ND(0.01)	ND(0.012)	-
Fluoranthene	ND(0.01) ^f	0.018 ^f	ND(0.01) ^f	0.01	0.02
Fluorene	0.046 ^f	0.037 ^f	0.027 ^f	0.037	0.02
Indeno(1,2,3-c,d)pyrene	ND(0.012)	ND(0.01)	ND(0.01)	ND(0.012)	-
Naphthalene	3.3 B	2.8 B	5.0 B	3.7	3
Phenanthrene	0.041	0.051	0.016 B	0.036	0.04
Pyrene	ND(0.01) ^f	0.0013 ^f	ND(0.01) ^f	ND(0.01)	0.01

^aCI = Confidence interval.^bA reagent blank analysis was performed and used to correct the sample results.^cThis is the total unit stack flow rate (i.e., two times the individual duct measurement).^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in appendix A for a comparison of sample and blank results.^eND indicates that the concentration is below the detection limit, which is shown in parentheses.^fA blank correction is not applied since the substance was not detected in the blank sample.^gNitric acid impinger was contaminated by backup of KMnO₄ mercury impinger solution, so a total concentration is not presented.^hA reagent blank analysis was not performed; therefore, the field blank was used to correct the sample results.

Table 3-3

**Volatile Organic Stack Emissions at Site 106
Residual Oil and Natural Gas Firing**

<u>Volatile Organic Compounds</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Mean</u>	<u>95% CI ^a</u>
<u>Residual Oil Firing</u>					
Duct	North	North	South		
Stack Flow ^b : 2,035,000 Nm ³ /hr					
Benzene (μg/Nm ³) ^c	ND(3.5) ^d	ND(3.5)	ND(3.5)	ND(3.5)	--
	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>		
Duct	North	South	South		
Stack Flow ^b : 2,017,000 Nm ³ /hr					
Formaldehyde (μg/Nm ³) ^c	ND(20)	ND(15)	ND(16)	ND(20)	--
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
<u>Natural Gas Firing</u>					
Duct	South	South	North		
Stack Flow ^b : 1,746,000 Nm ³ /hr					
Benzene (μg/Nm ³) ^c	ND(3.5)	ND(3.5)	ND(3.5)	ND(3.5)	--
Stack Flow: 1,747,000 Nm ³ /hr					
Formaldehyde (μg/Nm ³) ^c	118	60	63	80	80

^aCI = Confidence interval.

^bThis is the total unit stack flow rate (i.e., two times the individual duct measurement).

^cA blank analysis was not performed.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eA reagent blank correction is not applied since the substance was not detected in the reagent blank sample.

chromium, hexavalent chromium, and PAHs indicate that the solid and vapor fractions were collected; however, the fractions were not analyzed separately. For these substances, the results are presented only as total concentrations. In addition, a reagent blank analysis was not performed for PAHs; therefore, the measured concentrations were corrected using the field blank results. The measured concentrations of several PAHs were below the detection limit of $0.01 \mu\text{g}/\text{Nm}^3$.

Table 3-3 compares volatile organic emissions from the same boiler fired by two different fuels--residual oil and natural gas. Benzene was not detected while firing either fuel. Formaldehyde was detected only during natural gas firing.

Appendix D, Table D-2, presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperatures, and the degree of isokinetic sampling.

Table 3-4 presents the average unit-energy-based emission factors in pounds of substance emitted per 10^{12} Btu input to the boiler. The emission factors were calculated from the total mean stack gas concentrations shown in Table 3-2c. The total unit stack flow rate, which was estimated to be two times the single air preheater exit duct measurement, was also used to calculate the emission factors. The total unit stack flow rate must be used to be consistent with the inlet fuel flow rate when calculating the overall emission factor. Section 5 contains an example calculation.

Table 3-4
Stack Gas Emission Factors at Site 106
(lb/10¹² Btu)

<u>Substance</u>	<u>Residual Oil Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Elements</u>		
Arsenic	26	34
Beryllium	0.15	0.2
Cadmium	1.2	1
Chromium	10	47
Chromium, hexavalent	3.8	12
Copper	14	10
Lead	28	9
Manganese	43	84
Mercury	ND(5) ^b	—
Nickel	380	74
Selenium	4.1	4
<u>Polynuclear Aromatic Hydrocarbons</u>		
Acenaphthene	0.66	3
Acenaphthylene	ND(0.01)	—
Anthracene	ND(0.01)	—
Benz(a)anthracene	ND(0.01)	—
Benzo(a)pyrene	ND(0.01)	—
Benzo(b+k)fluoranthene	ND(0.01)	—
Benzo(g,h,i)perylene	ND(0.01)	—
Chrysene	ND(0.01)	—
Dibenz(a,h)anthracene	ND(0.01)	—
Fluoranthene	0.009	0.05
Fluorene	0.037	0.05
Indeno(1,2,3-c,d)perylene	ND(0.01)	—
Naphthalene	3.7	7
Phenanthrene	0.036	0.1
Pyrene	ND(0.01)	—
<u>Volatile Organic Compounds</u>		
Benzene	ND(3)	—
Formaldehyde	ND(20)	—
	<u>Natural Gas Firing</u>	
<u>Volatile Organic Compounds</u>		
Benzene	ND(4)	—
Formaldehyde	82	88

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² BTU), which is shown in parentheses.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 106, two methods were used to evaluate data quality. First, and most important, was evaluation of the traditional QA/QC protocol for sampling and analytical procedures used at Site 106, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 106 QA/QC data are compared with FCEM project objectives for similar QA/QC procedures. The second data evaluation tool involves calculating material balances around the entire plant for various substances. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute a significant amount to the overall inlet or outlet mass rate.

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during the sampling and analysis process. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, which 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 a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. Table 4-1 lists the QA/QC measures commonly used as part of the FCEM data assessment protocol, and the characteristic information obtained. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data but does limit the ability to measure the various components of measurement error.

As shown in the table, different QC checks provide different types of information, particularly pertaining to the source of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that include as much of the total sampling and analytical process as feasible. Precision and accuracy estimates are based primarily on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 summarizes the precision and accuracy estimates.

Based on the quality control data evaluated, use of the data from Site 106 is limited, primarily because of artifacts evident in the blank samples and uncertainty about the averages of replicate test results. There is no reason to conclude, however, that the data reported are not valid in terms of following proper procedures; however, not enough information is available to unequivocally validate the data.

The measurement precision and accuracy indicators reported are generally good. Accepted methods were used for sampling and analysis, and stack gas sample collection records are strongly supportive. The surrogate recovery data show that somewhat greater inaccuracy is seen in the PAH results than expected. The relatively high blank results decrease confidence in many measurements.

A discussion of precision and accuracy appears below for each measurement type, followed by a review of the stack gas sampling quality control data, which includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias, or a persistent positive or negative deviation from the "true" value.

Table 4-2
Types of Quality Control Data Reported

Analysis	Precision				Accuracy			Blank				
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals by ICP/AAS ^a	✓		✓			✓						
Ultimate and Proximate ^b	✓											
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by ICP ^c	✓		✓			✓			✓			✓
Arsenic by GFAAS	✓								✓			✓
Lead by GFAAS	✓					✓			✓			✓
Mercury by CVAAS	✓		✓			✓			✓			✓
Hexavalent Chromium by IC	✓		✓			✓			✓			
Total Chromium by AAS	✓		✓			✓			✓			✓
Benzene by GC/PID	✓											
Formaldehyde by HPLC	✓			✓		✓			✓		✓	
Polynuclear Aromatic Hydrocarbons by GC/MS ^d	✓							✓				

^aIncludes As, Be, Cd, Cr, Cr(VI), Cu, Pb, Hg, Mn, Ni, P, Se, Zn by EPA SW-846 Methods 6010 (ICP-AES) AND 7000 series (AAS).

^bAsh, carbon, hydrogen, nitrogen, oxygen, sulfur, specific gravity, and chlorine.

^cIncludes Be, Cd, Cu, Pb, Mn, Ni, Se, and Zn by ICP-AES.

^dIncludes acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene.

Table 4-3

Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured ^a	Objectives		Measured		Data Evaluation
		Precision ^b	Accuracy ^c	Precision	Accuracy	
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	<1% RPD	97%	
Beryllium		20% RPD	75-125%	<1% RPD	89%	
Cadmium		20% RPD	75-125%	<1% RPD	91%	
Chromium		20% RPD	75-125%	5% RPD	88%	
Copper		20% RPD	75-125%	14% RPD	91%	
Lead		20% RPD	75-125%	2% RPD	99%	
Manganese		20% RPD	75-125%	2% RPD	87%	
Mercury		20% RPD	75-125%	2% RPD	88%	
Nickel		20% RPD	75-125%	<1% RPD	103%	
Selenium		20% RPD	75-125%	7% RPD	96%	
Metals in Stack Gas - Vapor Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	<1% RPD	90%	
Beryllium		20% RPD	75-125%	<1% RPD	96%	
Cadmium		20% RPD	75-125%	<1% RPD	77%	
Copper		20% RPD	75-125%	1% RPD	95%	
Lead		20% RPD	75-125%	8% RPD	81%	
Manganese		20% RPD	75-125%	4% RPD	92%	
Mercury		20% RPD	75-125%	<1% RPD	94-100%	
Nickel		20% RPD	75-125%	3% RPD	97%	
Selenium		20% RPD	75-125%	<1% RPD	109%	
Metals in Stack Gas - Solid Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	10% RPD	112%	
Beryllium		20% RPD	75-125%	<1% RPD	94%	
Cadmium		20% RPD	75-125%	<1% RPD	100%	
Copper		20% RPD	75-125%	3% RPD	101%	
Lead		20% RPD	75-125%	<1% RPD	92%	

Table 4-3 (Continued)

Measurement Parameter	How Measured ^a	Objectives		Measured	
		Precision ^b	Accuracy ^c	Precision	Accuracy
Manganese		20% RPD	75-125%	<1% RPD	96%
Mercury		20% RPD	75-125%	<1% RPD	109%
Nickel		20% RPD	75-125%	<1% RPD	101%
Selenium		20% RPD	75-125%	4% RPD	85%
Total Chromium in Stack Gas	Precision - Duplicate Analysis Accuracy - Matrix Spike	20% RPD	75-125%	6% RPD	79%
Hexavalent Chromium in Stack Gas	Precision - Not performed Accuracy - Matrix Spike	20% RPD	75-125%	--	96%
PAHs in Stack Gas	Precision & Accuracy - Surrogate Spikes	35% CV	50-150%	32% CV	49-95%
d10-Acenaphthene		35% CV	50-150%	33% CV	18-67%
d10-Anthracene		35% CV	50-150%	21% CV	98-150%
d12-Chrysene		35% CV	50-150%	69% CV	10-71%
d12-Benzo(a)pyrene		40% RPD	50-150%	3% RPD	104-107%
Formaldehyde in Stack Gas	Precision and Accuracy - Matrix Spike Duplicates				

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicate, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) between the duplicate results. The objectives cited are intended to include components of both sampling and analytical variability, although in most cases only analytical variability data were available; consequently, the sample variability component is not incorporated into the comparison with the stated objectives.

^cAccuracy is expressed as the range of recoveries expected for individual analysis results.

The efficiency of the analytical procedure for the sample matrix is quantified by analyzing spiked samples containing target or indicator analytes, or by other quality assurance measures, as necessary. Spiked samples usually provide a measure of accuracy or bias at medium concentration levels, expressed as percent recovery; blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. Table 4-3 presents precision estimates for the analysis of metals. The precision estimates are based on duplicate laboratory analyses, which represent analytical variability alone. The precision objectives cited in Table 4-3 are intended for sampling and analytical variability. Despite the lack of QC information to compare specifically with these objectives, the data demonstrate good analytical precision for metals analyses in all matrices, including stack gas (vapor phase and particulate matter) and fuel oil.

The measurement data for the replicate runs, presented in Section 3 of this report, show considerable variability, although the levels measured are mostly low concentrations for which increased variability is normal. The measured value for arsenic in the Run 7 stack gas is significantly higher than in the other five runs. The results for beryllium, manganese, and selenium are also highly variable across the different test runs. As shown by the large confidence intervals cited in the tables in Section 3, confidence in the accuracy of the average emissions is not great.

Accuracy. The accuracy estimates for metals analyses shown in Table 4-3, are based on matrix spike recovery data. These data show all recoveries for stack gas particulate matter and for vapor-phase and fuel oil samples to be within the stated objectives.

Blanks. In most instances, the reagent blank results were used to correct stack gas concentrations. For some substances, the blank levels were similar to the levels in the

sample. In almost all cases, the reagent blank values were on the same order of magnitude as those of the field blank. Blank sample results appear in Appendices A and F.

At least one stack gas solid or vapor-phase test result for arsenic, beryllium, copper, lead, and selenium is flagged with a "B", indicating that the reagent blank result is equal to or greater than 50% of the measured result. For arsenic, two vapor-phase runs are flagged with a "B". The arsenic vapor-phase result, however, is less than 50% of the combined result; therefore, the total concentration is not flagged. Five of the vapor-phase copper results are flagged. The solid and vapor-phase blank results are both large enough to label the combined concentration with a "B". In several cases, the blank value is larger than the sample result, indicating problems with the sampling or analytical procedure.

Four of the solid-phase beryllium concentrations were flagged, along with the combined result. Two solid-phase lead results are flagged, but only one of the combined results is flagged. Five solid-phase selenium concentrations are flagged, as are the combined results, since the vapor-phase portion is small, compared to that of the solid phase. Since so many of the measurement results are flagged, the actual concentrations of these substances is highly uncertain.

PAHs

Precision. Precision estimates for the analysis of PAHs in stack gas samples, as shown in Table 4-3, are based on the scatter of surrogate spike recoveries in the three replicate sample analyses, expressed as the percent coefficient of variation (% CV). These data show greater than expected imprecision, ranging from 21 to 69% CV for the four surrogate compounds. At the low levels of PAHs measured in the stack gas, the combined process, sampling, and analytical variability, expressed in terms of the confidence interval about the mean, measured value, is often as large as the average measured values. The confidence in the measurements is consequently not high.

Accuracy. Accuracy estimates for PAHs in the stack gas are based on surrogate spike recoveries in the three replicate test samples. The surrogate recoveries indicate that the analyses were effective but more inaccurate than expected. The recoveries for two out of the four surrogates were below the 50-150% recovery objective, and recoveries for the other two surrogate compounds were near the limits of the recovery objective.

Blanks. Seven of the PAHs analyzed were detected in the stack gas stream during oil firing: acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene. However, anthracene, fluoranthene, and pyrene were detected in only one of the three runs at levels very near the detection limit. For several of the PAHs, the field blank levels were high compared to the stack gas measurements; these concentrations are marked with a "B" flag in Table 3-2c. A reagent blank analysis was not performed for PAHs. Appendix A contains the blank results, as well as the reported values.

The high levels of PAHs in several of the field blanks make the PAH measurements for these substances suspect. Naphthalene, in particular, had a very high field blank level of 13 μg , compared with measured values of 20 μg , 19 μg , and 24 μg . The absence of a reagent blank analysis makes it difficult to determine the cause of the high blank results.

Formaldehyde

Precision. The precision of formaldehyde analyses, expressed in terms of the relative percent difference (RPD) for matrix spike duplicate analyses, is 3 RPD, within the objective of 40 RPD.

Accuracy. Accuracy estimates for formaldehyde concentrations in the stack gas, based on matrix-spiked sample analyses (104-107% recovery), are well within the 50-150% objective.

Blanks. The concentrations presented for formaldehyde in the stack gas are not corrected for the blank result because the reagent blank value was below the detection limit. The field blank value was only slightly above the detection limit and was less than 20% of the sample results obtained during natural gas firing.

Stack Gas Sampling Quality Control

Sampling quality control was addressed in a summary of the quality assurance program used by Carnot and in a letter of certification from the California Air Resources Board. Also included were calibration records for the dry gas meters and a table outlining the schedule and procedures used to calibrate these and other equipment.

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant at each sample location.

Sampling accuracy is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases that may be caused by contamination of the equipment, by location or operator errors. Blanks were included for all tests except for the CARB 410 (benzenes), which are grab bag samples.

Sampling representativeness depends on precision and accuracy, and also on the characteristics of the sampling locations. The sampling locations, on the inlet ducts to the stack were not ideal in terms of the undisturbed flow distances upstream and downstream of the ports, but a large enough number (42) of traverse points were used to ensure representativeness. The isokinetic variation is a measure of the operational performance of sampling for particulate matter and can be used to indicate precision, with consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation.

Because of the adherence to accepted reference methods for sampling and analysis, sound documentation of the sampling events, and especially the use of six test runs for metals (three per duct), the samples collected should be considered representative. However, the high blank results and variability across the runs decreases the confidence in the representativeness of some of the results, which might have been influenced by artifacts or spurious events. Corrections for blank artifacts are discussed in Section 3. The smaller sampling scope for organic compounds (two samples from one duct and one from the other) provides less assurance that representative samples were collected.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011, using the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 method for semivolatile organic compounds, dioxins, and furans is well established, both for sampling and analysis. The EPA multi-metals procedure is still being evaluated, but it is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag. Recognizing limitations from the blank results and other undetermined sources of variability, the data reported should be comparable to data from similar studies.

Sampling completeness is mainly a function of providing the requisite number of samples and of proper documentation. In particular, the data necessary for calculating the results, including equipment calibration and all pertinent entries on the run data sheets, should be present. Calibration data provided in this report were adequate, and sampling sheets were acceptably filled out, although the temperatures of the sampling probe and filter oven for the PAH and metals tests were not recorded. The necessary number of samples was successfully taken and sample custody was transferred properly to the analytical laboratories.

Material Balance Results

The streams considered in the material balance for Site 106 were the fuel oil as input and the flue gas as output. Stream flow rates and concentrations and the bias and precision errors associated with these measurements were entered into a statistical error propagation model to estimate the overall material balance closure. A detailed discussion of the statistical error propagation analysis appears in Appendix E.

Material balance closure is defined as the ratio of outlet to inlet mass. A 100% closure indicates perfect agreement. When trace substances are analyzed, closures of between 70% and 130% have been set as a goal for the FCEM project. This range reflects a typical level of analytical uncertainty. Closures within this range indicate that inlet and outlet stream mass rates are statistically equivalent. Poor closures may indicate measurement problems in one or more of the sample matrices.

The measured oil flow rate was compared with the unit generating capacity by calculating a heat input using the oil flow rate, HHV, and an efficiency of 30 percent. The flow rate and generating capacity were in good agreement. Both oil and stack gas flow rates have narrow confidence intervals, indicating good precision in their measurements.

The chromium, copper, manganese, and nickel material balance closures and the error propagation analysis results are presented in Table 4-4. Only nickel was within the desired closure limits and the only element significantly above detection limits in the fuel oil. This evaluation procedure is not a good check on analytical accuracy, since only one oil sample was analyzed, compared with six gas stream measurements. Therefore, the 95% confidence intervals for the closures were not calculated. Material balances were not calculated for other elements because the concentrations in the fuel oil were below detection limits. An ash balance was not performed because particulate loadings were not measured in the stack gas.

Chromium

The material balance closure, 23%, is outside the desired range. The measured flue gas concentrations of chromium were highly variable. The blank analysis results were low, compared with the measured flue gas values. The matrix spike recoveries, presented in Appendix F, were acceptable for the flue gas and fuel oil analyses. The measured oil concentration of 0.4 mg/L was near the detection limit.

Copper

The material balance closure, 8.6%, is outside the desired range. The measured flue gas concentrations of copper are highly variable. Both the reagent and field blank results were high. In three of the six runs, the reagent blank and field blank results were more than 50% of the uncorrected flue gas sample. The matrix spike recoveries for copper were acceptable for the flue gas and fuel oil analyses.

Manganese

The material balance closure, 340%, is outside the desired range. The impingers for Runs 3 and 5 were contaminated with KMnO_4 present in the solution used in the mercury impingers; therefore, the mean manganese concentration was calculated from only four values. The measured flue gas concentrations of manganese are highly variable. The reagent blank results were low, but manganese levels in one of the two field blanks for each phase were quite high; in some runs, the blank result was greater than the value for the flue gas, indicating a potential problem with the sampling or analytical procedures. The matrix spike recoveries were acceptable for the solid- and vapor-phase analyses and for the fuel oil analysis. The oil value of 0.22 mg/L is near the detection limit.

Nickel

The nickel material balance closure of 104% indicates that stream flow rates and concentrations for the inlet and outlet samples are reasonably accurate. The measured flue gas concentrations of nickel were fairly consistent, and oil concentrations were well above the detection limit. The blank results were low, compared with the measured flue

Table 4-4
Material Balance Closure Results for Site 106

<u>Substance</u>	<u>Mean Closure (%)</u>	<u>95% CI ^a</u>
Chromium	23	--
Copper	8.6	--
Manganese	340	--
Nickel	104	--

^aCI = Confidence interval. CI not calculated because only one oil sample was collected and analyzed.

gas values. The matrix spike recoveries were acceptable for the solid- and vapor-phase analyses and for the fuel oil analysis.

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

$$C = \frac{(M - B)}{SV * F} * 35.3 * \frac{520}{492} \quad (5-1)$$

where:

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

M = Mass measured in the sample, μg

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

SV = Sample volume (at 60°F), dscf

F = Sample correction factor (see below)

35.3 = Conversion of ft^3 to m^3 (standard)

$\frac{520}{492}$ = Temperature correction for normal conditions, i.e., 32°F (60°F to 32°F)

The sample correction factor depends on the specific analytical procedure where:

- F = 0.95 for the multi-metals train since 5% of the sample was removed for mercury analysis.
- F = 1.0 for mercury, benzene, formaldehyde, and PAHs.

Example Calculations

- $F = 0.5$ for total and hexavalent chromium since one-half of the sample was used for each analysis.

Note that the mercury results were corrected for the sample aliquot in the analytical reports prepared by the lab. All concentrations are presented at normal conditions (32°F, 1 atm).

Unit Energy Calculations

The unit-energy-based emission factors (Table 3-4) were determined from the mass flow rate of a substance being emitted divided by the fuel heat input to the boiler during testing.

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

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

g = Mean flue gas flow rate, Nm^3/hr

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

HHV = Mean oil higher heating value, Btu/lb

oil = Mean oil feed rate, lb/hr

2202.6 = Unit conversion coefficient, $\text{lb Btu}/\mu\text{g } 10^{12} \text{ Btu}$

For this unit, the mean flue gas flow rate was calculated as the average from the individual runs, which were estimated as two times the individual exit duct flow rate measured for each run. The total unit stack flow rate must be used to be consistent with the inlet fuel flow rate.

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

$$g = 1,959,000 \text{ Nm}^3/\text{hr}$$

$$c = 398 \mu\text{g}/\text{Nm}^3$$

$$\text{HHV} = 19,000 \text{ Btu}/\text{lb}$$

$$\text{oil} = 236,000 \text{ lb}/\text{hr}$$

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

$$E = \frac{1,959,000 * 398 * 2202.6}{19,000 * 236,000} = 380 \text{ lb}/10^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{\text{HHVg} * \text{Gas}} * 2202.6 \quad (5-3)$$

where:

HHVg = Mean natural gas higher heating value, Btu/scf

Gas = Mean natural gas feed rate, scf/hr

Confidence Interval Calculations

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

CIs for Stream Concentrations

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

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

Example Calculations

where:

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

β_r = Bias component

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

S_r = Standard deviation of the individual run measurements

N = Number of measurements

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

$$\beta_r = \sqrt{\sum_{m=1}^n (\beta_{pm} * \theta_{pm})^2} \quad (5-5)$$

where:

β_{pm} = Individual bias for run m

θ_{pm} = Sensitivity to run m = $1/N$

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Tables 3-2a, 3-2b, and 3-2c, will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Fraction</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>
Nickel	Solid Phase	370	331	415	376	424	206
Nickel	Vapor Phase	122	9.0	14.2	7.66	4.73	106
		<u>Run 6</u>	<u>Run 9</u>	<u>Run 10</u>			
Anthracene	Total	0.014	ND(0.01)	ND(0.01)			

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

<u>Substance</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Mean</u>	<u>Standard Deviation</u>
Nickel	492	340	429	384	429	312	398	66

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

$$\beta_r = 0 \text{ (no values below the detection limit)}$$

$$t = 2.57$$

$$S_r = 66$$

$$N = 6$$

The 95% CI (U_{TOT}) for the total nickel concentration is $69.3 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for anthracene is calculated the same way. Since the concentrations for Runs 9 and 10 are below the detection limit, the bias components are not zero. The individual bias, β_p , for each run is:

	<u>Run 6</u>	<u>Run 9</u>	<u>Run 10</u>
β_p	0	0.005	0.005

The bias component is then calculated from Equation 5-5, using these values. In this example, the sensitivity is 0.33 or $1/3$.

$$\beta_r = \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{0.005}{3}\right)^2 + \left(\frac{0.005}{3}\right)^2}$$

$$= 0.0024$$

The standard deviation (S_r) calculated from the three individual pyrene concentrations is 0.005. Substituting these values into Equation 5-4,

$$U_{TOT} = \sqrt{(0.0024)^2 + \left(\frac{4.3 * 0.005}{\sqrt{3}}\right)^2}$$

$$= 0.006 \mu\text{g}/\text{Nm}^3$$

CIs for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors and material balance closures were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A
Analytical Data from the Carnot Report

Table A-1 presents the test results for each run, as well as the results of the blank analyses. Blanks were analyzed for metals in both the solid and vapor phase fractions. A field blank analysis was performed for PAHs.

Table A-1
Results of the Sample, Field Blank, and Reagent Blank Analyses for FCEM Site 106

Oil Firing Multi-Metals	Mass Measured in the Sample (µg)					Field Blanks (µg)	Reagent Blank (µg)
	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	
Gas Sample Volume, Nm ³	1.11	1.43	1.42	1.54	1.49	1.48	
<u>Vapor Phase</u>							
Arsenic	1.1	ND(3.0)	1.3	ND(3.0)	2.6	2.3	1.1
Beryllium	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)
Cadmium	1.5	1.7	3.6	0.99	1.2	ND(0.3)	ND(0.3)
Copper	7.5	17	4.9	5.3	12	7.9	8.6
Lead	4.7	ND(3.0)	13	20	5.9	19	ND(3.0)
Manganese	36	170,000*	11	49,000*	5.3	ND(3.0)	ND(3.0)
Mercury ^b	ND(5)	ND(6)	ND(4)	ND(5)	ND(4)	78	33
Nickel	ND(3)	ND(2)	ND(1)	ND(1)	ND(1)	ND(1)	ND(2.0)
Selenium	130	13	20	12	7.5	150	ND(1.0)
	4.1	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	1.2	0.8
						ND(3.0)	ND(3.0)
<u>Solid Phase</u>							
Arsenic	15	14	24	23	24	130	1.7
Beryllium	0.5	1.0	0.4	0.6	0.6	0.5	0.4
Cadmium	ND(0.9)	ND(0.9)	ND(0.9)	ND(0.9)	ND(0.9)	ND(0.9)	ND(0.9)
Copper	19	43	24	27	26	21	7.5
Lead	48	72	61	59	53	44	26
Manganese	58	30	12	12	24	12	2.7
Mercury	ND(1.0)	ND(1.0)	ND(1.0)	ND(1.0)	ND(1.0)	ND(1.0)	ND(1.0)
Nickel	390	450	560	550	600	290	ND(1.0)
Selenium	5.8	6.9	20	8.5	ND(5.0)	8.5	ND(1.0)
						7.1	6.4
<u>Chromium</u>							
Gas Sample Volume, Nm ³	1.41	1.35	1.51				
Chromium	9.6	8.0	30.4				ND(1.0)
Chromium, hexavalent	1.46	1.80	14.30				ND(0.0014)
						1.75	

* Impinger was contaminated by backup of KMnO₄ into earlier impinger, according to the Carnot report.

^b Two impingers analyzed for mercury—the standard multi-metals train impinger and the potassium permanganate impinger.

Table A-1 (Continued)

PAHs	Mass Measured in the Sample (ug)			Field Blank (ug)	Reagent Blank (ug)
	Run 6	Run 9	Run 10		
Gas Sample Volume, Nm ³	2.14	2.11	2.18		
Naphthalene	20	19	24	13	
Acenaphthylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Acenaphthene	2.3	1.7	0.27	ND(0.025)	
Fluorene	0.099	0.078	0.058	ND(0.025)	
Phenanthrene	0.14	0.16	0.086	0.052	
Anthracene	0.078	0.052	0.059	0.048	
Fluoranthene	ND(0.025)	0.039	ND(0.025)	ND(0.025)	
Pyrene	ND(0.025)	0.028	ND(0.025)	ND(0.025)	
Chrysene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benz(a)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(b+k)fluoranthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(a)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Indeno(1,2,3-c,d)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Dibenz(a,h)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(g,h,i)perylene	ND(0.025)	ND(0.025)	ND(0.025)	0.04	
<u>Volatile Organics</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>		
Gas Sample Volume, Nm ³	0.029	0.027	0.035		
Formaldehyde	ND(0.47)	ND(0.47)	ND(0.47)	0.51	ND(0.47)
Natural Gas Firing					
<u>Volatile Organics</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm ³	0.023	0.032	0.030		
Formaldehyde	3.41	1.64	2.19	0.51	ND(0.47)

Appendix B
Individual Stream Concentrations

This appendix presents the results from the Site 106 sampling event in February 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 106 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented in the Carnot report, which are shown in Appendix A. These concentrations were corrected for the reagent or field blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis and the field blank analysis. The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration presented is the detection limit.

Table B-1 Site 106 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3		12.6	9.05	16.7
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography (GC)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		0.095		B<
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	6.74	1.42	0.44	0.07
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3		5.93	1.25	2.67
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3	1.04	1.33		
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		2.4	32.4	B
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		25.4	36	35.6
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		85.8	14.5	14.5
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3		5	4	3
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		492	340	429
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		8.63	0.37	10.1
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		475	1236	B
441.6						
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3		2.2	2.2	B
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		0.06	0.04	<
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		1.42	1.25	2.67
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		0.6	6.33	B<
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		4.45	2.21	9.64

Table B-1 Site 106 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		1.08		
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B 0.014		
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	14.6	16.9	92.2	
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Benzene	Gas chromatography (GC)	ppbv		< 1	< 1	1
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B< 0.012		
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B 0.137	B 0.14	B 0.071	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.68	0.85	< 0.64	
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3		20.1		
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3		9.47		
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	13.3	15.6	B 9.6	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		0.046		
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	36.3	23.3	B 17.07	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		18.2	61.5	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	< 3	< 3	< 3	
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		B 3.3		
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	384	429	312	
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		0.041		
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3		< 0.012		
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B 1.44	B 3.53	B 1.49	
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B 468.3	B 551	B 415	
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	< 1.8	1.06	0.85	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	< 0.04	< 0.042	< 0.043	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.68	0.85	< 0.21	
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B< 0.4	B 2.54	B< 0.43	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	13.7	4.17	4.27	

Table B-1 Site 106 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.81	0.13		
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B< 0.012	B< 0.011		
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Benzo(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Benzene	Gas chromatography (GC)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B< 0.012	B< 0.011		
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.018	< 0.011		
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.037	0.027		
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	< 20	< 15	< 16	
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	< 0.012	< 0.011		
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	B	5.0	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.051	B	0.016	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.013	< 0.011		
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				

Table B-1 Site 106 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		33.4		7.56
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3		<	4	<
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		122	9	14.2
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		3.89	<	2.2
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		28.5	7.43	18.6
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3		12.6	9.05	16.5
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		B	0.095	0.44
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		<	0.9	<
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		2.4	26.1	12.2
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		20.9	33.8	26
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		52.4	20.1	6.9
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3		<	0.9	<
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		370	331	415
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		B	4.74	10.1
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		B	1229	423
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l	<	1.1		
Beryllium	EPA method 6010	mg/l	<	0.22		
Cadmium	EPA method 6010	mg/l	<	0.22		
Carbon	Ultimate analysis	wt %		85.22		
Chloride	ASTM D808-87	mg/l		150		
Chromium	EPA method 6010	mg/l		0.41		
Chromium, hexavalent	EPA method 6010	mg/l	<	0.5		
Copper	EPA method 6010	mg/l		2.9		
Hydrogen	Ultimate analysis	wt %		12.54		
Lead	EPA method 6010	mg/l	<	1.1		
Manganese	EPA method 6010	mg/l	<	0.23		
Mercury	EPA method 6010	mg/l	<	0.1		
Nickel	EPA method 6010	mg/l		6.7		
Nitrogen	Ultimate analysis	wt %		0.01		
Oxygen	Ultimate analysis	wt %		2.06		
Selenium	EPA method 6010	mg/l	<	1		
Sulfur	Ultimate analysis	wt %		0.15		
Zinc	EPA method 6010	mg/l		0.94		

Table B-1 Site 106 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<	3.18	54.9	
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	7.66	<	<	3
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	4.73	106	
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	10.3	<	<	2.1
				7.13	10	
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	14.6	15.8	91.3	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.137	0.14	0.071	
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	<	<	0.64
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	13.3	13.1	9.6	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	22.6	19.1	12.8	
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	6.4	15	6.6	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	<	<	<	0.7
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	376	424	206	
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	1.44	3.53	1.49	
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	458	544	405	
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Ultimate analysis	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Ultimate analysis	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Nitrogen	Ultimate analysis	wt %				
Oxygen	Ultimate analysis	wt %				
Selenium	EPA method 6010	mg/l				
Sulfur	Ultimate analysis	wt %				
Zinc	EPA method 6010	mg/l				

Table B-1 Site 106 Stream Concentrations During 011-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> 011 <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Ultimate analysis	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Ultimate analysis	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Nitrogen	Ultimate analysis	wt %				
Oxygen	Ultimate analysis	wt %				
Selenium	EPA method 6010	mg/l				
Sulfur	Ultimate analysis	wt %				
Zinc	EPA method 6010	mg/l				

Table B-2 Site 106 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<						
Benzene	Gas chromatography (GC)					
Formaldehyde	High performance liquid chromatography (HPLC)	ppbv	< 1	< 1	< 1	1
		ug/Nm3	118	60		63
>>>> Natural gas <<<<						
Butane	Not specified	vol %	0.3			
Carbon dioxide	Not specified	vol %	1.2			
Ethane	Not specified	vol %	3.5			
Methane	Not specified	vol %	84.7			
Nitrogen	Not specified	vol %	5.2			
Oxygen	Not specified	vol %	1.8			
Propane	Not specified	vol %	0.7			

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Table C-1
Stream Sampling Methods

<u>Sampling Stream</u>	<u>Collection Method</u>	<u>Substance Measured</u>
Stack Gas	Draft EPA Metals Method	Metals
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410A	Benzene
	CARB Method 429	PAH
	CARB Method 430	Formaldehyde
Oil	Grab	Metals

Table C-2

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Inorganic Components in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>FCEM Target Elements by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)</u>	
Preparation	
Parr-Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by GFAAS	
Arsenic	EPA Method 7060
Chromium	EPA Method 7191
<u>FCEM Target Elements by Cold Vapor Atomic Absorption Spectrophotometry (CVAAS)</u>	
Preparation	
Parr-Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by CVAAS	
Mercury	EPA Method 7470
<u>FCEM Target Elements by Inductively Coupled Argon Plasma Emissions Spectrophotometry (ICP-AES)</u>	
Preparation	
Parr-Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by ICP-AES	EPA Method 6010
Beryllium	
Cadmium	
Copper	
Lead	
Manganese	
Nickel	
Selenium	
<u>FCEM Target Elements by Ion Chromatography (IC)</u>	
Preparation	
Extraction by Alkaline Solution	CARB Method 425
Analysis by IC	
Hexavalent Chromium	

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>Benzene</u>	
Sample Collection	
Tedlar Bags	CARB Method 410A
Analysis by Gas Chromatography/Photo Ionization Detector (GC/PID)	CARB Method 410A
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by High Performance Liquid Chromatography (HPLC)	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>	
Sample Collection	
Modified Method 5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by GC/MS	CARB Method 429
Naphthalene	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Chrysene	
Benz(a)anthracene	
Benzo(b + k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-c,d)pyrene	
Dibenz(a,h)anthracene	
Benzo(g,h,i)perylene	

Table C-4

**Preparation and Chemical Analysis
Methods Applied to Oil for Site 106**

<u>Substance</u>	<u>Method Reference</u>
Arsenic	EPA Method 6010, ICP-AES
Beryllium	EPA Method 6010, ICP-AES
Cadmium	EPA Method 6010, ICP-AES
Chloride	ASTM D808-87
Chromium	EPA Method 6010, ICP-AES
Chromium, hexavalent	EPA Method 6010, ICP-AES
Copper	EPA Method 6010, ICP-AES
Lead	EPA Method 6010, ICP-AES
Manganese	EPA Method 6010, ICP-AES
Mercury	EPA Method 6010, ICP-AES
Nickel	EPA Method 6010, ICP-AES
Selenium	EPA Method 6010, ICP-AES
Sulfur	ASTM D4294

Table C-5
Sampling Periods for Flue Gas and Oil

<u>Stack Gas</u>	<u>3/12/90</u>	<u>3/13/90</u>	<u>3/14/90</u>	<u>3/15/90</u>	<u>3/16/90</u>
Multi-metals		0905-1130 (2 runs) 1320-1547 (2 runs)	0825-1057 (2 runs)		
Chromium	1526-1744	1622-1842	1223-1444		
Semi-VOST			1256-1634	0902-1245 1526-1744	
Benzene			0902-0912 0919-0928 0946-0957		0930-0950 0955-1015 1110-1130
Formaldehyde			1405-1435 1538-1608 1614-1644		1405-1435 1538-1608 1614-1644

Oil

Grab Sample

Natural Gas

Grab Sample

*Natural gas firing.

Appendix D
Process Stream Information

Table D-1
Natural Gas Analysis - March 19, 1990

Substance	Volume %
CH ₄	84.7
C ₂ H ₆	3.5
C ₃ H ₈	0.7
C ₄ H ₁₀	0.3
CO ₂	1.2
N ₂	5.2
O ₂	1.8

HHV = 947 Btu/scf.

Fuel factor (60°F) = 8,449 dscf/10⁶ MMBtu @ 0% O₂.

Table D-2

**Process Stream Flow Rates, Stack Gas Characterization Data,
Unit Operating Load, and the Degree of Isokinetic Sampling**

<u>Stream</u>	<u>Units of Measure</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Average</u>
<u>Residual Oil Firing</u>								
<u>Oil</u>								
Flow Rate ^c	lb/hr L/hr							235,890 ^a 112,000 ^b
<u>Stack Gas</u>								
<u>Multi-Metals</u>								
Flow Rate ^c	dscfm ^d Nm ³ /hr ^e	1,006,890 1,619,000	1,255,268 2,018,000	1,246,768 2,005,000	1,267,448 2,038,000	1,260,004 2,026,000	1,271,480 2,045,000	1,217,976 1,959,000
Load	MW	471	471	468	468	465	465	468
Isokinetic	%	95.5	95.87	98.63	102.30	102.19	97.60	98.7
Stack Temperature	°F	257.3	271.3	257.3	273.9	247.8	269.9	263
Moisture	%	9.6	9.7	9.0	8.8	8.6	9.0	9.1
Oxygen	%	5.51	6.09	6.68	6.44	5.99	5.85	5.8
Carbon Dioxide	%	11.81	11.36	10.91	11.10	11.61	11.72	
<u>Chromium</u>								
Flow Rate ^c	dscfm ^d Nm ³ /hr	1,215,044 1,954,000	1,156,772 1,860,000	1,259,360 2,025,000				1,210,379 1,946,000
Load	MW	472	470	466				469
Isokinetic	%	97.56	101.20	104.31				101.02
Stack Temperature	°F	273.3	257.3	252.9				261
Moisture	%	10.3	10.7	9.4				10.1
Oxygen	%	6.20	5.91	6.21				6.11
Carbon Dioxide	%	10.83	11.46	11.09				11.13

Table D-2 (Continued)

<u>Stream</u>	<u>Units of Measure</u>	<u>Run 6</u>	<u>Run 2</u>	<u>Run 10</u>	<u>Average</u>
<u>Semi-VOST</u>					
Flow Rate ^c	dscfm ^d	1,299,696	1,149,146	1,307,074	1,251,972
	Nm ³ /hr ^e	2,090,000	1,848,000	2,102,000	2,013,000
Load	MW	466	471	470	469
Isokinetic	%	92.23	106.05	95.65	97.98
Stack Temperature	°F	270.4	263.8	272.2	269
Moisture	%	9.0	9.3	9.6	9.3
Oxygen	%	6.05	6.32	6.48	6.28
Carbon Dioxide	%	11.21	11.01	10.80	11.01
<u>Formaldehyde</u>					
Flow Rate ^c	dscfm ^d	1,149,146	1,307,074	1,307,074	1,254,431
	Nm ³ /hr ^e	1,848,000	2,102,000	2,102,000	2,017,333
Load	MW	470	470	470	470
<u>Benzene</u>					
Flow Rate ^c	dscfm ^d	1,265,742	1,265,742	1,265,742	1,265,742
	Nm ³ /hr ^e	2,035,000	2,035,000	2,035,000	2,035,000
Load	MW	465	465	465	465
<u>Natural Gas Firing</u>					
<u>Natural Gas</u>					
Flow Rate ^c	kcft/h ^d				3,975
<u>Formaldehyde</u>					
Flow Rate ^c	dscfm ^d	1,087,750	1,087,750	1,083,930	1,086,477
	Nm ³ /hr ^e	1,749,000	1,749,000	1,743,000	1,747,000
Load	MW	476	476	476	476
<u>Benzene</u>					
Flow Rate ^c	dscfm ^d	1,085,840	1,085,840	1,085,840	1,085,840
	Nm ³ /hr ^e	1,746,000	1,746,000	1,746,000	1,746,000
Load	MW	476	476	476	476

Table D-2 (Continued)

^aAverage of 18 runs.

^bCalculated from mass flow rate based on an assumed specific gravity of 0.95.

^cThis is the total unit stack flow rate (i.e., two times the individual duct measurement).

^dStandard conditions: 1 atm, 60°F.

^eNormal conditions: 1 atm, 32°F.

^fAverage of two runs.

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 108 are included here.

Emission Factor Results

Uncertainty Contributor Output Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	25.94657	1.24E+00	3.44E+01	3.4E+01	2.57E+00	5.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Arsenic conc	uo/m3	27	PREC	1.18E+03	9.61E-01	8.74E+01	6
2) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	5.92E+00	1.32E-05	4.50E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	1.53E+00	-1.05E-04	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	8.01E-03	-1.05E-04	3.63E+03	18

* PRECISION COMPONENT = $t \cdot S_{\text{rbar}}$

** $(S_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{\text{0bar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Beryllium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1470306	3.44E-02	2.02E-01	2.1E-01	2.57E+00	5.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Beryllium conc	uo/Nm3	.153	PREC	4.07E-02	9.61E-01	5.14E-01	6
2) baconc	Beryllium conc	uo/Nm3	.153	BIAS	1.13E-03	9.61E-01	3.50E-02	-
3) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	1.90E-04	7.51E-08	4.50E+05	6
4) oil	Oil flow rate	lb/hr	235890	BIAS	4.90E-05	-5.94E-07	1.18E+04	-
5) oil	Oil flow rate	lb/hr	235890	PREC	2.57E-07	-5.94E-07	3.63E+03	18

* PRECISION COMPONENT = $t \cdot S_{\text{rbar}}$

** $(S_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{\text{0bar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.153181	2.93E-01	9.14E-01	9.6E-01	2.57E+00	5.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Cadmium conc	uo/Nm3	1.2	PREC	8.24E-01	9.61E-01	2.31E+00	6
2) baconc	Cadmium conc	uo/Nm3	1.2	BIAS	8.31E-02	9.61E-01	3.00E-01	-
3) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	1.17E-02	5.89E-07	4.50E+05	6
4) oil	Oil flow rate	lb/hr	235890	BIAS	3.02E-03	-4.66E-06	1.18E+04	-
5) oil	Oil flow rate	lb/hr	235890	PREC	1.58E-05	-4.66E-06	3.63E+03	18

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$

** $(D_0 \cdot \text{SIGMA}_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{\bar{r}} \cdot \text{SIGMA}_D)^2$ FOR PRECISION ERRORS

-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** D_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	5.231246	2.49E-01	9.50E+00	9.5E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium conc	uo/Nm3	5.48	PREC	9.00E+01	9.55E-01	1.72E+01	3
2) oas	Stack gas flow rate	Nm3/hr	1946000	PREC	3.38E-01	2.69E-06	3.74E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	6.21E-02	-2.11E-05	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	9.12E-04	-2.11E-05	6.07E+03	18

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$

** $(D_0 \cdot \text{SIGMA}_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{\bar{r}} \cdot \text{SIGMA}_D)^2$ FOR PRECISION ERRORS

-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** D_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Chromium +6

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.770697	1.80E-01	1.19E+01	1.2E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium+6 conc	uo/Nm3	3.95	PREC	1.41E+02	9.55E-01	2.15E+01	3
2) oas	Stack gas flow rate	Nm3/hr	1946000	PREC	1.75E-01	1.94E-06	3.74E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	3.22E-02	-1.52E-05	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	4.74E-04	-1.52E-05	6.07E+03	18

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{rbar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{rbar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	13.74207	6.54E-01	1.02E+01	1.0E+01	2.57E+00	5.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Copper conc	uo/Nm3	14.3	PREC	1.02E+02	9.61E-01	2.57E+01	6
2) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	1.66E+00	7.01E-06	4.50E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	4.28E-01	-5.55E-05	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	2.25E-03	-5.55E-05	3.63E+03	18

* PRECISION COMPONENT = $t \cdot s_{rbar}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{rbar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{rbar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Uncertainty Contributor Output Lead

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	27.86854	1.33E+00	8.99E+00	9.1E+00	2.45E+00	5.8E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Lead conc	ug/M ₀ 3	29	PREC	7.47E+01	9.61E-01	2.20E+01	6
2) oas	Stack gas flow rate	M ₀ 3/hr	1959000	PREC	6.19E+00	1.42E-05	4.28E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	1.76E+00	-1.13E-04	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	8.37E-03	-1.13E-04	3.45E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	43.24428	2.06E+00	8.42E+01	8.4E+01	3.18E+00	3.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Manganese conc	ug/M ₀ 3	45	PREC	7.07E+03	9.61E-01	1.75E+02	4
2) oas	Stack gas flow rate	M ₀ 3/hr	1959000	PREC	2.52E+01	2.21E-05	5.57E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	4.24E+00	-1.75E-04	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	3.41E-02	-1.75E-04	4.49E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	382.4716	1.82E+01	7.20E+01	7.4E+01	2.37E+00	7.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Nickel conc	uo/Nm3	398	PREC	4.10E+03	9.61E-01	1.63E+02	6
2) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	1.09E+03	1.95E-04	4.14E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	3.32E+02	-1.54E-03	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	1.47E+00	-1.54E-03	3.33E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Selenium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	4.093792	1.95E-01	4.05E+00	4.1E+00	2.57E+00	5.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Selenium conc	uo/Nm3	4.26	PREC	1.63E+01	9.61E-01	1.03E+01	6
2) oas	Stack gas flow rate	Nm3/hr	1959000	PREC	1.47E-01	2.09E-06	4.50E+05	6
3) oil	Oil flow rate	lb/hr	235890	BIAS	3.80E-02	-1.65E-05	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	1.99E-04	-1.65E-05	3.63E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Acenaphthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.6616073	3.15E-02	2.46E+00	2.5E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthene conc	uo/Mn3	.67	PREC	6.02E+00	9.87E-01	4.30E+00	3
2) oas	Stack oas flow rate	Mn3/hr	2013000	PREC	1.50E-02	3.29E-07	6.45E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	9.93E-04	-2.67E-06	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	1.46E-05	-2.67E-06	6.07E+03	18

* PRECISION COMPONENT = $t \cdot s_{\text{rbar}}$
 ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\text{obar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS
 -WHERE s_{obar} = PRECISION INDEX OF THE MEAN, $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY
 *** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.874735E-03	4.70E-04	4.91E-02	4.9E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluoranthene conc	uo/Mn3	9.999999E-03	PREC	2.41E-03	9.87E-01	8.61E-02	3
2) oas	Stack oas flow rate	Mn3/hr	2013000	PREC	3.34E-06	4.91E-09	6.45E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	2.21E-07	-3.99E-08	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	3.25E-09	-3.99E-08	6.07E+03	18

* PRECISION COMPONENT = $t \cdot s_{\text{rbar}}$
 ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\text{obar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS
 -WHERE s_{obar} = PRECISION INDEX OF THE MEAN, $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY
 *** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.653653E-02	1.74E-03	4.95E-02	5.0E-02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluorene conc	uo/Nm3	.037	PREC	2.41E-03	9.87E-01	8.61E-02	3
2) oas	Stack gas flow rate	Nm3/hr	2013000	PREC	4.57E-05	1.82E-08	6.45E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	3.03E-06	-1.48E-07	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	4.45E-08	-1.48E-07	6.07E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.653652	1.74E-01	7.39E+00	7.4E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Naphthalene conc	uo/Nm3	3.7	PREC	5.42E+01	9.87E-01	1.29E+01	3
2) oas	Stack gas flow rate	Nm3/hr	2013000	PREC	4.57E-01	1.82E-06	6.45E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	3.03E-02	-1.48E-05	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	4.45E-04	-1.48E-05	6.07E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Uncertainty Contributor Output
Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.554905E-02	1.69E-03	9.83E-02	9.8E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Phenanthrene conc	ug/M ³	.036	PREC	9.63E-03	9.87E-01	1.72E-01	3
2) oas	Stack gas flow rate	M ³ /hr	2013000	PREC	4.33E-05	1.77E-08	6.45E+05	3
3) oil	Oil flow rate	lb/hr	235890	BIAS	2.87E-06	-1.44E-07	1.18E+04	-
4) oil	Oil flow rate	lb/hr	235890	PREC	4.21E-08	-1.44E-07	6.07E+03	18

* PRECISION COMPONENT = t*Srbar

** (B₀*SIGMA₀)² FOR BIAS ERRORS; (t*S₀bar*SIGMA₀)² FOR PRECISION ERRORS-WHERE S₀bar=PRECISION INDEX OF THE MEAN. S₀/(NUMBER OF SAMPLES)^{.5}

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B₀ FOR BIAS ERRORS; S₀t FOR PRECISION ERRORSUncertainty Contributor Output
Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	81.77866	3.87E+00	8.84E+01	8.8E+01	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	ug/M ³	80	PREC	7.46E+03	1.02E+00	1.46E+02	3
2) oil	Natural gas flow rate	cfd	3975000	PREC	3.53E+02	-1.95E-05	1.36E+06	2
3) oil	Natural gas flow rate	cfd	3975000	BIAS	1.50E+01	-1.95E-05	1.99E+05	-
4) oas	Stack gas flow rate	M ³ /hr	1747000	PREC	1.79E-01	4.68E-05	1.56E+04	3

* PRECISION COMPONENT = t*Srbar

** (B₀*SIGMA₀)² FOR BIAS ERRORS; (t*S₀bar*SIGMA₀)² FOR PRECISION ERRORS-WHERE S₀bar=PRECISION INDEX OF THE MEAN. S₀/(NUMBER OF SAMPLES)^{.5}

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B₀ FOR BIAS ERRORS; S₀t FOR PRECISION ERRORS

Uncertainty Contributor Output Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	23.22317	1.10E+00	4.22E+01	4.2E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) aboc	Chromium gas conc	uo/Nm3	5.48	PREC	1.77E+03	4.24E+00	1.72E+01	3
2) gas	Stack gas flow rate	Nm3/hr	1946000	PREC	6.65E+00	1.19E-05	3.74E+05	3
3) oilvol	Oil flow rate	L/hr	112000	BIAS	1.21E+00	-1.98E-04	5.56E+03	-
4) oilvol	Oil flow rate	L/hr	112000	PREC	7.87E-02	-1.98E-04	6.02E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(S_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	8.624909	4.08E-01	6.38E+00	6.4E+00	2.57E+00	5.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) aboc	Copper gas conc	uo/Nm3	14.3	PREC	4.01E+01	6.03E-01	2.57E+01	6
2) gas	Stack gas flow rate	Nm3/hr	1959000	PREC	6.54E-01	4.40E-06	4.50E+05	6
3) oilvol	Oil flow rate	L/hr	112000	BIAS	1.66E-01	-7.34E-05	5.56E+03	-
4) oilvol	Oil flow rate	L/hr	112000	PREC	3.87E-03	-7.34E-05	3.60E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(S_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Uncertainty Contributor Output Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	342.2166	1.62E+01	6.67E+02	6.7E+02	3.18E+00	3.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) mboc	Manganese gas conc	ug/M ³	45	PREC	4.43E+05	7.60E+00	1.75E+02	4
2) gas	Stack gas flow rate	M ³ /hr	1959000	PREC	1.58E+03	1.75E-04	5.57E+05	6
3) oilvol	Oil flow rate	L/hr	112000	BIAS	2.62E+02	-2.91E-03	5.56E+03	-
4) oilvol	Oil flow rate	L/hr	112000	PREC	9.34E+00	-2.91E-03	4.45E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} =PRECISION INDEX OF THE MEAN, $S_D/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Uncertainty Contributor Output Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	103.9022	4.91E+00	1.96E+01	2.0E+01	2.37E+00	7.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) mboc	Nickel gas conc	ug/M ³	398	PREC	3.02E+02	2.61E-01	1.63E+02	6
2) gas	Stack gas flow rate	M ³ /hr	1959000	PREC	8.03E+01	5.30E-05	4.14E+05	6
3) oilvol	Oil flow rate	L/hr	112000	BIAS	2.41E+01	-8.84E-04	5.56E+03	-
4) oilvol	Oil flow rate	L/hr	112000	PREC	4.76E-01	-8.84E-04	3.31E+03	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} =PRECISION INDEX OF THE MEAN, $S_D/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Appendix F
Quality Assurance/Quality Control Data

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected μg</u>	<u>Detection Limits</u>
Manganese	1	1	2.7	1.0 μg
Mercury	1	0		1.0 μg
Nickel	1	0		1.0 μg
Selenium	1	1	6.4	3.0 μg
Metals - Vapor Phase				
<u>Field Blank</u>				
Arsenic	2	2	0.73, 0.77	3.0 μg
Beryllium	2	0		0.06 μg
Cadmium	2	0		0.3 μg
Copper	2	2	8.6, 19	0.6 μg
Lead	2	0		3.0 μg
Manganese	2	2	1.2, 33	0.6 μg
Mercury *	4	1	14 ^b	3.0 μg
Nickel	2	2	1.2, 6.1	0.6 μg
Selenium	2	0		3.0 μg
<u>Reagent Blank</u>				
Arsenic	1	1	1.1	3.0 μg
Beryllium	1	0		0.06 μg
Cadmium	1	0		0.3 μg
Copper	1	1	8.4	0.6 μg
Lead	1	0		3.0 μg
Manganese	1	1	0.8	0.6 μg
Mercury *	2	0		3.0 μg
Nickel	1	1	0.8	0.6 μg
Selenium	1	0		3.0 μg
Chromium				
<u>Field Blank</u>				
Chromium	1	1	1.75	1.25 μg
Chromium, hexavalent	1	0		0.0014 $\mu\text{g/mL}$
<u>Reagent Blank</u>				
Chromium	1	0		1.25 μg
Chromium, hexavalent	1	0		0.0014 $\mu\text{g/mL}$

*Includes blanks for permanganate impinger.

^bDetected in permanganate impinger.

Table F-2
Summary of Quality Control Results for Stack Gas

<u>Substance</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
<u>Stack Gas - Solid Phase</u>		
Arsenic	112	20
Beryllium	94	<1
Cadmium	100	<1
Copper	101	<1
Lead	92	3
Manganese	96	<1
Mercury	109	<1
Nickel	101	<1
Selenium	85	<4
<u>Stack Gas - Vapor Phase</u>		
Arsenic	90	<1
Beryllium	96	<1
Cadmium	77	<1
Copper	95	3
Lead	81	8
Manganese	92	2
Mercury ^b	94, 100	6 ^c , <1
Nickel	97	1
Selenium	109	<1
<u>Stack Gas - Total</u>		
Chromium	79	6
Chromium, hexavalent	96	--
Formaldehyde	107, 104	3 ^c
Formaldehyde (field spike)	114	--

^a

$$RPD = \left[\frac{A - B}{\left(\frac{A + B}{2} \right)} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

^bResults from both sets of impingers.

^cRPD for matrix spike duplicate results.

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented, as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Reagent blank and field blank analyses were performed for the metals (solid and vapor phase). A field blank consisting of a complete semi-VOST sampling train was analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

Table F-2 presents matrix spike recovery data performed for one of the multi-metals stack gas samples. A duplicate analysis was run on one of the flue gas samples for metals. Table F-2 presents the relative percent difference (RPD) between the duplicate analyses for this sample.

Table F-3 presents the matrix spike recovery results for the oil samples. The relative percent difference between the matrix spike and the matrix spike duplicate is also presented. Table F-4 presents the results for the lab spike recoveries for the PAH analyses.

Table F-1
Summary of Blank Sample Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected μg</u>	<u>Detection Limits</u>
PAHs				
<u>Field Blank</u>				
Naphthalene	1	1	13	0.025 μg
Acenaphthylene	1	0		0.025 μg
Acenaphthene	1	0		0.025 μg
Fluorene	1	0		0.025 μg
Phenanthrene	1	1	0.052	0.025 μg
Anthracene	1	1	0.048	0.025 μg
Fluoranthene	1	0		0.025 μg
Pyrene	1	0		0.025 μg
Chrysene	1	0		0.025 μg
Benz(a)anthracene	1	0		0.025 μg
Benzo(b+k)fluoranthene	1	0		0.025 μg
Benzo(a)pyrene	1	0		0.025 μg
Indeno(1,2,3-c,d)pyrene	1	0		0.025 μg
Dibenz(a,h)anthracene	1	0		0.025 μg
Benzo(g,h,i)perylene	1	1	0.04	0.025 μg
Volatile Organics				
<u>Method Blank</u>				
Formaldehyde	1	0		0.47 $\mu\text{g/ml}$
Benzene	0	0		
<u>Field Blank</u>				
Formaldehyde	1	1	0.51	0.47 $\mu\text{g/ml}$
Benzene	0	0		
Metals - Solid Phase				
<u>Field Blank</u>				
Arsenic	2	2	3.8, 4.0	0.05 μg
Beryllium	2	2	0.4, 0.7	0.10 μg
Cadmium	2	0		0.9 μg
Copper	2	2	9.8, 16	1.0 μg
Lead	2	2	28, 46	5.0 μg
Manganese	2	2	5.3, 11	1.0 μg
Mercury	2	0		1.0 μg
Nickel	2	2	5.8, 2.2	1.0 μg
Selenium	2	0		3.0 μg
<u>Reagent Blank</u>				
Arsenic	1	1	1.7	0.05 μg
Beryllium	1	1	0.4	0.10 μg
Cadmium	1	0		0.9 μg
Copper	1	1	7.5	1.0 μg
Lead	1	1	26	5.0 μg

Table F-3

Summary of Quality Control Results for Fuel Oil

<u>Substance</u>	<u>Detection Limit (mg/L)</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD *</u>
Arsenic	1.1	97	<1
Beryllium	0.22	89	<1
Cadmium	0.22	91	<1
Chromium	--	88	5
Chromium, hexavalent	0.50	--	--
Copper	--	91	14
Lead	1.1	99	2
Manganese	--	87	2
Mercury	0.10	88	2
Nickel	--	103	1
Selenium	1.0	96	7

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-4

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

Substance	Number of Analyses	Mean Spike Recovery (%)	Std. Dev. (% Rec.)
d10 Acenaphthene	4	85	26
d10 Anthracene	4	62	33
d12 Chrysene	4	127	22
d12 Benzo(a)pyrene	4	63	38

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PART V: SITE 107 EMISSIONS REPORT

PRELIMINARY DRAFT REPORT

Test Contractor:

**Carnot, Inc.
15991 Red Hill Avenue, Suite 110
Tustin, California 92680-7388**

3 March 1993

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Table F-1

Summary of Blank Sample Results^a

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Reported, μg</u>	<u>Reporting Limit, μg</u>
PAHs				
<u>Method Blank</u>				
Naphthalene	1	1	0.062	-- ^b
Acenaphthylene	1	0		0.013
Acenaphthene	1	0		0.0041
Fluorene	1	0		0.0051
Phenanthrene	1	1	0.048	--
Anthracene	1	0		0.0029
Fluoranthene	1	1	0.018	--
Pyrene	1	1	0.024	--
Chrysene	1	1	0.095	--
Benz(a)anthracene	1	0		0.0015
Benzo(b)fluoranthene	1	0		0.022
Benzo(k)fluoranthene	1	0		0.027
Benzo(a)pyrene	1	0		0.011
Indeno(1,2,3-c,d)pyrene	1	0		0.017
Dibenz(a,h)anthracene	1	0		0.010
Benzo(g,h,i)perylene	1	0		0.024
<u>Field Blank</u>				
Naphthalene	1	1	100	--
Acenaphthylene	1	1	0.018	--
Acenaphthene	1	1	0.036	--
Fluorene	1	1	0.073	--
Phenanthrene	1	1	0.15	--
Anthracene	1	1	0.022	--
Fluoranthene	1	1	0.048	--
Pyrene	1	1	0.070	--
Chrysene	1	1	0.013	--
Benz(a)anthracene	1	1	0.011	--
Benzo(b)fluoranthene	1	0		0.0089
Benzo(k)fluoranthene	1	0		0.0077
Benzo(a)pyrene	1	0		0.0072
Indeno(1,2,3-c,d)pyrene	1	0		0.0059
Dibenz(a,h)anthracene	1	0		0.0011
Benzo(g,h,i)perylene	1	0		0.0086

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented, as well as the sample spike results and reporting and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. No reagent blank or field blank analyses were performed for the metals. A method blank and a field blank were analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

No QA/QC data were performed for the oil and stack gas metals analyses.

Table F-2 presents the results for the lab spike recoveries for the PAH analyses.

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected, μg</u>	<u>Detection Limit, μg</u>
<u>Field Blank (continued)</u>				
Naphthalene	1	1	53	--
Acenaphthylene	1	1	0.013	--
Acenaphthene	1	1	0.033	--
Fluorene	1	1	0.063	--
Phenanthrene	1	1	0.17	--
Anthracene	1	1	0.020	--
Fluoranthene	1	1	0.049	--
Pyrene	1	1	0.063	--
Chrysene	1	1	--	0.011
Benz(a)anthracene	1	1	--	0.014
Benzo(b)fluoranthene	1	0	--	0.0096
Benzo(k)fluoranthene	1	0	--	0.0089
Benzo(a)pyrene	1	0	--	0.0071
Indeno(1,2,3-c,d)pyrene	1	0	--	0.0063
Dibenz(a,h)anthracene	1	0	--	0.0046
Benzo(g,h,i)perylene	1	0	--	0.0086
<u>Volatile Organics</u>				
<u>Method Blank</u>				
Formaldehyde		0		1
Benzene	3	0		0.010 mg/m^3
<u>Field Blank</u>				
Formaldehyde	1	0		1

*No blanks were analyzed for metals.

^bReporting limit was not available.

Table F-2

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean Spike Recovery (%)</u>	<u>Std. Dev. (% Rec.)</u>
d10 Biphenyl	10	149	24
d8 Naphthalene	11	106	32
d8 Acenaphthylene	11	135	24
d10 Acenaphthene	11	129	24
d10 Fluorene	11	134	18
d10 Phenanthrene	11	141	24
d10 Anthracene	11	144	22
d10 Fluoranthene	11	146	20
d10 Pyrene	11	144	25
d12 Benz(a)anthracene	11	133	31
d12 Chrysene	11	117	27
d12 Benzo(b)fluoranthene	11	96	29
d12 Benzo(k)fluoranthene	11	73	27
d12 Benzo(a)pyrene	11	90	31
d12 Benzo(g,h,i)perylene	11	73	38
d14 Dibenz(a,h)anthracene	11	71	35

Section 1

INTRODUCTION

This section of the document summarizes data gathered by Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 107, during a sampling program sponsored by the electric utility company. The power plant, a Babcock and Wilcox radiant heat boiler, was tested during both residual fuel oil and natural gas firing in February of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The primary emphasis of the sampling effort was on collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the plant and sample locations. Section 3 discusses the results of the chemical analyses of the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data using traditional QA/QC techniques and engineering calculations. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 107

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Selenium	X		X
<u>Organic</u>			
Benzene			X
Formaldehyde			X
Polycyclic Aromatic Hydrocarbons (15)			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ -C ₄ Hydrocarbons		X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section describes the test site, Site 107, and gives the locations of the sampling points.

Facility Information

At this site, a steam electric generating unit with a capacity of approximately 175 megawatts (MW) was tested. The boiler was operated at a minimum of 86% of the full rated load during the test period. Testing was conducted during both 100% oil firing and 100% natural gas firing. During the testing at Site 107, the unit was operating at a relatively consistent load level--during oil firing between 156 and 173 MW and during natural gas firing at 151 MW. Refer to Appendix D for the unit load during each sampling event.

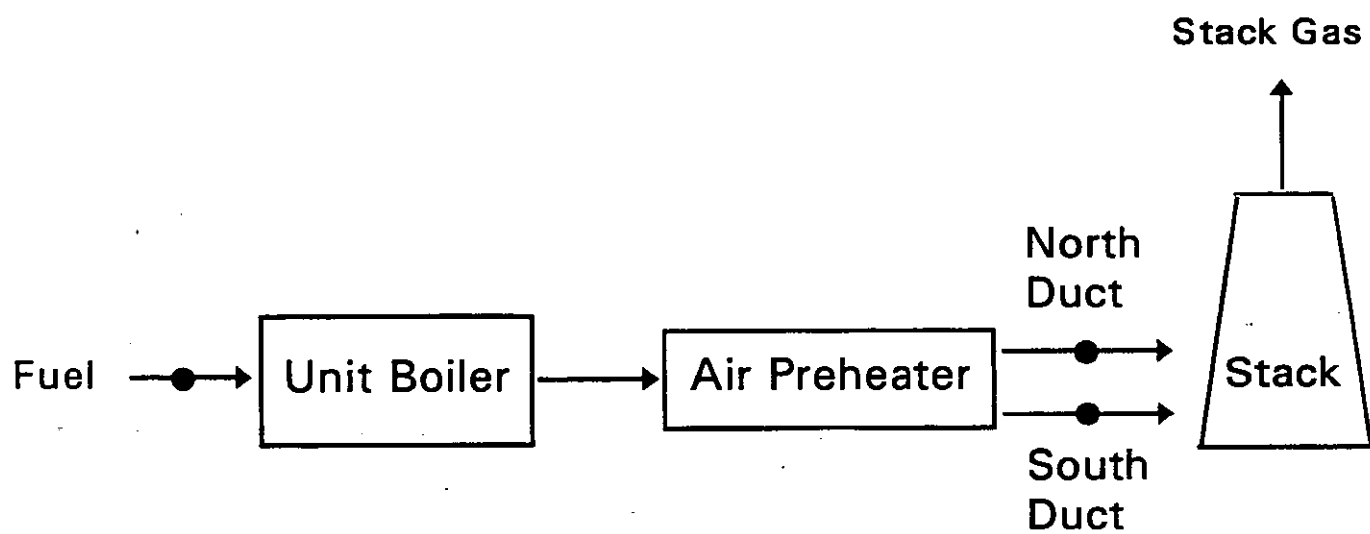
Figure 2-1 is a process flow diagram of the unit at Site 107. Steam is generated in a Babcock & Wilcox boiler that can be fueled by either natural gas or residual fuel oil. No emission control devices are located downstream of the boiler.

The residual oil fuel at this site has a sulfur content of 0.18%, a higher heating value (HHV) of approximately 19,150 Btu/lb, and an ash content of 0.02 percent. The natural gas fired at Site 107 has a HHV of 19,900 Btu/lb.

Sampling Locations

The boiler fuel and the flue gas emitted through the stack were the two streams sampled in this study. The locations of the sampling points are shown in Figure 2-1. Brief descriptions of the sampling locations are given below:

- Oil grab samples were collected from the feedlines into the boiler.
- Natural gas analysis was conducted at a header feeding the boiler.
- Stack gas samples were collected from ports located in each of two air preheater exit ducts. For all trains except chromium, two tests were performed in the north duct and one test was performed in the south duct to obtain three tests for each train. For chromium, two tests were conducted in the south duct and one in the north duct.



● Sampling Locations

Figure 2-1. Process Flow Diagram for Site 107

Section 3

RESULTS

This section summarizes the fuel and emitted gas stream data collected at Site 107 during oil firing. The results were calculated from laboratory and field data reported by Carnot. Only formaldehyde and benzene emissions were measured during the firing of natural gas; metals, PAHs, benzene, and formaldehyde emissions were measured during fuel oil firing.

Appendix A presents the raw analytical data generated by Carnot and their contracting labs during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 107 was sampled in February 1990. As shown in Figure 3-1, which gives the sequence of tests performed, samples are numbered in chronological order. Each fuel type has its own unique set of run numbers. The run numbers are shown in both Figure 3-1 and the summary tables.

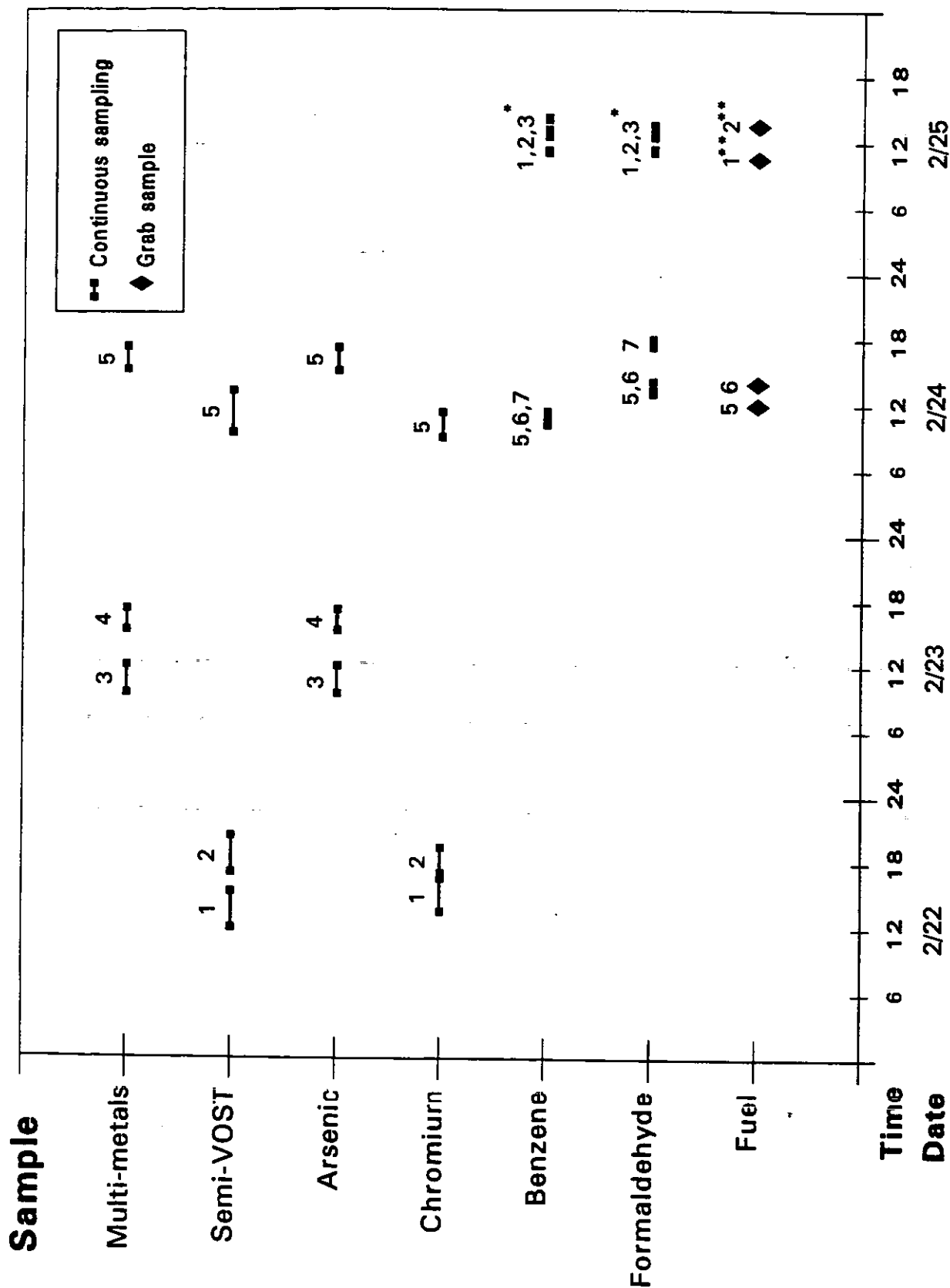
Four collection trains were used to sample the stack gas during oil firing. These trains include a Draft EPA Metals Method train for multi-metals, a CARB Method 423 train for arsenic, a CARB Method 425 train for total and hexavalent chromium, and a semi-VOST (Modified Method 5) train for polynuclear aromatic hydrocarbons (PAHs). Benzene was collected by CARB Method 410A and formaldehyde was sampled using CARB Method 430 to compare emissions produced during natural gas and oil firing. Duplicate samples of both the fuel oil and natural gas were collected during the corresponding stack gas sampling periods.

Appendix C presents details of the analytical and sampling methods used at this site.

Data Treatment

Several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

The convention for using blank results to correct the data in this group of reports was to use the reagent blank analysis results when they were available. If a reagent blank analysis was not performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no blank correcting was done.



*Natural gas firing.

**Natural gas analysis.

Figure 3-1. Summary of February 1990 Flue Gas Stream and Fuel Sampling Schedule for Site 107, Including Run Numbers

Blank Corrections

At Site 107 metals, CARB 423, chromium, and hexavalent chromium by CARB 425 and formaldehyde were corrected for the reagent blank results; while PAH results were corrected for the field blank results.

The individual run measurements for both the solid and vapor phases were corrected for the reagent blank analytical result when available. If the reagent blank was not analyzed, the measurement was corrected for the field blank result. When the blank result was equal to or greater than 50% of the uncorrected actual measurement, the concentration is flagged with a "B" in the summary tables. When the blank correction resulted in a value less than the detection limit, the concentration is presented as ND(DL), meaning that the concentration is below the detection limit (DL), which is presented in parentheses. The test contractor has defined the term "detection limit" as three to ten times the instrument detection limit, depending on the laboratory that performed the analysis.

Total Concentrations

The solid- and vapor-phase concentrations were both considered when determining the total gas stream concentration. The absence of detectable concentrations in either (or both) phase required that conventions be established for calculating total values. For each substance, there were three possible combinations of solid- and vapor-phase concentrations in the emitted gas stream:

- Case 1: The concentrations in both phases are above the detection limits.
- Case 2: The concentrations in both phases are below the detection limits.
- Case 3: The concentration in one phase is above the detection limit and the concentration in the other phase is below the detection limit.

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

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

For example, the total cadmium (Cd) concentration in the stack gas is calculated as follows for Run 3:

$$\text{Cd in the solid phase} = 0.81 \mu\text{g}/\text{Nm}^3$$

$$\text{Cd in the vapor phase} = 0.21 \mu\text{g}/\text{Nm}^3$$

Results

Total Cd in the stack gas = $1.02 \mu\text{g}/\text{Nm}^3$

Case 2: The total concentration is considered to be the solid phase detection limit.

For example, the total beryllium (Be) concentration in the stack gas is calculated as follows for Run 3:

Be in the solid phase = $\text{ND}(0.09) \mu\text{g}/\text{Nm}^3$

Be in the vapor phase = $\text{ND}(0.04) \mu\text{g}/\text{Nm}^3$

Total Be in the stack gas = $\text{ND}(0.09) \mu\text{g}/\text{Nm}^3$

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

For example, the total selenium (Se) concentration in the stack gas is calculated as follows for Run 3:

Se in the solid phase = $0.44 \mu\text{g}/\text{Nm}^3$

Se in the vapor phase = $\text{ND}(2) \mu\text{g}/\text{Nm}^3$

Total Se in the stack gas = $0.44 \mu\text{g}/\text{Nm}^3$

In historical data and previous FCEM data, mercury has been shown to exist primarily in the vapor phase. For Case 2, then, the total concentration in the gas stream is considered to be the vapor-phase detection limit. For Cases 1 and 3, the conventions are the same as those described above.

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

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all values are above the detection limit, the arithmetic mean concentration is calculated from the reported quantities.
- For results that include values both above and below the detection limit, one-half of the DL is used for values below the detection limit to calculate the mean. For example:

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

By our convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8, which is less than the largest detection limit, so the reported mean becomes ND(4).

<u>Analytical Values</u>	<u>Mean Value</u>
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the two residual oil fuel analyses. For each reported substance, a mean concentration was calculated, along with the 95% confidence interval about the mean. The confidence interval is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean chromium concentration in the oil is 0.22 ± 0.06 mg/L (between 0.16 and 0.28 mg/L), according to the two results shown in Table 3-1]. The confidence interval calculation is discussed in Section 5.

Natural gas fuel was analyzed for C_1 through C_4 hydrocarbons, nitrogen, carbon dioxide, and oxygen. The results for the natural gas analysis appear in Appendix D, Table D-1.

Stack Gas

Tables 3-2a, 3-2b, and 3-2c present concentration data for the emitted gas at Site 107. The probe and nozzle rinse, and filter portions (solid phase) from the multimetals train were analyzed separately from the impinger solutions (vapor phase). The solid- and vapor-phase analytical results, corrected for the reagent blank values, are presented in Tables 3-2a and 3-2b, respectively. The three measured concentrations for each phase are presented, as well as the mean and the 95% confidence interval (CI) associated with the mean.

In some cases, the reagent blank corrections were fairly significant. Appendix A contains the results of the blank analyses, as well as the test results for each run.

The concentrations in each duct were not expected to be significantly different since they are generated by the same boiler. As can be seen in Tables 3-2a, b, c, and 3-3, concentration is independent of sampling location. Therefore, the total concentrations from each run were averaged (according to the conventions outlined previously) to obtain an overall mean concentration of each measured substance.

Table 3-1
Oil Composition Data for Site 107

	<u>Run 5</u>	<u>Run 6</u>	<u>Mean</u>	<u>95% CI ^a</u>
Sample Date	2/24/90	2/24/90		
Mass Flow Rate (lb/hr)	--	--	75,100 ^b	2,600
Volumetric Flow Rate (L/hr)			35,900 ^b	1,200
<u>Elements (mg/L)</u>				
Arsenic	ND(1) ^c	ND(1)	ND(1)	--
Beryllium	ND(0.2)	ND(0.2)	ND(0.2)	--
Cadmium	ND(0.2)	ND(0.2)	ND(0.2)	--
Chloride	107	156	132	310
Chromium	0.22	0.21	0.22	0.06
Chromium, hexavalent	ND(0.5)	ND(0.5)	ND(0.5)	--
Copper	0.47	0.41	0.44	0.4
Lead	ND(1)	ND(1)	ND(1)	--
Manganese	ND(0.4)	ND(0.4)	ND(0.4)	--
Mercury	ND(0.1)	ND(0.1)	ND(0.1)	--
Nickel	10	10	10	0
Selenium	ND(1)	ND(1)	ND(1)	--
Ash (%)	0.02	0.01	0.02	0.06
Sulfur (%)	0.17	0.18	0.18	0.06
Higher Heating Value (Btu/lb)	19,200	19,100	19,150	630

^aCI = Confidence interval.

^bFlow rate is an average of 18 measurements taken over a four-day period at or near full load.

^cND indicates that the concentration is below the detection limit; the detection limit is shown in parentheses.

Table 3-2a

**Stack Gas Composition Data at Site 107
Residual Oil Firing**

Solid Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Substance^a</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^b</u>
Duct	North	North	South		
Sample Date	2/23/90	2/23/90	2/24/90		
Stream Flow Rate (Nm^3/hr)	772,000	762,000	718,000	751,000	71,000
Arsenic	10.7	7.22	8.87	8.9	4.3
Beryllium	ND(0.09) ^c	B ^d	ND(0.08)	ND(0.09)	--
Cadmium	0.81 ^e	0.66 ^e	1.20 ^e	0.89	0.69
Copper	8.38	11.6	22.8	14	19
Lead	ND(2)	ND(2)	ND(2)	ND(2)	--
Manganese	6.84	10.0	5.85	7.6	5.4
Mercury	ND(1) ^e	ND(2) ^e	ND(2) ^e	ND(2)	--
Nickel	313	350	412	360	120
Selenium	0.44	ND(2)	ND(2)	ND(2)	--

^aA reagent blank analysis was performed and used to correct the sample results.

^bCI = Confidence interval.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^eA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-2b

Stack Gas Composition Data at Site 107
Residual Oil Firing

Vapor Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Substance^a</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^b</u>
Duct	North	North	South		
Sample Date	2/23/90	2/23/90	2/23/90		
Stream Flow Rate (Nm^3/hr)	772,000	762,000	718,000	751,000	71,000
Arsenic	2.8	1.6	2.9	2.4	1.8
Beryllium	ND(0.04) ^{c,d}	ND(0.05) ^d	ND(0.04) ^d	ND(0.05)	--
Cadmium	0.21	0.81	0.37	0.46	0.77
Copper	2.5	3.5	3.6	3.2	1.5
Lead	ND(0.4) B ^c	ND(0.5) B	ND(0.4) B	ND(0.5)	--
Manganese	3.0	ND(0.4) B	ND(0.4) B	1.1	4.0
Mercury	ND(32) ^d	ND(32) ^d	ND(26) ^d	ND(32)	--
Nickel	15 ^d	1.8 ^d	1.6 ^d	6	19
Selenium	ND(2) ^d	2.2 ^d	ND(2) ^d	ND(2)	--

^aA reagent blank analysis was performed and used to correct the sample results.

^bCI = Confidence interval.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dA blank correction is not applied since the substance was not detected in the blank sample.

^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-2c

**Stack Gas Composition Data at Site 107
Residual Oil Firing**

Combined Phases ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>95% CI^a</u>	<u>Results</u>
<u>Elements</u>							
Duct		North	North	South			
Sample Date		2/23/90	2/23/90	2/2/90			
Stream Flow Rate (Nm^3/hr)		772,000	762,000	718,000	751,000	71,000	
Arsenic ^b		13.5	8.8	11.8	11.4	5.9	
Beryllium ^b		ND(0.09) ^c	ND(0.09)	ND(0.08)	ND(0.09)	--	
Cadmium ^b		1.02	1.5	1.57	1.4	0.7	
Copper ^b		10.9	15.1	26.4	18	20	
Lead ^b		ND(2)	ND(2)	ND(2)	ND(2)	--	
Manganese ^b		9.8	10.0	5.85	8.6	6	
Mercury ^b		ND(32) ^c	ND(32) ^c	ND(26) ^c	ND(32)	--	
Nickel ^b		328	352	414	370	110	
Selenium ^b		0.44	2.2	ND(2)	ND(2)	--	
Duct		South	South	North			
Stream Flow Rate (Nm^3/hr)		694,000	702,000	760,000	719,000	89,000	
Arsenic ^{b,f}		0.58	1.9	3.1	1.9	3.1	
Duct		South	North	North			
Sample Date		2/22/90	2/22/90	2/24/90			
Stream Flow Rate (Nm^3/hr)		752,000	740,000	776,000	756,000	45,000	
Chromium ^b		10.5	6.46	4.36	7.1	7.7	
Chromium, hexavalent ^b		1.69 ^d	1.86 ^d	0.81 ^d	1.5	1.4	

Table 3-2c (Continued)

Substance		Run 1	Run 2	Run 5	Mean	95%CI ^a
<u>Polynuclear Aromatic Hydrocarbons^g</u>						
Duct		North	North	North		
Sample Date		2/22/90	2/22/90	2/24/90		
Stream Flow Rate (Nm ³ /hr)		824,000	794,000	728,000	782,000	122,000
Acenaphthene		ND(0.008) B	ND(0.007) B	ND(0.008) B	ND(0.008)	--
Acenaphthylene		ND(0.008)	ND(0.007)	ND(0.008)	ND(0.008)	--
Anthracene		0.016 B	ND(0.007) B	ND(0.008) B	0.008	0.018
Benz(a)anthracene		0.29 ^c	ND(0.007) ^c	0.049 ^c	0.11	0.38
Benzo(a)pyrene		ND(0.008)	ND(0.007)	ND(0.007)	ND(0.008)	--
Benzo(b+k)fluoranthene		ND(0.008) ^c	ND(0.007) ^c	0.10 ^c	0.04	0.14
Benzo(g,h,i)perylene		0.076 B	ND(0.007) B	ND(0.008) B	0.03	0.10
Chrysene		0.13 ^c	ND(0.007) ^c	0.017 ^c	0.05	0.17
Dibenz(a,h)anthracene		0.018 B	ND(0.007) B	ND(0.008) B	0.008	0.021
Fluoranthene		0.20	ND(0.007) B	0.020 B	0.08	0.27
Fluorene		0.0015 B	ND(0.007) B	ND(0.008) B	0.003	0.004
Indeno(1,2,3-c,d)pyrene		0.067 B	ND(0.007) B	ND(0.008) B	0.025	0.091
Naphthalene		ND(0.008) B	ND(0.007) B	14.0	5	20
Phenanthrene		0.22	ND(0.007)	0.068	0.10	0.28
Pyrene		0.18	ND(0.007) B	0.018 B	0.07	0.24

^aCI = Confidence interval.^bA reagent blank analysis was performed and used to correct the sample results.^cND indicates that the concentration is below the detection limit, which is shown in parentheses.^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.^eA blank correction is not applied since the substance was not detected in the blank sample.^fSampled by CARB 423.^gA reagent blank analysis was not performed, therefore, the field blank results were used to correct the sample results.

Table 3-3

**Volatile Organic Stack Emissions at Site 107
Residual Oil and Natural Gas Firing**

<u>Volatile Organic Compounds</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Residual Oil Firing</u>					
Duct	North	North	South		
Stack Flow: 752,000 Nm ³ /hr					
Benzene (μg/Nm ³) ^b	ND(3.5) ^b	ND(3.5)	ND(3.5)	ND(3.5)	--
	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
Duct	North	North	South		
Stack Flow: 756,000 Nm ³ /hr					
Formaldehyde (μg/Nm ³) ^c	413 ^d	853 ^d	395 ^d	550	640
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
<u>Natural Gas Firing</u>					
Duct	North	North	South		
Stack Flow: 674,000 Nm ³ /hr					
Benzene (μg/Nm ³) ^b	ND(3.5)	ND(3.5)	ND(3.5)	ND(3.5)	--
Duct	South	North	North		
Stack Flow: 684,000 Nm ³ /hr					
Formaldehyde (μg/Nm ³) ^c	795 ^d	846 ^d	621 ^d	750	290

^aCI = Confidence interval.

^bA blank analysis was not performed.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dA reagent blank correction is not applied since the substance was not detected in the reagent blank sample.

Table 3-2c presents the total concentrations measured for each run, as well as the mean and 95% CI associated with each total value. The sampling methods cited for total and hexavalent chromium and PAHs suggest that both the solid and vapor fractions were collected; however, the fractions were not analyzed separately. For these substances, the results are presented only as total concentrations. In addition, a reagent blank analysis was not performed for PAHs; therefore, the field blank results were used to correct the measured concentrations. The measured concentrations of three PAHs were below the detection limit of $0.008 \mu\text{g}/\text{Nm}^3$.

Table 3-3 compares volatile organic emissions from the same boiler fired by two different fuels--residual oil and natural gas. Benzene was not detected while firing either fuel. Formaldehyde was detected in all runs during the firing of fuel oil and natural gas.

Appendix D, Table D-2, presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperature, and the degree of isokinetic sampling.

Table 3-4 presents the average unit-energy-based emission factors in pounds of substance emitted per 10^{12} Btu input to the boiler. The emission factors were calculated from the total mean stack gas concentration shown in Table 3-2c. Section 5 contains an example calculation.

Table 3-4
Stack Gas Emission Factors at Site 107
(lb/10¹² Btu)

<u>Substance</u>	<u>Residual Oil Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Elements</u>		
Arsenic	13	17
Beryllium	ND(0.1) ^b	--
Cadmium	1.6	2.0
Chromium	8	23
Chromium, hexavalent	1.7	2.9
Copper	20	57
Lead	ND(2)	--
Manganese	10	17
Mercury	ND(37)	--
Nickel	420	33
Selenium	ND(2)	--
Arsenic ^c	2.1	8.2
<u>Polynuclear Aromatic Hydrocarbons</u>		
Acenaphthene	ND(0.01)	--
Acenaphthylene	ND(0.01)	--
Anthracene	0.010	0.060
Benz(a)anthracene	0.1	1.2
Benzo(a)pyrene	ND(0.01)	--
Benzo(b+k)fluoranthene	0.04	0.30
Benzo(g,h,i)perylene	0.03	0.30
Chrysene	0.06	0.60
Dibenz(a,h)anthracene	0.010	0.060
Fluoranthene	0.09	0.89
Fluorene	0.004	0.012
Indeno(1,2,3-c,d)pyrene	0.03	0.27
Naphthalene	6	60
Phenanthrene	0.12	0.89
Pyrene	0.08	0.60

Table 3-4 (Continued)

<u>Substance</u>	<u>Residual Oil Firing</u>	
<u>Volatile Organic Compounds</u>		
Benzene	ND(4)	--
Formaldehyde	600	1,900
<u>Natural Gas Firing</u>		
<u>Volatile Organic Compounds</u>		
Benzene	ND(4)	--
Formaldehyde	800	610

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Btu), which is shown in parentheses.

^cSampled by CARB Method 423.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 107, two methods were used to evaluate data quality. First, and most important, was evaluation of the traditional QA/QC protocol for sampling and analytical procedures used at Site 107, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 107 QA/QC data are compared with FCEM project objectives. The second data assessment tool involves calculating material balances around the entire plant for various substances. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute significantly to the overall inlet or outlet mass rate (e.g., coal, bottom ash, collected fly ash, etc.).

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during sampling and analysis. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure sources of variability. The QA/QC measures commonly used as part of the FCEM data evaluation protocol and the characteristic information obtained are summarized in Table 4-1. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data, but does limit the ability to measure the various components of measurement error.

As indicated in the table, different QC checks provide different types of information, particularly pertaining to the sources of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Precision and accuracy estimates are based primarily on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 presents a summary of precision and accuracy estimates.

Based on the quality control data evaluated, there is reason to conclude that the data reported are acceptable, although not enough information is available to unequivocally validate the data. The QC indicators are generally good except for the PAHs. Accepted methods were used for sampling and analysis, and stack gas sample collection records are strongly supportive. The confidence in some measurements is reduced because of relatively high blank results. In particular, high levels of PAHs in the field blank and poor surrogate recoveries make PAH measurements suspect. No quality control measurements were performed for benzene, natural gas composition, or proximate and ultimate analyses.

A discussion of precision and accuracy is presented below for each measurement type, followed by stack gas sampling quality control data review, which includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias or persistent positive or negative deviation from the "true" value.

The efficiency of the analytical procedure in the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes and other quality assurance measures, as necessary. While spiked samples usually provide a measure of accuracy or

Table 4-2
Types of Quality Control Data Reported

Analysis	Precision			Accuracy			Blank					
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals by ICP/AAS ^a	✓		✓			✓						
Ultimate and Proximate ^b	✓											
<u>Stack Gas</u>												
Metals by ICP ^c	✓		✓			✓			✓			✓
Arsenic by GFAAS	✓								✓			✓
Lead by GFAAS	✓								✓			✓
Mercury by CVAAS	✓		✓			✓			✓			✓
Hexavalent Chromium by IC	✓					✓						✓
Total Chromium by AAS	✓											✓
Benzene by GC/PID	✓											
Formaldehyde by HPLC	✓								✓		✓	
Polynuclear Aromatic Hydrocarbons by GC/MS	✓				✓			✓	✓		✓	

^aIncludes As, Be, Cd, Cr, Cr(VI), Cu, Pb, Hg, Mn, Ni, P, Se, Zn by EPA SW-846 Methods 6010 (ICP-AES) AND 7000 series (AAS).

^bAsh, carbon, hydrogen, nitrogen, oxygen, sulfur, specific gravity, and chlorine.

^cIncludes Be, Cd, Cu, Pb, Mn, Ni, Se, and Zn by ICP-AES.

Table 4-3

Summary of Precision and Accuracy Estimates

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Metals in Stack Gas/Solid Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike				
Arsenic		20% RPD	75-125%	9	88%
Beryllium		20% RPD	75-125%	<1	80%
Cadmium		20% RPD	75-125%	3	73% ^d
Copper		20% RPD	75-125%	3	96%
Lead		20% RPD	75-125%	4	84%
Manganese		20% RPD	75-125%	2	83%
Mercury		20% RPD	75-125%	<1	93%
Nickel		20% RPD	75-125%	1	99%
Selenium		20% RPD	75-125%	<1	80%
Metals in Stack Gas - Vapor Phase					
Arsenic		20% RPD	75-125%	--	--
Beryllium		20% RPD	75-125%	<1	89%
Cadmium		20% RPD	75-125%	8	77%
Copper		20% RPD	75-125%	<1	89%
Lead		20% RPD	75-125%	--	--
Manganese		20% RPD	75-125%	<1	86%
Mercury		20% RPD	75-125%	1 ^e , <1	98,99%
Nickel		20% RPD	75-125%	4	
Selenium		20% RPD	75-125%	<1	
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spike				
Arsenic		20% RPD	75-125%	10	83%
Beryllium		20% RPD	75-125%	<1	88%
Cadmium		20% RPD	75-125%	<1	88%
Chromium		20% RPD	75-125%	2	84%
Copper		20% RPD	75-125%	<1	88%
Lead		20% RPD	75-125%	9	76%

Data Evaluation

Table 4-3 (Continued)

Measurement Parameter	How Measured ^a	Objectives		Measured	
		Precision ^b	Accuracy ^c	Precision	Accuracy
Manganese		20% RPD	75-125%	9	85%
Mercury		20% RPD	75-125%	6	102%
Nickel		20% RPD	75-125%	10	94%
Selenium		20% RPD	75-125%	3	98%
Metals in Stack Gas - Total	Precision - Data not available Accuracy - Matrix Spike	20% RPD	75-125%		
Chromium				NA	NA
Chromium, hexavalent				NA	90.3%
Formaldehyde	Precision & Accuracy - Matrix Spike Duplicate	40% RPD	50-150%	18	97,116%
PAHs in Stack Gas	Precision & Accuracy - Surrogates Spikes	35%	50-150%		
d10-Acenaphthene		35% CV	50-150%	99.3% CV	ND-40%
d10-anthracene		35% CV	50-150%	3% CV	ND-110%
d12-Chrysene		35% CV	50-150%	85% CV	1-100%
d12-Benzo(a)pyrene		35% CV	50-150%	NC	ND-20%

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicate, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) between the duplicate results.

^cAccuracy is expressed as the range of recoveries expected for individual analysis results.

^dOutside accuracy objectives.

^eRPD for matrix spike duplicates.

NA - Not available

NC - Not calculated

bias at medium concentration levels, expressed as percent recovery, blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. Table 4-3 presents the precision estimates for the metals analyses. The precision estimates are based on duplicate laboratory analyses that represent analytical variability alone. The precision objectives cited in Table 4-3 are intended for sampling and analytical variability. The QC data demonstrate good analytical precision for metals analyses in all matrices, including stack gas particulate and vapor phase and fuel oil sample matrices. Measurement data for the duplicate sample analyses indicate good overall precision, with all relative percent differences falling below the 20% objective.

The measurement data for the replicate runs, presented in Section 3 of this report, show good overall repeatability. At low trace-level concentrations, the absolute differences between the replicate results are typically small, whereas the relative differences are large, which is not unexpected as the measured values approach zero. At such low levels, especially where the uncertainty is equal to or greater than the magnitude of the measurements, the results should be considered as semi-quantitative or qualitative.

Accuracy. Accuracy estimates for metals analyses, as shown in Table 4-3, are based on matrix spike recovery data. Recoveries for all samples analyzed were within the specified accuracy objectives of 75 to 125%, with one exception. The matrix recovery for cadmium in the solid phase stack sample was 73%, slightly lower than expected. This exception should not adversely affect the accuracy of the sample data.

Blanks. Blank data from reagent and laboratory blanks for metals analysis are shown in Appendix A-1 and F-1. In most cases the stack gas concentrations were corrected for the reagent blank analyses. For some metals identified, the reagent blank results were

similar, even greater than levels found in the samples. The metals most affected were copper and lead in both the vapor- and solid-phase samples, and manganese and selenium in the solid sample. Field blank results indicate a similar correlation between the blank and the samples.

Stack gas results for beryllium, lead, and selenium in the solid phase, and lead and manganese in both the solid and combined phase are reported with a "B" flag. This flag is used when the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The combined results for beryllium and selenium are flagged because the solid phases are a large portion of the totals for these substances. In all cases except Run 4 for selenium, the vapor phases of these two substances were not detected.

The blank results showed copper in the solid phase reagent blank at levels equivalent to 50 to 65% of the total measured amounts in the stack gas. The results for lead were similar to the arsenic results; one measured stack gas solid-phase lead result was less than the level found in the reagent blank, indicating a possible analytical problem. The other two reported solid-phase lead results include reagent blank corrections that were 70 to 90% of the actual measured values.

PAHs

Precision. Precision estimates for PAH analyses in stack gas samples, as shown in Table 4-3, are based on the surrogate spike recoveries in the three replicate sample analyses, expressed as the percent coefficient of variation (% CV). These data show that the precision was not within the 35% objective.

Accuracy. Accuracy estimates for PAHs in stack gas, based on surrogate spike recoveries for the three replicate samples, were not within the 50 to 150% accuracy objective. All but one of the surrogate compounds, d10 chrysene, had lower-than-expected recoveries ranging from 0 to 40%. Recoveries for d10 chrysene were acceptable for only two of the three replicate samples. No PAHs were detected in Run 2 and only low levels of PAHs were reported in the other two runs. Considering that the surrogate recoveries were all outside the objectives and no other way of determining accuracy is available, the quality of the PAH data is suspect.

Blanks. Ten PAHs were identified in the field blank sample. Most of the PAHs reported as present in the field blank sample were present at high levels compared to the flue gas measurements; these concentrations are flagged with a "B" flag in Table 3-2c. Some measured concentrations were below the field blank values. A reagent blank analysis was not performed for PAHs, so it is difficult to determine the cause of the high blank results for some compounds. Appendix A shows the blank results, along with the routine sample results for comparison.

Formaldehyde

Precision. Precision for formaldehyde analyses, expressed in terms of relative percent difference (RPD) for matrix spike duplicate analyses, is 18 RPD. This value is well within the objectives for precision.

Accuracy. Accuracy estimates for formaldehyde in the stack gas are based on matrix-spiked samples. The results indicated acceptable recoveries of 97 and 116% which were within the accuracy objectives of 50 to 150 percent.

Blanks. Estimates of the blank contribution are based on the results of both reagent blank and field formaldehyde blank samples. The sample concentrations presented for formaldehyde were not corrected for the reagent blank results because the levels were below the detection limit. However, the field blank level was high, 16 μg , compared to the sample results of 15 to 16.2 μg during oil firing and 23.6 μg to 30.2 μg during natural gas firing. The data are questionable because of high field blank levels that could indicate sample collection problems and/or high ambient concentrations.

Stack Gas Sampling Quality Control

Sampling quality control was documented in a summary of the quality assurance program used by Carnot and in a letter of certification from the California Air Resources Board. Also included were calibration records for the dry gas meters, a pilot inspection form, and a table outlining the schedule and procedures used for calibrating these and other equipment, and CEM standard certification sheets.

The precision of the sampling can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location.

The accuracy of the sampling is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blank results are used to correct for any biases that may be caused by contamination of the equipment or location, or by operator errors. Blanks were included for all tests except the CARB 425 chromium impinger samples and CARB 410 (benzenes), which are grab bag samples.

The representativeness of the sampling depends on the precision and accuracy and also on the characteristics of the sampling locations. The sampling locations, on the inlet ducts to the stack, were not ideal in terms of the undisturbed flow distances upstream and downstream of the ports, but a large enough number of traverse points (42) were used on each to ensure representativeness. The isokinetic variation is a measure of the operational performance of the sampling for particulate matter. It can be used to indicate precision and has consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation.

The comparability of sampling depends on the representativeness of the samples and on the use of consistently applied standard methods. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011 and uses the same acidified 2,4-dinitro-phenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 methodology for semivolatile organic compounds, dioxins, and furans is well established for both sampling and analysis. The EPA multi-metals procedure is still in the evaluation process, but it is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag.

The completeness of the sampling is mainly a function of generating the requisite number of samples and proper documentation. In particular, the data necessary for calculating the results, including the calibration of the equipment and all pertinent entries on the run data sheets, should be present. Calibration data provided in this report were adequate, and sampling sheets were acceptably filled out. The necessary number of samples were successfully taken and custody of them was transferred properly to the analytical laboratories.

Material Balance Results

Material balance closures were not calculated for Site 107. Duplicate oil samples were collected only once during the stack gas sampling. Therefore, the material balance was not considered an appropriate method for evaluating the data.

The measured oil flow rate was compared with the unit generating capacity by calculating a heat input using the oil flow rate data, HHV, and an efficiency of 30 percent. The oil flow rate and generating capacity are in good agreement. Both oil and stack gas flow rates have narrow confidence intervals, indicating good precision in their measurements.

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

$$C = \frac{(M - B)}{SV * F} * 35.3 * \frac{520}{492} \quad (5-1)$$

where:

C =	Concentration, $\mu\text{g}/\text{Nm}^3$
M =	Mass measured in the sample, μg
B =	Mass measured in the blank (reagent or field), μg
SV =	Sample volume (at 60° F), dscf
F =	Sample correction factor (see below)
35.3 =	Conversion of ft^3 to m^3 (standard)
$\frac{520}{492}$ =	Temperature correction for normal conditions, i.e., 32° F (60° F to 32° F)

The sample correction factor depends on the specific analytical procedure, where:

- F = 0.95 for the multimetals train since 5% of the sample was removed for the mercury analysis.

Example Calculations

- $F = 1.0$ for mercury, arsenic (by CARB Method 423), benzene, formaldehyde, and PAHs.
- $F = 0.5$ for total and hexavalent chromium since one-half of the sample was used for each analysis.

Note that the mercury results were corrected for the sample aliquot in the analytical reports prepared by the lab. All concentrations are presented at normal conditions (32° F, 1 atm).

Unit Energy Calculations

The unit-energy-based emission factors (Table 3-4) were determined from the mass flow rate of a substance being emitted, divided by the fuel heat input to the boiler during testing.

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

E	=	Mean stack emission factor, $\text{lb}/10^{12} \text{ Btu}$
g	=	Mean flue gas flow rate, Nm^3/hr
c	=	Mean total flue gas concentration, $\mu\text{g}/\text{Nm}^3$
HHV	=	Mean oil higher heating value, Btu/lb
oil	=	Mean oil feed rate, lb/hr
2202.6	=	Unit conversion coefficient, $\text{lb Btu}/\mu\text{g } 10^{12} \text{ Btu}$

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

g	=	751,000 Nm^3/hr
c	=	370 $\mu\text{g}/\text{Nm}^3$

$$\text{HHV} = 19,150 \text{ Btu/lb}$$

$$\text{oil} = 75,100 \text{ lb/hr}$$

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

$$E = \frac{751,000 * 370 * 2202.6}{19,150 * 75,100} = 420 \text{ lb}/10^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{\text{HHV}_g * \text{Gas}} * 2202.6 \quad (5-3)$$

where:

HHV_g = Mean natural gas higher heating value, Btu/scf

Gas = Mean natural gas feed rate, scf/hr

Confidence Interval Calculations

Confidence intervals (CIs) were calculated for the total mean concentrations in the gas and oil streams. In addition, confidence intervals were determined for the stack gas emission factors presented in Table 3-4. Additional details of the CI calculation can be found in Appendix E.

CIs for Stream Concentrations

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

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

where:

Example Calculations

U_{TOT}	=	95% CI for the total mean
β_r	=	Bias component
t	=	Student's "t" factor for 97.5 percentile (one-tail) and N-1 degrees of freedom
S_r	=	Standard deviation of the individual run measurements
N	=	Number of measurements

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

$$\beta_r = \sqrt{\sum_{m=1}^n (\beta_{pm} * \theta_{pm})^2} \quad (5-5)$$

where:

β_{pm}	=	Individual bias for run m
θ_{pm}	=	Sensitivity to run m = $1/N$

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Tables 3-2a, 3-2b, and 3-2c, will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Fraction</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>
Nickel	Solid Phase	313	350	412
Nickel	Vapor Phase	15	1.8	1.6
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 5</u>
Pyrene	Total	0.18	ND(0.007)	0.018

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

<u>Substance</u>	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Mean</u>	<u>Standard Deviation</u>
Nickel	328	352	414	370	44

The 95% confidence interval is calculated by inserting the following values into Equation 5-4:

$$\beta_r = 0 \text{ (no values below the detection limit)}$$

$$t = 4.3$$

$$S_r = 44$$

$$N = 3$$

The 95% CI (U_{TOT}) for the total nickel concentration is $110 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for pyrene is calculated the same way. Since the concentration for Run 10 is below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>
β_p	0	0.0035	0

The bias component is then calculated from Equation 5-5, using these values. In this example, the sensitivity is 0.33 or $1/3$.

$$\beta_r = \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{0.0035}{3}\right)^2 + \left(\frac{0}{3}\right)^2}$$

$$= 0.0012$$

The standard deviation (S_r) calculated from the three individual pyrene concentrations is 0.098. Substituting these values into Equation 5-4,

Example Calculations

$$U_{TOT} = \sqrt{(0.0012)^2 + \left(\frac{4.3 * 0.098}{\sqrt{3}}\right)^2}$$

$$= 0.24 \mu\text{g}/\text{Nm}^3$$

CIs for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Table 8-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run
Nitrogen	Ultimate analysis	wt %	0.08	0.11		
Oxygen	Ultimate analysis	wt %	2.47	0.76		
Selenium	EPA method 6010	mg/l	<	<	1	
Sulfur	Ultimate analysis	wt %	0.17	0.18		
Zinc	EPA method 6010	mg/l	0.96	0.97		

Table B-2 Site 107 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<						
Benzene	Gas chromatography (GC)		1	1	1	
Formaldehyde	High performance liquid chromatography (HPLC)	ug/lm3	795	846	<	621
>>>> Natural gas <<<<						
Butane	Not specified	vol %	0.1	<	0.1	
Carbon dioxide	Not specified	vol %	1	1	1	
Ethane	Not specified	vol %	3.8	3.8	3.8	
Isobutane	Not specified	vol %	0.1	0.1	0.1	
Methane	Not specified	vol %	86.5	85.6	85.6	
Nitrogen	Not specified	vol %	3.1	4.1	4.1	
Oxygen	Not specified	vol %	1.7	1.8	1.8	
Propane	Not specified	vol %	0.8	0.6	0.6	

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Nitrogen	Ultimate analysis	wt %				0.08
Oxygen	Ultimate analysis	wt %				2.47
Selenium	EPA method 6010	mg/l				<
Sulfur	Ultimate analysis	wt %				0.17
Zinc	EPA method 6010	mg/l				0.96

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run	Run
Nitrogen	Ultimate analysis	wt %	0.11		
Oxygen	Ultimate analysis	wt %	0.76		
Selenium	EPA method 6010	mg/l	<	1	
Sulfur	Ultimate analysis	wt %	0.18		
Zinc	EPA method 6010	mg/l	0.97		

Table B-2 Site 107 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Benzene	Gas chromatography (GC)	ppbv	<	<	<	1
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Mm3	795	846	621	
>>>> Natural gas <<<<						
Butane	Not specified	vol %				0.1
Carbon dioxide	Not specified	vol %				1
Ethane	Not specified	vol %				3.8
Isobutane	Not specified	vol %				0.1
Methane	Not specified	vol %				86.5
Nitrogen	Not specified	vol %				3.1
Oxygen	Not specified	vol %				1.7
Propane	Not specified	vol %				0.8

Table B-2 Site 107 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 5	Run	Run
>>>> Emitted gas <<<<					
Benzene	Gas chromatography (GC)	ppbv			
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Km3			
>>>> Natural gas <<<<					
Butane	Not specified	vol %	<	0.1	
Carbon dioxide	Not specified	vol %		1	
Ethane	Not specified	vol %		3.8	
Isobutane	Not specified	vol %	<	0.1	
Methane	Not specified	vol %		85.6	
Nitrogen	Not specified	vol %		4.1	
Oxygen	Not specified	vol %		1.8	
Propane	Not specified	vol %		0.6	

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Table C-1

Reference Table for Sampling Methods - By Sample Stream

<u>Sampling Stream</u>	<u>Collection Method</u>	<u>Substance Measured</u>
Stack Gas	Draft EPA Metals Method	Metals
	CARB Method 423	Arsenic
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410A	Benzene
	CARB Method 429	PAH
	CARB Method 430	Formaldehyde
Oil	Grab	Metals

Table C-2

**Summary of Preparation Procedures and Analytical Methods
Used to Measure Inorganic Components Measured in the Flue Gas**

<u>Substance</u>	<u>Method Reference</u>
<u>FCEM Target Elements by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)</u>	
Preparation	
Parr Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by GFAAS	
Arsenic *	EPA Method 7060
Chromium	EPA Method 7191
<u>FCEM Target Elements by Cold Vapor Atomic Absorption Spectrophotometry (CVAAS)</u>	
Preparation	
Parr Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by CVAAS	
Mercury	EPA Method 7470
<u>FCEM Target Elements by Inductively Coupled Argon Plasma Emissions Spectrophotometry (ICP-AES)</u>	
Preparation	
Parr Bomb Digestion for Filters	EPA Draft Metals Method
Analysis by ICP-AES	EPA Method 6010
Beryllium	
Cadmium	
Copper	
Lead	
Manganese	
Nickel	
Selenium	
<u>FCEM Target Elements by Ion Chromatography (IC)</u>	
Preparation	
Extraction by Alkaline Solution	CARB Method 425
Analysis by IC	
Hexavalent Chromium	

*For CARB Method 423 and Draft EPA Metals Method.

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds in the Flue Gas**

<u>Substance</u>	<u>Method Reference</u>
<u>Benzene</u>	
Sample Collection	
Tedlar Bags	CARB Method 410A
Analysis by Gas Chromatography/ Photoionization Detector (GC/PID)	CARB Method 410A
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by High Performance Liquid Chromatography (HPLC)	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>	
Sample Collection	
Modified Method 5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by Gas Chromatography/Mass Spectroscopy (GC/MS) with Selective Ion Monitoring	CARB Method 429
Naphthalene	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Chrysene	
Benz(a)anthracene	
Benzo(b + k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-c,d)pyrene	
Dibenz(a,h)anthracene	
Benzo(g,h,i)perylene	

Table C-4

**Preparation Methods and Chemical Analysis
Methods Applied to Oil for Site 107**

<u>Substance</u>	<u>Method Reference</u>
Arsenic	EPA Method 6010, ICP-AES
Beryllium	EPA Method 6010, ICP-AES
Cadmium	EPA Method 6010, ICP-AES
Chloride	ASTM D808-87
Chromium	EPA Method 6010, ICP-AES
Chromium, hexavalent	EPA Method 6010, ICP-AES
Copper	EPA Method 6010, ICP-AES
Lead	EPA Method 6010, ICP-AES
Manganese	EPA Method 6010, ICP-AES
Mercury	EPA Method 6010, ICP-AES
Nickel	EPA Method 6010, ICP-AES
Selenium	EPA Method 6010, ICP-AES
Sulfur	ASTM D4294

Table C-5
Sampling Periods for Flue Gas and Oil

<u>Stack Gas</u>	<u>2/22/90</u>	<u>2/23/90</u>	<u>2/24/90</u>	<u>2/25/90</u>	<u>4/07/90</u>
Multi-metals		0945-1200 1531-1721	1508-1717		
Arsenic		0944-1159 1530-1720	1507-1716		
Chromium	1350-1615 1702-1936		0900-1129		
Semi-VOST	1200-1531 1706-2041		0937-1322		
Benzene			1017-1037 1040-1100 1122-1142	1100-1120 ^a 1248-1308 ^a 1400-1420 ^a	
Formaldehyde			1311-1341 1319-1419 1736-1804	1102-1132 ^a 1242-1310 ^a 1320-1350 ^a	

Oil

Grab Sample

• •

Natural Gas

Grab Sample

• •

^aNatural gas firing.

Appendix D
Process Stream Flow Rates

Table D-1
Natural Gas Analysis - February 25, 1990

Substance	Volume %	
	Sample 1	Sample 2
CH ₄	86.5	86.5
C ₂ H ₆	3.8	3.8
C ₃ H ₈	0.8	0.6
C ₄ H ₁₀ -N	0.1	ND(0.1)
C ₄ H ₁₀ -I	ND(0.1)	ND(0.1)
CO ₂	1.0	1.0
N ₂	3.1	4.1
O ₂	1.7	1.8

HHV = 957 Btu/scf.

Fuel factor (60°F) = 8,487 dscf/10⁶ Btu @ 0% O₂.

Table D-2

**Process Stream Flow Rates, Stack Gas Characterization Data,
Unit Operating Load, and the Degree of Isokinetic Sampling**

<u>Stream</u>	<u>Units of Measure</u>	<u>Average</u>			
<u>Fuel Oil Firing</u>					
<u>Residual Fuel Oil</u>					
Flow Rate	lb/hr L/hr				75,100 ^a 35,900 ^b
<u>Stack Gas</u>					
<u>Multi-Metals</u>					
		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	
Flow Rate	dscfm ^c Nm ³ /hr ^d	480,118 772,000	473,954 762,000	446,206 718,000	466,759 751,000
Unit Load	MW	157	158	157	157
Isokinetic	%	94.61	94.06	106.07	98.2
Moisture	%	8.5	8.8	9.1	8.8
Oxygen	%	7.56	7.36	7.70	7.54
Carbon Dioxide	%	9.40	9.86	9.68	9.65
Stack Temperature	° F	341.0	347.0	340.0	343
<u>Chromium</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 5</u>	
Flow Rate	dscfm ^c Nm ³ /hr ^d	467,216 752,000	460,376 740,000	482,762 776,000	470,118 756,000
Unit Load	MW	173	170	157	167
Isokinetic	%	104.88	99.25	93.39	99.17
Moisture	%	8.8	8.6	7.4	8.3
Oxygen	%	7.5	7.70	7.55	7.58
Carbon Dioxide	%	10.0	9.73	9.0	9.6
Stack Temperature	° F	323.0	329.6	343.5	332
<u>Arsenic</u>					
		<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>	
Flow Rate	dscfm ^c Nm ³ /hr ^d	431,402 694,000	436,236 702,000	473,092 760,000	446,910 719,000
Unit Load	MW	157	158	157	157
Isokinetic	%	101.76	103.02	94.08	99.62
Moisture	%	8.9	9.5	8.6	9.0
Oxygen	%	7.5	7.36	7.7	7.52
Carbon Dioxide	%	9.6	9.86	9.68	9.71
Stack Temperature	° F	328.6	323.0	342.0	331
<u>PAHs</u>					
		<u>Run 1</u>	<u>Run 12</u>	<u>Run 15</u>	
Flow Rate	dscfm ^c Nm ³ /hr ^d	512,490 824,000	493,524 794,000	453,094 728,000	486,369 782,000
Unit Load	MW	172	170	157	166
Isokinetic	%	91.08	94.96	96.23	94.09
Moisture	%	8.8	8.2	8.4	8.5
Oxygen	%	7.27	7.66	7.45	7.46
Carbon Dioxide	%	10.1	9.77	9.7	9.9
Stack Temperature	° F	327.2	328.9	336.5	331

Table D-2 (Continued)

<u>Stream</u>	<u>Units of Measure</u>				<u>Average</u>
<u>Formaldehyde</u>					
		<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	
Flow Rate	dscfm ^c	482,762	482,762	446,206	470,577
	Nm ³ /hr ^d	776,000	776,000	717,000	756,000
Unit Load	MW	157	157	157	157
<u>Benzene</u>					
		<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	
Flow Rate	dscfm ^c	467,928	467,928	467,928	467,928
	Nm ³ /hr ^d	752,000	752,000	752,000	752,000
Unit Load	MW	156	156	157	156
<u>Natural Gas Firing</u>					
<u>Natural Gas</u>					
Flow Rate	KCFH				1,565.2 ^e
<u>Formaldehyde</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^c	401,006	437,190	437,190	425,129
	Nm ³ /hr ^d	645,000	703,000	703,000	684,000
Unit Load	MW	151	151	151	151
<u>Benzene</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^c	419,098	419,098	419,098	419,098
	Nm ³ /hr ^d	674,000	674,000	674,000	674,000
Unit Load	MW	151	151	151	151

^a Average of 18 measurements.

^b Calculated from mass flow rate based on an assumed specific gravity of 0.95.

^c Standard conditions: 1 atm, 60° F.

^d Normal conditions: 1 atm, 32° F.

^e Average of 3 measurements.

Appendix E
Error Propagation for Emission Factors

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 107 are included here.

Emission Factor Results

Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	13.11234	6.24E-01	1.75E+01	1.7E+01	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Arsenic conc	ug/m3	11.4	PREC	2.94E+02	1.15E+00	2.58E+01	3
2) gas	Stack gas flow rate	Nm3/hr	751000	PREC	9.48E+00	1.75E-05	3.06E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.65E+00	-6.69E-04	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	3.90E-01	-1.66E-04	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	1.92E-01	-1.66E-04	1.12E+04	18

* PRECISION COMPONENT = $t \cdot s_{\text{rbar}}$

** $(B_0 + \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot s_{\text{rbar}} + \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{rbar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $s_0 \cdot t$ FOR PRECISION ERRORS

Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.610287	7.67E-02	2.04E+00	2.0E+00	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Cadmium conc	ug/m3	1.4	PREC	4.00E+00	1.15E+00	3.01E+00	3
2) gas	Stack gas flow rate	Nm3/hr	751000	PREC	1.43E-01	2.14E-06	3.06E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	2.48E-02	-8.22E-05	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	5.88E-03	-2.04E-05	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	2.90E-03	-2.04E-05	1.12E+04	18

* PRECISION COMPONENT = $t \cdot s_{\text{rbar}}$

** $(B_0 + \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot s_{\text{rbar}} + \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{rbar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $s_0 \cdot t$ FOR PRECISION ERRORS

Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	8.220828	3.91E-01	2.31E+01	2.3E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium conc	ug/m3	7.1	PREC	5.30E+02	1.16E+00	3.44E+01	3
2) gas	Stack gas flow rate	Nm3/hr	756000	PREC	1.48E+00	1.09E-05	1.94E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	6.47E-01	-4.20E-04	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	1.53E-01	-1.04E-04	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	7.56E-02	-1.04E-04	1.12E+04	18

* PRECISION COMPONENT = $t \cdot s_{\text{bar}}$

** $(b_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\text{bar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{bar} = PRECISION INDEX OF THE MEAN, $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** b_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Chromium +6

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.736795	8.27E-02	2.89E+00	2.9E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium+6 conc	ug/m3	1.5	PREC	8.27E+00	1.16E+00	4.30E+00	3
2) gas	Stack gas flow rate	Nm3/hr	756000	PREC	6.60E-02	2.30E-06	1.94E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	2.89E-02	-8.86E-05	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	6.84E-03	-2.20E-05	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	3.37E-03	-2.20E-05	1.12E+04	18

* PRECISION COMPONENT = $t \cdot s_{\text{bar}}$

** $(b_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\text{bar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{bar} = PRECISION INDEX OF THE MEAN, $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** b_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	20.12859	9.59E-01	5.74E+01	5.7E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Copper conc	uo/m3	17.5	PREC	3.27E+03	1.15E+00	8.61E+01	3
2) oas	Stack oas flow rate	Nm3/hr	751000	PREC	2.24E+01	2.68E-05	3.06E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	3.88E+00	-1.03E-03	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	9.19E-01	-2.55E-04	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	4.53E-01	-2.55E-04	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.891766	4.71E-01	1.73E+01	1.7E+01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Manganese conc	uo/m3	8.600001	PREC	2.94E+02	1.15E+00	2.58E+01	3
2) oas	Stack oas flow rate	Nm3/hr	751000	PREC	5.40E+00	1.32E-05	3.06E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	9.36E-01	-5.05E-04	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	2.22E-01	-1.25E-04	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	1.09E-01	-1.25E-04	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	419.8249	2.00E+01	3.32E+02	3.3E+02	4.30E+00	2.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Nickel conc	ug/m ³	365	PREC	9.88E+04	1.15E+00	4.73E+02	3
2) oas	Stack gas flow rate	Nm ³ /hr	751000	PREC	9.72E+03	5.59E-04	3.06E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.69E+03	-2.14E-02	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	4.00E+02	-5.32E-03	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	1.97E+02	-5.32E-03	1.12E+04	18

* PRECISION COMPONENT = $t \cdot s_{\bar{r}}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot s_{\text{obar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{obar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $s_0 \cdot t$ FOR PRECISION ERRORS

Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	2.092271	9.96E-02	8.24E+00	8.2E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Arsenic conc	ug/m3	1.9	PREC	6.74E+01	1.10E+00	1.29E+01	3
2) oas	Stack gas flow rate	Mm3/hr	719000	PREC	4.14E-01	2.91E-06	3.83E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	4.19E-02	-1.07E-04	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	9.93E-03	-2.65E-05	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	4.90E-03	-2.65E-05	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.581471E-03	2.20E-03	5.96E-02	6.0E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Anthracene conc	ug/m3	8.000001E-03	PREC	3.54E-03	1.20E+00	8.61E-02	3
2) oas	Stack gas flow rate	Mm3/hr	782000	PREC	1.38E-05	1.23E-08	5.25E+05	3
3) baconc	Anthracene conc	ug/m3	8.000001E-03	BIAS	4.65E-06	1.20E+00	1.80E-03	-
4) hhv	Higher heating value	BTU/lb	19150	PREC	8.79E-07	-4.89E-07	2.71E+03	2
5) oil	Oil flow rate	lb/hr	75100	BIAS	2.08E-07	-1.22E-07	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	1.03E-07	-1.22E-07	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Benz(a)anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1317452	6.44E-03	1.19E+00	1.2E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benz(a)anthracene conc	uo/μ3	.11	PREC	1.42E+00	1.20E+00	1.72E+00	3
2) oas	Stack gas flow rate	Nm3/hr	782000	PREC	2.61E-03	1.68E-07	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.66E-04	-6.72E-06	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	3.94E-05	-1.67E-06	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	1.94E-05	-1.67E-06	1.12E+04	18
6) baconc	Benz(a)anthracene conc	uo/μ3	.11	BIAS	2.07E-06	1.20E+00	1.20E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Benzo(b+k)fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	4.311662E-02	2.98E-03	2.98E-01	3.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benzo(b+k)fluoranthene	uo/μ3	.036	PREC	8.85E-02	1.20E+00	4.30E-01	3
2) oas	Stack gas flow rate	Nm3/hr	782000	PREC	2.79E-04	5.51E-08	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.78E-05	-2.20E-06	2.71E+03	2
4) baconc	Benzo(b+k)fluoranthene	uo/μ3	.036	BIAS	4.65E-06	1.20E+00	1.80E-03	-
5) oil	Oil flow rate	lb/hr	75100	BIAS	4.22E-06	-5.47E-07	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	2.08E-06	-5.47E-07	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Benzo(a,h,i)pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.353515E-02	2.68E-03	2.98E-01	3.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benzo(a,h,i)pyrene conc	ug/m3	.028	PREC	8.85E-02	1.20E+00	4.30E-01	3
2) gas	Stack gas flow rate	Nm3/hr	782000	PREC	1.69E-04	4.29E-08	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.08E-05	-1.71E-06	2.71E+03	2
4) baconc	Benzo(a,h,i)pyrene conc	ug/m3	.028	BIAS	4.65E-06	1.20E+00	1.80E-03	-
5) oil	Oil flow rate	lb/hr	75100	BIAS	2.55E-06	-4.25E-07	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	1.26E-06	-4.25E-07	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS**Chrysene**

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	5.988419E-02	3.19E-03	5.96E-01	6.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chrysene conc	ug/m3	5.000001E-02	PREC	3.54E-01	1.20E+00	8.61E-01	3
2) gas	Stack gas flow rate	Nm3/hr	782000	PREC	5.39E-04	7.66E-08	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	3.43E-05	-3.06E-06	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	8.13E-06	-7.59E-07	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	4.01E-06	-7.59E-07	1.12E+04	18
6) baconc	Chrysene conc	ug/m3	5.000001E-02	BIAS	2.07E-06	1.20E+00	1.20E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Dibenzo(a,h)anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.581471E-03	2.20E-03	5.96E-02	6.0E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Dibenz(a,h)anthracene	uo/m3	8.000001E-03	PREC	3.54E-03	1.20E+00	8.61E-02	3
2) gas	Stack gas flow rate	Mm3/hr	782000	PREC	1.38E-05	1.23E-08	5.25E+05	3
3) baconc	Dibenz(a,h)anthracene	uo/m3	8.000001E-03	BIAS	4.65E-06	1.20E+00	1.80E-03	-
4) hhv	Higher heating value	BTU/lb	19150	PREC	8.79E-07	-4.89E-07	2.71E+03	2
5) oil	Oil flow rate	lb/hr	75100	BIAS	2.08E-07	-1.22E-07	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	1.03E-07	-1.22E-07	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	8.982629E-02	4.51E-03	8.93E-01	8.9E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluoranthene conc	uo/m3	.075	PREC	7.97E-01	1.20E+00	1.29E+00	3
2) gas	Stack gas flow rate	Mm3/hr	782000	PREC	1.21E-03	1.15E-07	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	7.72E-05	-4.58E-06	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	1.83E-05	-1.14E-06	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	9.02E-06	-1.14E-06	1.12E+04	18
6) baconc	Fluoranthene conc	uo/m3	.075	BIAS	2.07E-06	1.20E+00	1.20E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.593052E-03	2.16E-03	1.20E-02	1.2E-02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluorene conc	ug/m3	.003	PREC	1.42E-04	1.20E+00	1.72E-02	3
2) baconc	Fluorene conc	ug/m3	.003	BIAS	4.65E-06	1.20E+00	1.80E-03	-
3) gas	Stack gas flow rate	Mm3/hr	782000	PREC	1.94E-06	4.59E-09	5.25E+05	3
4) hhv	Higher heating value	BTU/lb	19150	PREC	1.24E-07	-1.83E-07	2.71E+03	2
5) oil	Oil flow rate	lb/hr	75100	BIAS	2.93E-08	-4.56E-08	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	1.44E-08	-4.56E-08	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS**Indeno(1,2,3-cd)pyrene**

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.0299421	2.58E-03	2.68E-01	2.7E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Indeno(123-cd)pyrene	ug/m3	.025	PREC	7.17E-02	1.20E+00	3.87E-01	3
2) gas	Stack gas flow rate	Mm3/hr	782000	PREC	1.35E-04	3.83E-08	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	8.58E-06	-1.53E-06	2.71E+03	2
4) baconc	Indeno(123-cd)pyrene	ug/m3	.025	BIAS	4.65E-06	1.20E+00	1.80E-03	-
5) oil	Oil flow rate	lb/hr	75100	BIAS	2.03E-06	-3.80E-07	3.76E+03	-
6) oil	Oil flow rate	lb/hr	75100	PREC	1.00E-06	-3.80E-07	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	5.629114	2.68E-01	5.96E+01	6.0E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Naphthalene conc	uo/m3	4.7	PREC	3.54E+03	1.20E+00	8.61E+01	3
2) gas	Stack gas flow rate	Nm3/hr	782000	PREC	4.76E+00	7.20E-06	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	3.03E-01	-2.87E-04	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	7.19E-02	-7.14E-05	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	3.54E-02	-7.14E-05	1.12E+04	18
6) baconc	Naphthalene conc	uo/m3	4.7	BIAS	4.65E-06	1.20E+00	1.80E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1161753	5.72E-03	8.94E-01	8.9E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Phenanthrene conc	uo/m3	9.699999E-02	PREC	7.97E-01	1.20E+00	1.29E+00	3
2) gas	Stack gas flow rate	Nm3/hr	782000	PREC	2.03E-03	1.49E-07	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	1.29E-04	-5.93E-06	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	3.06E-05	-1.47E-06	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	1.51E-05	-1.47E-06	1.12E+04	18
6) baconc	Phenanthrene conc	uo/m3	9.699999E-02	BIAS	2.07E-06	1.20E+00	1.20E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	8.024481E-02	4.08E-03	5.96E-01	6.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Pyrene conc	ug/m3	.067	PREC	3.54E-01	1.20E+00	8.61E-01	3
2) gas	Stack gas flow rate	Nm3/hr	782000	PREC	9.67E-04	1.03E-07	5.25E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	6.16E-05	-4.10E-06	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	1.46E-05	-1.02E-06	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	7.20E-06	-1.02E-06	1.12E+04	18
6) baconc	Pyrene conc	ug/m3	.067	BIAS	2.07E-06	1.20E+00	1.20E-03	-

* PRECISION COMPONENT = $t \cdot s_{\bar{r}}$

** $(B_0 \cdot \text{SIGMA}_D)^2$ FOR BIAS ERRORS: $(t \cdot s_{\bar{r}} \cdot \text{SIGMA}_D)^2$ FOR PRECISION ERRORS

-WHERE $s_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $s_{\bar{r}} / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $s_{\bar{r}} \cdot t$ FOR PRECISION ERRORS

Appendix E

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	641.4562	3.05E+01	1.86E+03	1.9E+03	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	uo/m3	554	PREC	3.42E+06	1.16E+00	2.77E+03	3
2) oas	Stack gas flow rate	Nm3/hr	756000	PREC	3.17E+04	8.48E-04	3.64E+05	3
3) hhv	Higher heating value	BTU/lb	19150	PREC	3.94E+03	-3.27E-02	2.71E+03	2
4) oil	Oil flow rate	lb/hr	75100	BIAS	9.33E+02	-8.13E-03	3.76E+03	-
5) oil	Oil flow rate	lb/hr	75100	PREC	4.60E+02	-8.13E-03	1.12E+04	18

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{rbar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	797.6565	3.80E+01	6.08E+02	6.1E+02	3.18E+00	2.6E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	uo/m3	754	PREC	3.24E+05	1.06E+00	9.32E+02	3
2) oas	Stack gas flow rate	Nm3/hr	684000	PREC	3.16E+04	1.17E-03	2.64E+05	3
3) hhv	Higher heating value	BTU/cf	910	PREC	1.31E+04	-8.37E-01	2.74E+02	4
4) oil	Gas flow rate	cfh	1565000	BIAS	1.44E+03	-4.85E-04	7.83E+04	-
5) oil	Gas flow rate	cfh	1565000	PREC	4.97E+02	-4.85E-04	7.96E+04	3

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{rbar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix F
Quality Assurance/Quality Control Data

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented, as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Reagent blank and field blank analyses were performed for the metals (solid phase and vapor phase). A field blank consisting of a complete semi-VOST sampling train was analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

Table F-2 presents matrix spike recovery data performed for one of the multi-metals stack gas samples. A duplicate analysis was run on one of the flue gas samples for metals. Table F-2 presents the relative percent difference (RPD) between the duplicate analyses for this sample.

Table F-3 presents the matrix spike recovery results for the oil samples. The relative percent difference between the matrix spike and the matrix spike duplicate is also presented. Table F-4 presents the results for the lab surrogate spike recoveries for the PAH analyses.

Table F-1
Summary of Blank Sample Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected (μg)</u>	<u>Detection Limit (μg)</u>
PAHs				
<u>Field Blank</u>				
Naphthalene	1	1	29	0.025
Acenaphthylene	1	0		0.025
Acenaphthene	1	1	0.48	0.025
Fluorene	1	1	0.07	0.025
Phenanthrene	1	1	0.11	0.025
Anthracene	1	1	0.058	0.025
Fluoranthene	1	1	0.057	0.025
Pyrene	1	1	0.055	0.025
Chrysene	1	0		0.025
Benz(a)anthracene	1	0		0.025
Benzo(b+k)fluoranthene	1	0		0.025
Benzo(a)pyrene	1	0		0.025
Indeno(1,2,3-c,d)pyrene	1	1	0.31	0.025
Dibenz(a,h)anthracene	1	1	0.15	0.025
Benzo(g,h,i)perylene	1	1	0.36	0.025
Volatile Organics				
<u>Method Blank</u>				
Formaldehyde	1	0		0.89 $\mu\text{g/mL}$
Benzene	0	0		
<u>Field Blank</u>				
Formaldehyde	1	1	16.3	0.47 $\mu\text{g/mL}$
Benzene	0	0		
Metals - Solid Phase				
<u>Field Blank</u>				
Arsenic	1	1	2.9	
Beryllium	1	1	0.15	
Cadmium	1	0		0.36
Copper	1	1	120	0.6
Lead	1	1	47	3.1
Manganese	1	1	6.6	
Mercury	1	0		1.7
Nickel	1	1	6.9	0.6
Selenium	1	1	15	3.1
<u>Reagent Blank</u>				
Arsenic	1	1	1.4	
Beryllium	1	1	0.28	
Cadmium	1	0		0.32
Copper	1	1	7.6	0.6
Lead	1	1	46	3.1

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected (μg)</u>	<u>Detection Limit (μg)</u>
Manganese	1	1	6.7	
Mercury	1	0		2.2
Nickel	1	1	4.8	0.6
Selenium	1	1	7.9	3.1
Metals - Vapor Phase				
<u>Field Blank</u>				
Arsenic	1	1	0.65	--
Beryllium	1	0		0.06
Cadmium	1	1	1.2	0.02
Copper	1	1	14	0.55
Lead	1	1	7.3	--
Manganese	1	1	1.6	0.55
Mercury*	1	0		41
Nickel	1	1	2.9	0.63
Selenium	1	0		2.8
<u>Reagent Blank</u>				
Arsenic	1	1	0.36	--
Beryllium	1	0		0.06
Cadmium	1	1	0.02	0.02
Copper	1	1	1.6	0.55
Lead	1	1	14	--
Manganese	1	1	1.2	0.55
Mercury*	1	0		41
Nickel	1	0		0.63
Selenium	1	0		3.1
Chromium				
<u>Field Blank</u>				
Chromium	0			
Chromium, hexavalent	0			
<u>Reagent Blank</u>				
Chromium	1	1	1.53	--
Chromium, hexavalent	1	0		0.28
Arsenic				
<u>Field Blank</u>				
Arsenic	1	1	0.42	
<u>Reagent Blank</u>				
Arsenic	1	1	0.48	

*Two impinger analyses, including a potassium permanganate impinger.

Table F-2
Summary of Quality Control Results for Stack Gas

<u>Substance</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
<u>Stack Gas - Solid Phase</u>		
Arsenic	88	9
Beryllium	80	<1
Cadmium	73	3
Copper	96	3
Lead	84	4
Manganese	83	2
Mercury	93	<1
Nickel	99	1
Selenium	80	<1
<u>Stack Gas - Vapor Phase</u>		
Arsenic	--	--
Beryllium	89	<1
Cadmium	77	8
Copper	89	<1
Lead	--	--
Manganese	86	<1
Mercury ^b	98, 99	<1, <1
Nickel	85	4
Selenium	98	<1
<u>Stack Gas - Total</u>		
Chromium	--	--
Chromium, hexavalent	90.3	--

^a

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

^bResults from both impingers.

Table F-3

Summary of Quality Control Results for Fuel Oil

<u>Substance</u>	<u>Detection Limit (mg/L)</u>	<u>Matrix Spike Recovery %</u>	<u>Matrix Spike Duplicate RPD ^a</u>
Arsenic	1.1	83	10
Beryllium	0.22	88	<1
Cadmium	0.22	88	<1
Chromium	--	84	2
Copper	--	88	<1
Lead	1.1	76	9
Manganese	0.43	85	9
Mercury	0.1	102	6
Nickel	--	94	10
Selenium	1.0	98	3

^a

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-4

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean Spike Recovery (%)</u>	<u>Std. Dev. (% Rec.)</u>
d10 Acenaphthene	3	21	17
d10 Anthracene	3	52	50
d12 Chrysene	4	70	46
d12 Benzo(a)pyrene	1	20	--

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PART VI: SITE 108 EMISSIONS REPORT

PRELIMINARY DRAFT REPORT

Test Contractor:

**Carnot, Inc.
15991 Red Hill Avenue, Suite 110
Tustin, California 92680-7388**

3 March 1993

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Section 1

INTRODUCTION

This part of the document summarizes data gathered by Carnot, Inc. (formerly Energy Systems Associates) at a California power plant, designated Site 108, during a sampling program sponsored by the electric utility. The power plant tested was a Riley Stoker boiler, fueled by either residual fuel oil or natural gas. Sampling was conducted in March of 1990.

The test matrix shown in Table 1-1 lists the substances of interest at this site. The *primary emphasis of the sampling effort* was collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the power plant and sampling locations. Section 3 discusses the results of the chemical analyses of the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data according to traditional QA/QC techniques and engineering calculations. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 108

<u>Substance</u>	<u>Process Streams Sampled</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Selenium	X		X
<u>Organic</u>			
Benzene		X	X
Formaldehyde			X
Polynuclear Aromatic Hydrocarbons (15)			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
C ₁ -C ₅ Hydrocarbons		X	
Sulfur Content	X		

Section 2

SITE DESCRIPTION

This section provides a description of the test site, Site 108, and gives the location of the sampling points.

Facility Information

At this site, testing of a steam electric generating unit with a capacity of approximately 50 megawatts (MW) was conducted. The boiler operated at a minimum of 96% of the full rated load during the test period. Testing was conducted during both 100% oil firing and 100% natural gas firing. During the testing at Site 108, the unit operated at a relatively consistent load level--between 53 and 56 MW.

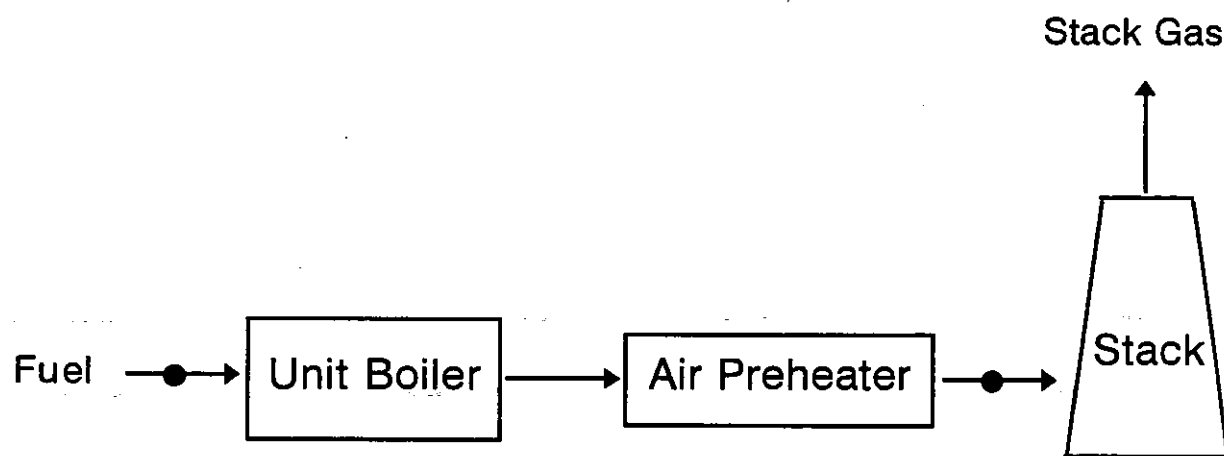
Figure 2-1 shows a process flow diagram of the unit at Site 108. Steam is generated in a Riley Stoker boiler that can be fueled by either natural gas or residual fuel oil. No emission control devices are located downstream of the boiler.

The residual oil fuel at this site has a sulfur content of 1.52%, a higher heating value (HHV) of approximately 18,300 Btu/lb, and an ash content of 0.05 percent. The natural gas fired at Site 108 has an HHV of 23,500 Btu/lb.

Sampling Locations

The fuel to the boiler (oil or natural gas) and the flue gas emitted through the stack were the two streams sampled in this study. Figure 2-1 shows the locations of the sampling points. Brief descriptions of the sampling locations are given below:

- The oil grab samples were collected from the feedlines into the boiler.
- The natural gas analysis was done at a pipeline metering station outside of the plant.
- Stack gas samples were collected through five sample ports located in the air preheater exit duct. For each test, a six-point traverse was made at each port.



- Sampling Locations

Figure 2-1. Process Flow Diagram for Site 108

Section 3

RESULTS

This section summarizes the fuel and emitted gas stream data collected at Site 108 during oil firing. These results were calculated from laboratory and field data reported by Carnot. Only formaldehyde and benzene emissions were measured during the firing of natural gas; metals, PAHs, benzene, and formaldehyde emissions were measured during fuel oil firing.

Appendix A presents the raw analytical data generated by Carnot and their contracting laboratories during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 108 was sampled in March 1990. Figure 3-1 shows the sequence of tests performed at this site. Sample runs have been numbered in chronological order. Each fuel type has its own unique set of run numbers, which are shown in Figure 3-1 and the summary tables.

Four collection trains were used to sample the stack gas during oil firing. These trains include a Draft EPA Metals Method train for multi-metals, a CARB Method 12 train for lead, a CARB Method 425 train for total and hexavalent chromium, and a semi-VOST (Modified Method 5) train for polynuclear aromatic hydrocarbons (PAHs). Benzene was collected by CARB Method 410A, and formaldehyde was sampled using CARB Method 430 for the comparison of emissions produced during natural gas firing and oil firing. Two grab samples of the fuel oil were collected during the five-day test period. A hydrocarbon analysis was performed on the natural gas feed.

Appendix C presents details of the analytical and sampling methods used at this site.

Data Treatment

Several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

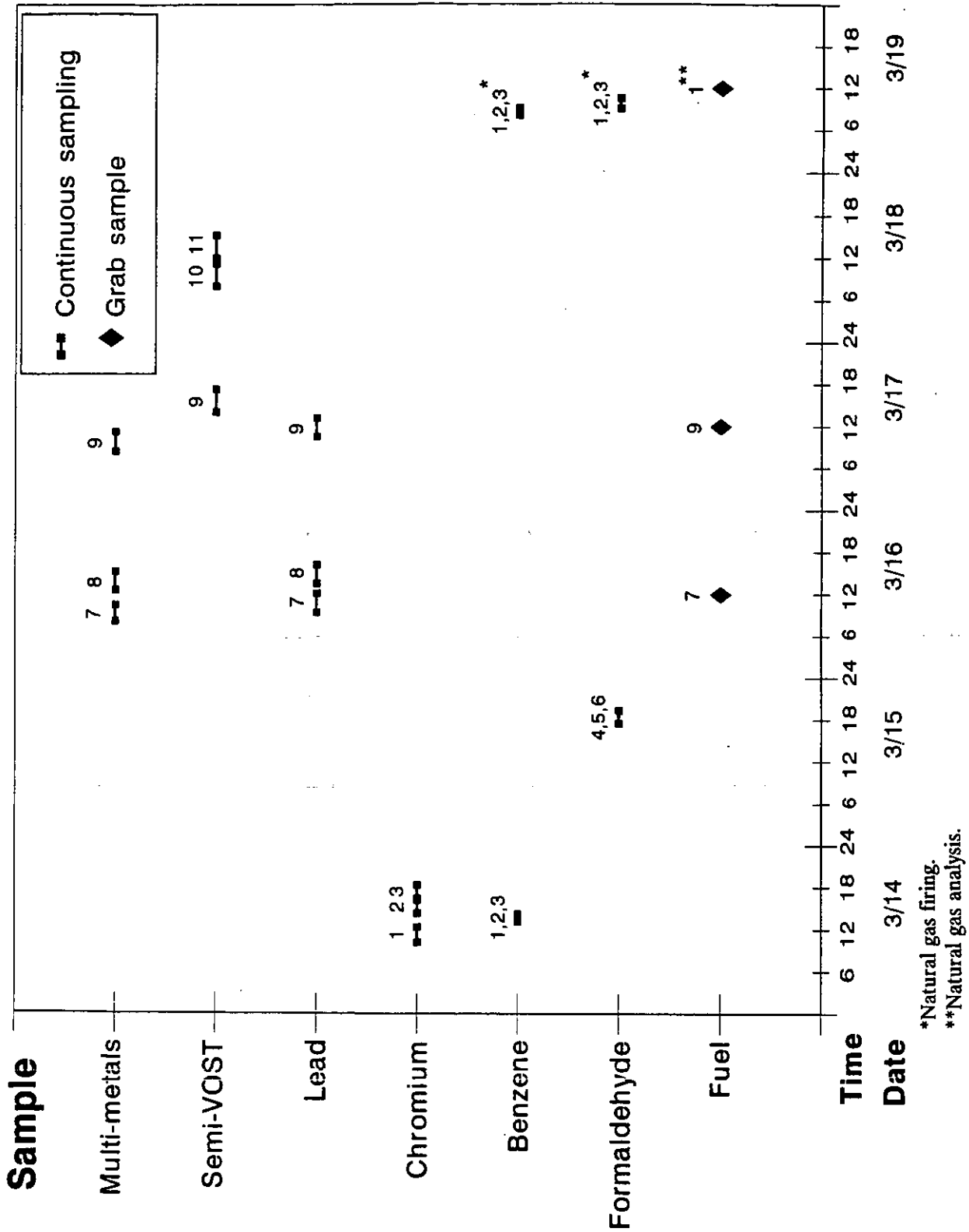


Figure 3-1. Summary of March 1990 Flue Gas Stream and Fuel Sampling Schedule for Site 108, Including Run Numbers

Blank Corrections

The convention for using blank results to correct the data in this group of reports was to use the reagent blank analysis results when they were available. If a reagent blank analysis was not performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no corrections were made.

At Site 108, the reagent blank results were used to correct the results for metals, lead by CARB 12, and formaldehyde. The field blank results were used to correct the chromium and hexavalent chromium by CARB 425 and PAHs results. When they were available, the reagent blank results were used to correct the individual run measurements for both the solid and vapor phases. If the reagent blank was not analyzed, the measurement was corrected for the field blank result. When the blank result was equal to or greater than 50% of the uncorrected measurement, the concentration was flagged with a "B". When the blank correction resulted in a value less than the detection limit given by the analyzing lab for each substance, the concentration is presented as ND(DL), which means that the concentration is below the detection limit (DL), which is presented in parentheses. The test contractor has defined the term "detection limit" as typically three to ten times the instrument detection limit, depending on the laboratory that performed the analysis.

Total Concentrations

The solid- and vapor-phase concentrations are both considered when determining the total gas stream concentration. The absence of detectable concentrations in either phase requires that conventions be established for calculating total values. For each substance, there are three possible combinations of solid and vapor phase concentrations in the emitted gas stream:

- Case 1: The concentrations in both phases are above the detection limits.
- Case 2: The concentrations in both phases are below the detection limits.
- Case 3: The concentration in one phase is above the detection limit, and the concentration in the other phase is below the detection limit.

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

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

For example, the total cadmium (Cd) concentration in the stack gas is calculated as follows for Run 7:

Cd in the solid phase = $2.0 \mu\text{g}/\text{Nm}^3$

Cd in the vapor phase = $0.7 \mu\text{g}/\text{Nm}^3$

Total Cd in the stack gas = $2.7 \mu\text{g}/\text{Nm}^3$

Case 2: The total concentration is considered to be the solid phase detection limit.

For example, the total beryllium (Be) concentration in the stack gas is calculated as follows for Run 7:

Be in the solid phase = $\text{ND}(0.04) \mu\text{g}/\text{Nm}^3$

Be in the vapor phase = $\text{ND}(0.03) \mu\text{g}/\text{Nm}^3$

Total Be in the stack gas = $\text{ND}(0.04) \mu\text{g}/\text{Nm}^3$

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

For example, the total lead (Pb) concentration in the stack gas is calculated as follows for Run 9:

Pb in the solid phase = $\text{ND}(1.6) \mu\text{g}/\text{Nm}^3$

Pb in the vapor phase = $4.5 \mu\text{g}/\text{Nm}^3$

Total Pb in the stack gas = $4.5 \mu\text{g}/\text{Nm}^3$

In historical data and previous FCEM data, mercury has been shown to exist primarily in the vapor phase. For Case 2, then, the total concentration in the gas stream is considered to be the vapor phase detection limit. For Cases 1 and 3, the conventions are the same as those described above.

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

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all values are above the detection limit, the arithmetic mean concentration is calculated using the reported quantities.
- For results that include values both above and below the detection limit, one-half of the DL is used for values below the detection limit to calculate the mean. For example:

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

By our convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8. This is less than the largest detection limit, so the reported mean becomes ND(4).

<u>Analytical Values</u>	<u>Mean Value</u>
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil and Natural Gas

Table 3-1 presents the results of the two residual oil fuel analyses. For each reported substance, a mean concentration has been calculated, along with the 95% confidence interval about the mean. The confidence interval is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean nickel concentration in the oil is 28 ± 6 mg/L (between 22 and 34 mg/L), according to the two results shown in Table 3-1]. The confidence interval calculation is discussed in Section 5.

Natural gas was analyzed for C_1 through C_5 hydrocarbons, nitrogen, and carbon dioxide. Benzene was detected at 280 ppmv. Natural gas analytical results are found in Appendix D, Table D-1.

Stack Gas

Tables 3-2a, 3-2b, and 3-2c present concentration data for the emitted gas at Site 108. The probe and nozzle rinse and filter portions (solid phase) from the multi-metals train were analyzed separately from the impinger solutions (vapor phase). The solid and vapor phase analytical results, corrected for reagent blank values, are presented in Tables 3-2a and 3-2b, respectively. The hexavalent chromium concentration was

Table 3-1
Oil Composition Data for Site 108

	<u>Run 7</u>	<u>Run 9</u>	<u>Mean</u>	<u>95% CI ^a</u>
Sample Date	3/16/90	3/17/90		
Mass Flow Rate (lb/hr)	--	--	32,800 ^b	1,600
Volumetric Flow Rate (L/hr)			15,100 ^b	760
<u>Elements (mg/L)</u>				
Arsenic	ND(1.2) ^c	ND(1.2)	ND(1.2)	--
Beryllium	ND(0.2)	ND(0.2)	ND(0.2)	--
Cadmium	ND(0.2)	ND(0.2)	ND(0.2)	--
Chloride	130	ND(50)	78	670
Chromium	0.3	0.4	0.4	0.6
Chromium, hexavalent	ND(0.2)	ND(0.2)	ND(0.2)	--
Copper	ND(0.7)	ND(0.6)	ND(0.7)	--
Lead	ND(1.2)	ND(1.2)	ND(1.2)	--
Manganese	0.2	0.2	0.2	0
Mercury	ND(0.1)	ND(0.1)	ND(0.1)	--
Nickel	28	27	28	6
Selenium	ND(1.2)	ND(1.2)	ND(1.2)	--
Phosphorus (mg/kg)	10	7.3	8.7	17
Ash (%)	0.05	0.05	0.05	0
Sulfur (%)	1.49	1.54	1.52	0.4
Higher Heating Value (Btu/lb)	18,300	18,300	18,300	0
Specific Gravity	0.987	0.985	0.986	0.009

^aCI = Confidence interval.

^bFlow rate is an average of 16 measurements taken over a four-day period at or near full load.

^cND indicates that the concentration is below the detection limit; the detection limit is shown in parentheses.

Table 3-2a

Stack Gas Composition Data at Site 108
Residual Oil Firing

Solid Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Mean</u>	<u>95% CI^a</u>
Sample Date	3/16/90	3/17/90	3/17/90		
Stream Flow Rate (Nm^3/hr)	229,000	232,000	230,000	230,000	3,800
Arsenic ^b	ND(1.9) ^c B ^d	4.5 B	ND(1.9) B	2.1	5
Beryllium ^b	ND(0.04)	ND(0.04)	ND(0.04)	ND(0.04)	--
Cadmium ^b	2.0 ^e	4.2 ^e	2.4 ^e	2.9	3
Copper ^b	12 B	16 B	9.5 B	13	8
Lead ^b	2.6 B	8.1 B	ND(1.6) B	3.8	9
Manganese ^b	11	13	9.3	11	5
Mercury ^b	ND(0.9) ^e	ND(0.8) ^e	ND(1.3) ^e	ND(1.3)	--
Nickel ^b	1,460	1,860	1,580	1,630	510
Selenium ^b	8.8	7.5	8.3	8.2	2
Sample Date	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Stream Flow Rate (Nm^3/hr)	3/14/90	3/14/90	3/14/90		
Chromium, hexavalent ^f	221,000	223,000	231,000	225,000	13,000
	1.4 ^e	3.4 ^e	1.3 ^e	2.0	3

^aCI = Confidence interval.

^bA reagent blank analysis was performed and used to correct the sample results.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

^eA blank correction is not applied since the substance was not detected in the blank sample.

^fA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.

Table 3-2b

Stack Gas Composition Data at Site 108
Residual Oil Firing

Vapor Phase ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Sample Date</u>	3/16/90	3/16/90	3/17/90		
Stream Flow Rate (Nm^3/hr)	229,000	232,000	230,000	230,000	3,800
Arsenic ^b	3.6	8.3	7.6	6.5	6
Beryllium ^b	ND(0.03) ^{c,d}	ND(0.03) ^d	ND(0.03) ^d	ND(0.03)	--
Cadmium ^b	0.7 ^d	4.0 ^d	0.9 ^d	1.9	5
Copper ^b	7.2	4.9	3.1	5.1	5
Lead ^b	8.0	12	4.5	8.2	9
Manganese ^b	8.9 ^d	-- ^e	5.8 ^d	7.4	20
Mercury ^b	ND(26) ^d	ND(38) ^d	ND(34) ^d	ND(38)	--
Nickel ^b	30	28	17	25	17
Selenium ^b	9.9 ^d	15 ^d	3.8 ^d	9.6	14
<u>Sample Date</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
	3/14/90	3/14/90	3/14/90		
Stream Flow Rate (Nm^3/hr)	221,000	223,000	231,000	225,000	13,100
Chromium, hexavalent ^f	ND(0.3) ^d	2.2 ^d	2.6 ^d	1.7	3

^aCI = Confidence interval.^bA reagent blank analysis was performed and used to correct the sample results.^cND indicates that the concentration is below the detection limit, which is shown in parentheses.^dA blank correction is not applied since the substance was not detected in the blank sample.^eImpinger was contaminated with KMnO_4 .^fA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.

Table 3-2c

Stack Gas Composition Data at Site 108
Residual Oil Firing

Combined Phases ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>		<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Mean</u>	<u>95% CI^a</u>	Results
<u>Elements</u>							
Sample Date		3/16/90	3/16/90	3/17/90			
Stream Flow Rate (Nm^3/hr)		229,000	232,000	230,000	230,000	3,800	
Arsenic ^b		3.6	13	7.6	8.1	12	
Beryllium ^b		ND(0.04) ^c	ND(0.04)	ND(0.04)	ND(0.04)	--	
Cadmium ^b		2.7 ^d	8.2 ^d	3.3 ^d	4.7	7	
Copper ^b		19 B ^e	21 B	13 B	18	10	
Lead ^b		11 B	20 B	4.5 B	12	19	
Manganese ^b		20	-- f	15	18	31	
Mercury ^b		ND(26) ^d	ND(38) ^d	ND(34) ^d	ND(38)	--	
Nickel ^b		1,490	1,890	1,600	1,660	510	
Selenium ^b		19	23	12	18	14	
Stream Flow Rate (Nm^3/hr)		217,000	227,000	227,000	224,000	14,000	
Lead ^g		7.2	9.6	8.5	8.4	3	
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>			
Sample Date		3/14/90	3/14/90	3/14/90			
Stream Flow Rate (Nm^3/hr)		221,000	223,000	231,000	225,000	13,000	
Chromium ^h		ND(1.4) B	ND(1.3) B	ND(1.3) B	ND(1.4)	--	
Chromium, hexavalent ^h		1.4 ^d	5.6 ^d	3.9 ^d	3.6	5	

Table 3-2c (Continued)

<u>Substance</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>	<u>Mean</u>	<u>95%CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons^b</u>					
Sample Date	3/17/90	3/18/90	3/18/90		
Stream Flow Rate (Nm ³ /hr)	232,000	223,000	221,000	225,000	14,500
Acenaphthene	ND(0.009) B	ND(0.01) B	ND(0.01) B	ND(0.01)	--
Acenaphthylene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Anthracene	ND(0.009) B	ND(0.01) B	ND(0.01) B	ND(0.01)	--
Benz(a)anthracene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Benzo(a)pyrene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Benzo(b+k)fluoranthene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Benzo(g,h,i)pyrene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Chrysene	ND(0.009)	ND(0.01)	ND(0.01)	ND(0.01)	--
Fluoranthene	0.009 B	ND(0.01) B	ND(0.01) B	ND(0.01)	--
Fluorene	ND(0.009) B	ND(0.01) B	ND(0.01) B	ND(0.01)	--
Indeno(1,2,3-c,d)pyrene	ND(0.09)	ND(0.01)	ND(0.01)	ND(0.01)	--
Naphthalene	0.69 B	1.2 B	ND(0.01) B	0.63	1.5
Phenanthrene	0.055	ND(0.01) B	ND(0.01) B	0.02	0.07
Pyrene	0.01 ^d	ND(0.01) ^d	0.015 ^d	0.01	0.01

^aCI = Confidence interval.^bA reagent blank analysis was performed.^cND indicates that the concentration is below the detection limit, which is shown in parentheses.^dA blank correction is not applied since the substance was not detected in the blank sample.^eB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.^fImpinger was contaminated with KMnO₄, so a total concentration is not presented.^gSampled by CARB Method 12.^hA reagent blank analysis was not performed; therefore, the field blank results were used to correct the sample results.

corrected for the field blank results since a reagent blank was not analyzed. The three measured concentrations for each phase are presented, as well as the mean and the 95% confidence interval (CI) associated with the mean.

In some cases, the reagent blank corrections were fairly significant. Appendix A presents the results of the blank analyses, as well as the test results for each run.

The total concentrations from each run were averaged (according to the conventions outlined previously) to obtain an overall mean concentration of each measured substance.

Table 3-2c presents the total concentrations measured for each run, as well as the mean and 95% CI associated with the total value. The sampling methods cited for total chromium and PAHs indicate that both solid and vapor fractions were collected; however, the fractions were not analyzed separately. For these substances, the results are presented only as total concentrations. In addition, a reagent blank analysis was not performed for chromium and PAHs; therefore, the field blank results were used to correct the measured concentrations. The measured concentrations of several PAHs were below the detection limit of $0.01 \mu\text{g}/\text{Nm}^3$.

Table 3-3 compares volatile organic emissions from the same boiler fired by two different fuels--residual oil and natural gas. Benzene was below the detection limits while firing either fuel. For each type of fuel, a relatively high formaldehyde level in the reagent blank resulted in only one corrected formaldehyde concentration being above the detection limit.

Appendix D, Table D-2, presents additional sampling information, including stream flow rates, unit load, stack gas characterization data, stack temperatures, and the degree of isokinetic sampling for each sampling event.

Table 3-4 shows the average unit-energy-based emission factors in pounds of substance emitted per 10^{12} Btu input to the boiler. The emission factors were calculated from the total mean stack gas concentration shown in Table 3-2c. Section 5 contains an example calculation.

Table 3-3

**Volatile Organic Stack Emissions at Site 108
Residual Oil and Natural Gas Firing**

<u>Volatile Organic Compounds</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>95% CI^a</u>		
<u>Residual Oil Firing</u>							
Stack Flow Rate: 221,000 Nm ³ /hr							
Benzene (μg/Nm ³) ^b	ND(3.5) ^c	ND(3.5)	ND(3.5)	ND(3.5)	--		
	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>				
Stack Flow Rate: 231,000 Nm ³ /hr							
Formaldehyde (μg/Nm ³)	14	ND(24)	B ^d	ND(23)	B	ND(24)	--
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>				
<u>Natural Gas Firing</u>							
Stack Flow Rate: 209,000 Nm ³ /hr							
Benzene (μg/Nm ³) ^b	ND(3.5)	ND(3.5)	ND(3.5)	ND(3.5)			--
Formaldehyde (μg/Nm ³)	22	ND(11)	B	ND(19)	B	ND(19)	--

^aCI = Confidence interval.

^bA blank analysis for benzene was not performed.

^cND indicates that the concentration is below the detection limit, which is shown in parentheses.

^dB indicates that the reagent blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-4
Stack Gas Emission Factors at Site 108
(lb/10¹² Btu)

<u>Substance</u>	<u>Residual Oil Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Elements</u>		
Arsenic	6.8	10
Beryllium	ND(0.03) ^b	--
Cadmium	4.0	6
Chromium	ND(1.2)	--
Chromium, hexavalent	3.0	4
Copper	15	9
Lead	10	16
Manganese	15	30
Mercury	ND(32)	--
Nickel	1,400	450
Selenium	15	13
<u>Polynuclear Aromatic Hydrocarbons</u>		
Acenaphthene	ND(0.008)	--
Acenaphthylene	ND(0.008)	--
Anthracene	ND(0.008)	--
Benz(a)anthracene	ND(0.008)	--
Benzo(a)pyrene	ND(0.008)	--
Benzo(b+k)fluoranthene	ND(0.008)	--
Benzo(g,h,i)perylene	ND(0.008)	--
Chrysene	ND(0.008)	--
Fluoranthene	ND(0.008)	--
Fluorene	ND(0.008)	--
Indeno(1,2,3-c,d)pyrene	ND(0.008)	--
Naphthalene	0.52	3
Phenanthrene	0.02	0.1
Pyrene	0.008	0.01
<u>Volatile Organic Compounds</u>		
Benzene	ND(2.8)	--
Formaldehyde	ND(20)	--
	<u>Natural Gas Firing</u>	
<u>Volatile Organic Compounds</u>		
Benzene	ND(2.2)	--
Formaldehyde	ND(12)	--

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Btu), which is shown in parentheses.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 108, two methods were used to evaluate the quality of the data. First, and most important, was evaluation of the traditional QA/QC protocol for sampling and analytical procedures used at Site 108, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 108 QA/QC data are compared with FCEM project objectives for similar QA/QC procedures. The second data evaluation tool involves calculating material balances around the entire plant for various substances. Material balances involve the summation and comparison of mass flow rates in several streams that are often samples are analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute significantly to the overall inlet or outlet mass rate (e.g., coal, bottom ash, collected fly ash, etc.).

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during the sampling and analysis process. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure the sources of variability. Table 4-1 summarizes the QA/QC measures commonly used as part of the FCEM data evaluation protocol and the characteristic information obtained. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data, but does limit the ability to measure the various components of measurement error.

As indicated in the table, different QC checks provide different types of information, particularly pertaining to the sources of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Estimates of precision and accuracy are based on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with Data Quality Objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The results of these analyses appear in Appendix F. Table 4-3 summarizes the precision and accuracy estimates.

According to the quality control data evaluated, there is reason to conclude that the data reported are acceptable, although not enough information is available to unequivocally validate the data. The QC indicators reported are generally good, accepted methods were used for sampling and analysis, and stack gas sample collection records are strongly supportive. The confidence in some measurements is low because of relatively high blank results. In particular, high levels of PAHs in the field blank make the PAH measurements suspect, except for one test result for phenanthrene and all test results for pyrene. The validity of the stack gas chromium results is questionable because of a field blank significantly higher than the mean stack gas value. No quality control measurements were performed for benzene, natural gas composition, or proximate and ultimate analyses.

A discussion of precision and accuracy is presented below for each measurement type, followed by a review of stack gas sampling quality control data. This review includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias, or persistent positive or negative deviation from the "true" value.

Table 4-2

Types of Quality Control Data Reported

Analysis	Precision			Accuracy			Blank					
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals by ICP/AAS ^a	✓		✓			✓						
Ultimate and Proximate ^b	✓											
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by ICP ^c	✓		✓			✓			✓			✓
Arsenic by GFAAS	✓								✓			✓
Lead by GFAAS	✓					✓			✓			✓
Mercury by CVAAS	✓		✓			✓			✓			✓
Hexavalent Chromium by IC	✓		✓			✓			✓			
Total Chromium by AAS	✓		✓			✓			✓			✓
Benzene by GC/PID	✓											
Formaldehyde by HPLC	✓			✓					✓		✓	
Polynuclear Aromatic Hydrocarbons by GC/MS ^d	✓							✓				✓

^aIncludes As, Be, Cd, Cr, Cr(VI), Cu, Pb, Hg, Mn, Ni, P, Se, Zn by EPA SW-846 Methods 6010 (ICP-AES) AND 7000 series (AAS).

^bAsh, carbon, hydrogen, nitrogen, oxygen, sulfur, specific gravity, and chlorine.

^cIncludes Be, Cd, Cu, Pb, Mn, Ni, Se, and Zn by ICP-AES.

^dIncludes acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene.

Table 4-3

Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured ^a	Objectives		Measured		Data Evaluation
		Precision ^b	Accuracy ^c	Precision	Accuracy	
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	<1% RPD	105%	
Beryllium		20% RPD	75-125%	<1% RPD	98%	
Cadmium		20% RPD	75-125%	5% RPD	86%	
Chromium		20% RPD	75-125%	5% RPD	114%	
Copper		20% RPD	75-125%	11% RPD	118%	
Lead		20% RPD	75-125%	5% RPD	111%	
Manganese		20% RPD	75-125%	4% RPD	104%	
Mercury		20% RPD	75-125%	3% RPD	95%	
Nickel		20% RPD	75-125%	<1% RPD	80%	
Phosphorus		20% RPD	75-125%	4% RPD	98%	
Selenium		20% RPD	75-125%	14% RPD	97%	
Metals in Stack Gas - Vapor Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Beryllium		20% RPD	75-125%	<1% RPD	90%	
Cadmium		20% RPD	75-125%	<1% RPD	74%	
Copper		20% RPD	75-125%	<1% RPD	82%	
Manganese		20% RPD	75-125%	1% RPD	79%	
Mercury		20% RPD	75-125%	4% RPD	89%	
Nickel		20% RPD	75-125%	<1% RPD	84%	
Selenium		20% RPD	75-125%	3% RPD	128%	
Metals in Stack Gas - Solid Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Beryllium		20% RPD	75-125%	<1% RPD	56%	
Cadmium		20% RPD	75-125%	<1% RPD	83%	
Copper		20% RPD	75-125%	2% RPD	96%	
Lead		20% RPD	75-125%	<1% RPD	88%	
Manganese		20% RPD	75-125%	2% RPD	88%	
Mercury		20% RPD	75-125%	<1% RPD	90%	

Table 4-3 (Continued)

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Nickel		20% RPD	75-125%	<1% RPD	99%
Selenium		20% RPD	75-125%	<1% RPD	84%
Total Chromium in Stack Gas	Precision - Duplicate Analysis Accuracy - Matrix Spike	20% RPD	75-125%	9% RPD	116%
Hexavalent Chromium in Stack Gas	Precision - Not performed Accuracy - Matrix Spike	20% RPD	75-125%	--	102%
PAHs in Stack Gas	Precision & Accuracy - Surrogate Spikes	35% CV	50-150%	15% CV	77-110%
d10-Acenaphthene		35% CV	50-150%	25% CV	45-70%
d10-anthracene		35% CV	50-150%	13% CV	120-150%
d12-Chrysene		35% CV	50-150%	41% CV	35-82%
d12-Benzo(a)pyrene		40% RPD	50-150%	22% RPD	93-116%
Formaldehyde in Stack Gas	Precision and Accuracy - Matrix Spike Duplicates				

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicate, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) between the duplicate results.

^cAccuracy is expressed as the range of recoveries expected for individual analysis results.

The efficiency of the analytical procedure as used on the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes or other quality assurance measures, as necessary. Spiked samples usually provide a measure of accuracy or bias at medium concentration levels, expressed as percent recovery; blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. Table 4-3 presents precision estimates for the metals analyses. The precision estimates are based on duplicate laboratory analyses, which represent solely analytical variability. The precision objectives cited in Table 4-3 are intended for sampling and analytical variability. Despite the lack of specific QC information to compare with these objectives, the data demonstrate good analytical precision for metals analyses in all matrices, including stack gas (vapor phase and particulate matter) and fuel oil.

The measurement data for the replicate runs, presented in Section 3 of this report, show good overall repeatability. At low trace-level concentrations, the absolute differences between the replicate results are typically small, whereas the relative differences are large, which would be expected as the measured values approach zero. At such low levels, especially where the uncertainty is equal to or greater than the magnitude of the measurements, the results should be considered semi-quantitative or qualitative.

Accuracy. Accuracy estimates for the metals analyses, as shown in Table 4-3, are based on matrix spike recovery data. These data show recoveries for stack gas (particulate matter and vapor phase) samples and fuel oil, to be well within the stated objectives, with only two exceptions. The recovery of beryllium (56%) in stack gas particulate matter was somewhat low compared with the 75-125% objective, and the recovery of selenium (128%) in the stack gas vapor phase was slightly high. These exceptions should not cause significant concern.

Blanks. In most instances, reagent blank results were used to correct the stack gas concentrations. For some substances, the blank levels were similar to the actual levels in the sample. In almost all cases, the reagent blank values were on the same order of magnitude as those of the field blanks. Blank sample results are shown in Appendices A and F. Field blank levels were used to correct the total and hexavalent chromium results since a reagent blank was not analyzed.

The stack gas concentrations of arsenic (solid phase), chromium (combined phases), copper (solid and combined phases), and lead (solid and combined phases) are flagged with a "B", indicating that the reagent blank result (field blank for chromium) is equal to or higher than 50% of the measured result. For arsenic, the reagent blank level was higher than one of the measured solid phase results (Run 9), indicating a potential problem with the analysis. For the other two solid-phase arsenic samples, the reagent blank value was nearly as high as the actual results (equivalent to 70 and 90% of the sample measurements). On the other hand, the level of arsenic in the solid-phase field blank was about 15% of the level in the reagent blank. Because the actual concentration was highly uncertain in this instance, the solid phase arsenic concentration is flagged with a "B".

The chromium field blank analysis (59 μg) was significantly higher than the average measured value in the stack gas (7.3 μg); therefore, the validity of the measured chromium results is questionable. Since the blank level was so high, the chromium results are flagged.

PAHs

Precision. Precision estimates for PAH analyses in stack gas samples, as shown in Table 4-3, are based on the scatter of surrogate spike recoveries in the three replicate sample analyses, expressed as the percent coefficient of variation (% CV). These data show the precision to be within expected limits, with CVs for three out of the four surrogate compounds within the 35% objective, and the fourth only slightly higher at 41% CV. The results for PAHs across the three replicate runs are equally consistent, although most of the target analytes were not detected.

Accuracy. Accuracy estimates for PAHs in the stack gas, based on surrogate spike recoveries in three samples, were within the nominal 50-150% recovery objective for two of the four surrogate compounds, and only slightly low for d10-anthracene (45-70%) and d12-benzo(a)pyrene (35-82%). Although these recoveries are low, the recoveries for d12-chrysene (120-150%) are slightly high, although within the objective. Overall, these data point to effective analyses.

Blanks. Seven of the PAHs analyzed were detected in the stack gas stream during oil firing: acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene. For most of the PAHs, the field blank levels were high compared to the stack gas measurements; these concentrations are marked with a "B" flag in Table 3-2c. Some measured concentrations were even below the field blank values. A reagent blank

analysis was not performed for PAHs. Appendix A contains the blank results and the the routine sample results for comparison.

The high levels of PAHs in the field blank make the PAH measurements suspect, except for one test results for phenanthrene and all test results for pyrene. The lack of a reagent blank analysis makes it difficult to determine the cause of the high blank result for some of the PAHs.

Formaldehyde

Precision. The precision of the formaldehyde analyses, expressed in terms of the relative percent difference (RPD) for matrix spike duplicate analyses, is 22 RPD, within the objective of 40 RPD.

Accuracy. Accuracy estimates for the analytical results for formaldehyde in the stack gas, based on matrix-spiked analytical results (93-116% recovery), are well within the 50-150% objective.

Blanks. The reagent blank value was used to correct the concentrations presented for formaldehyde in the stack gas. In two cases, the formaldehyde level in the reagent blank was slightly less than 50% of the measured results (Run 4 during oil firing and Run 1 during natural gas firing). For the other two measurements from each fuel test, the reagent blank level was equivalent to at least 50% of the measured value. The field blank measurement for formaldehyde was twice the reagent blank level, indicating possible problems in the sampling or analytical procedures.

Stack Gas Sampling Quality Control

Sampling quality control was addressed in a summary of the quality assurance program used by Carnot and in a letter of certification from the California Air Resources Board. Also included were calibration records for the dry gas meters and a table outlining the schedule and procedures used to calibrate these and other equipment.

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location. Some variation was noted in the sample volumes for the formaldehyde tests, but the analytical results were relatively consistent.

Sampling accuracy is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases, which may be caused by contamination of the equipment or location or by operator errors. Blanks were included for all tests except the CARB 410A benzene samples, which are collected by grab bag.

Sampling representativeness depends on the precision and accuracy and also on the characteristics of the sampling locations. The sampling location on the inlet duct

connecting to the stack was not ideal as far as meeting the requirements for undisturbed flow distances upstream and downstream of the sampling ports to allow a minimum number (12) of traverse points for velocity and particulate matter measurements, but representativeness was maintained by using a larger number (30) of points. The isokinetic variation is a measure of the operational performance of sampling for particulate matter. It can be used as an indicator of precision, with consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011. It uses the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 methodology for semivolatile organic compounds, dioxins, and furans is well established both for sampling and analysis. The EPA multi-metals procedure is still in the evaluation process, but it is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of collection medium and analytical procedures. CARB 410A for benzene is the same as EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag.

Sampling completeness is mainly a function of providing the requisite number of samples and of proper documentation. In particular, the data necessary for calculating the results, including calibration of the equipment and all pertinent entries on the run data sheets, should be present. The calibration data provided in this report were adequate, and sampling sheets were acceptably filled out, although neither the temperatures on the impinger exits nor those of the condenser exits of the PAH trains were recorded. The necessary number of samples were successfully taken and sample custody was transferred properly to the analytical laboratories. No significant data losses were reported. However, manganese results were not available for one of the three stack gas samples because of a contaminated impinger solution.

Material Balance Results

The streams considered in the material balance for Site 108 were the fuel oil as input and the flue gas as output. Stream flow rates and concentrations and the bias and precision errors associated with these measurements were entered into a statistical error propagation model to estimate the overall material balance closure. A detailed discussion of the statistical error propagation analysis appears in Appendix E.

A material balance closure is defined as the ratio of outlet to inlet mass. A 100% closure indicates perfect agreement. When trace substances are analyzed, closures of between 70% and 130% have been set as a goal for the FCEM project. This range reflects a typical level of analytical uncertainty. Closures within this range indicate that

inlet and outlet stream mass rates are statistically equivalent. Poor closure values may indicate measurement problems in one or more of the sample matrices.

The measured oil flow rate was compared with the unit generating capacity by calculating a heat input using the oil flow rate and higher heating value and an efficiency of 30 percent. The flow and generating capacity were in good agreement. Both oil and stack gas flow rates have narrow confidence intervals, indicating good precision in their measurements.

Table 4-4 presents the manganese and nickel material balance closures and the error propagation analytical results. The elemental balance for nickel was within acceptable closure limits. Material balances were not calculated for other elements because the concentrations in the fuel oil were below the detection limits. For chromium, the oil sampling period did not coincide with the stack gas sampling; therefore, the material balance closure was not calculated. An ash balance could not be performed because particulate loadings were not measured in the stack gas.

Manganese

The material balance closure, $137 \pm 270\%$, is nominally outside of the desired range. The impinger for Run 8 was contaminated with KMnO_4 ; therefore, the mean manganese concentration was calculated from two test results. The two measured flue gas concentrations of manganese are reasonably consistent. The large 95% CI is a result of having only two samples. The amount of manganese in the reagent blank was equivalent to nearly one-fourth of each measured result. The matrix spike recoveries are acceptable for both the solid and vapor phase analyses. The spike recovery of manganese in the fuel oil was good (104%). However, the manganese concentration in the fuel oil was only reported to one significant figure (i.e., 0.2 mg/L). Thus, uncertainty about the amount of manganese present in the oil can be as much as $\pm 25\%$ (i.e., ± 0.05 mg/L).

Nickel

The nickel material balance closure of $90 \pm 30\%$ indicates that the stream flow rates and concentrations for the inlet and outlet samples are probably accurate. The reagent blank level of nickel is low compared to the overall concentration of nickel in the stack gas. The spike recoveries were within acceptable limits.

Table 4-4
Material Balance Closure Results for Site 108

<u>Substance</u>	<u>Mean Closure (%)</u>	<u>95% CI</u>
Manganese	137	270
Nickel	90	30

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

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

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

where:

- C = Concentration, $\mu\text{g}/\text{Nm}^3$
- M = Mass measured in the sample, μg
- B = Mass measured in the blank (reagent or field), μg
- SV = Sample volume (at 68°F), dscf
- F = Sample correction factor (see below)
- 35.3 = Conversion of ft^3 to m^3 (standard)
- $\frac{528}{492}$ = Temperature correction for normal conditions, i.e., 32°F (68°F to 32°F)

The sample correction factor depends on the specific analytical procedure where:

- F = 0.95 for the multi-metals train since 5% of the sample was removed for mercury analysis.
- F = 1.0 for mercury, lead (by CARB Method 12), benzene, formaldehyde, and PAHs.

Example Calculations

- $F = 0.5$ for total and hexavalent chromium since one-half of the sample was used for each substance.

Note that the mercury results were corrected for the sample aliquot in the analytical reports prepared by the lab. All concentrations are presented at normal conditions (32° F, 1 atm).

Unit Energy Calculations

The unit-energy-based emission factors (Table 3-4) were determined from the mass flow rate of a substance being emitted divided by the fuel heat input to the boiler during testing.

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

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

g = Mean flue gas flow rate, Nm^3/hr

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

HHV = Mean oil higher heating value, Btu/lb

oil = Mean oil feed rate, lb/hr

2202.6 = Unit conversion coefficient, $lb\ Btu/\mu g\ 10^{12}\ Btu$

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

g = 230,000 Nm^3/hr

c = 1,660 $\mu g/Nm^3$

HHV = 18,300 Btu/lb

oil = 32,800 lb/hr

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

$$E = \frac{230,000 * 1,660 * 2202.6}{18,300 * 32,800} = 1,400 \text{ lb}/10^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{h} * 2202.6 \quad (5-3)$$

where:

h = Heat input (estimated by Carnot), Btu/hr

Confidence Interval Calculations

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

CIs for Stream Concentrations

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

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

where:

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

β_r = Bias component

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

S_r = Standard deviation of the individual run measurements

Example Calculations

$N =$ Number of measurements

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

$$\beta_r = \sqrt{\sum_{m=1}^n (\beta_{pm} * \theta_{pm})^2} \quad (5-5)$$

where:

$\beta_{pm} =$ Individual bias for run m

$\theta_{pm} =$ Sensitivity to run $m = 1/N$

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

The following concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Tables 3-2a, 3-2b, and 3-2c, will be used to demonstrate the method for calculating the 95% CI:

<u>Substance</u>	<u>Fraction</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>
Nickel	Solid Phase	1,460	1,860	1,580
Nickel	Vapor Phase	30	28	17
		<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>
Pyrene	Total	0.01	ND(0.01)	0.015

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

<u>Substance</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>Standard Deviation</u>
Nickel	1,490	1,890	1,600	1,660	207

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

$$\begin{aligned}
 \beta_r &= 0 \text{ (no values below the detection limit)} \\
 t &= 4.3 \\
 S_r &= 207 \\
 N &= 3
 \end{aligned}$$

The 95% CI (U_{TOT}) for the total nickel concentration is $510 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for pyrene is calculated the same way. Since the concentration for Run 10 is below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>
β_p	0	0.005	0

The bias component is then calculated from Equation 5-5 using these values. In this example, the sensitivity is 0.33 or $1/3$.

$$\begin{aligned}
 \beta_r &= \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{0.005}{3}\right)^2 + \left(\frac{0}{3}\right)^2} \\
 &= 0.002
 \end{aligned}$$

The standard deviation (S_r) calculated from the three individual pyrene concentrations is 0.005. Substituting these values into Equation 5-4,

$$\begin{aligned}
 U_{TOT} &= \sqrt{(0.002)^2 + \left(\frac{4.3 * 0.005}{\sqrt{3}}\right)^2} \\
 &= 0.01 \mu\text{g}/\text{Nm}^3
 \end{aligned}$$

CIs for Emission Factors and Material Balance Closures

The 95% CIs for the emission factors and material balance closures were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A
Analytical Data from the Carnot Report

Table A-1 presents the test results for each run, as well as the results of the blank analyses. Blanks were analyzed for metals in both the solid phase and vapor phase fractions. A field blank analysis was performed for PAHs.

Table A-1
Results of the Sample, Field Blank, and
Reagent Blank Analyses for FCEM Site 108

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
Oil Firing					
<u>Elements</u>					
<u>Multi-Metals Sampling Train</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>		
Gas Sample Volume, Nm ³	2.01	2.09	2.00		
<u>Vapor Phase</u>					
Arsenic	7.3	17	15	0.4	0.5
Beryllium	ND(0.06)	ND(0.05)	ND(0.05)	ND(0.07)	ND(0.07)
Cadmium	1.3	7.9	1.7	ND(0.3)	ND(0.3)
Copper	15	11	7.1	3.7	1.3
Lead	16	24	9.3	0.9	0.7
Manganese	17	42,000 ^a	11	ND(0.6)	ND(0.6)
Mercury ^b	ND(53)	ND(79)	ND(68)	ND(19)	ND(20)
	ND(2.2)	ND(1.6)	ND(2.4)	ND(2.3)	ND(1.0)
Nickel	58	58	34	6.8	1.6
Selenium	19	30	7.3	ND(3.0)	ND(3.0)
<u>Solid Phase</u>					
Arsenic	23	29	7.5	3	20
Beryllium	ND(0.07)	ND(0.07)	ND(0.07)	0.22	0.22
Cadmium	3.8	8.4	4.6	ND(0.3)	ND(0.3)
Copper	56	64	51	40	33
Lead	46	57	27	66	41
Manganese	29	34	25	8	7.3
Mercury	ND(1.9)	ND(1.7)	ND(2.6)	ND(1.5)	ND(2)
Nickel	2,800	3,700	3,000	23	4.8
Selenium	21	19	20	5.4	4.2
<u>Individual Metal Sampling Trains</u>					
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm ³	1.84	1.91	1.96		
Chromium	5.50	7.75	5.75	59	
<u>Vapor Phase</u>					
Chromium, hexavalent	ND(0.6)	2.11	2.57	ND(0.6)	
<u>Solid Phase</u>					
Chromium, hexavalent	1.31	3.28	1.24	ND(0.6)	

^aThe impinger was contaminated by KMnO₄, according to the Carnot report.

^bTwo impingers were analyzed for mercury--the standard multi-metals train impinger and the potassium permanganate impinger.

Table A-1 (Continued)

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>		
Gas Sample Volume, Nm^3	1.89	1.94	1.95		
Lead	14	19	17	9.2	0.4
<u>PAHs</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>		
Gas Sample Volume, Nm^3	2.89	2.50	1.92		
Naphthalene	22	23	11	20	
Acenaphthylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Acenaphthene	1.2	1.7	0.36	2	
Fluorene	ND(0.025)	0.08	0.068	0.089	
Phenanthrene	0.3	0.073	0.098	0.14	
Anthracene	0.074	0.062	0.049	0.068	
Fluoranthene	0.062	ND(0.025)	0.038	0.035	
Pyrene	0.03	ND(0.025)	0.028	ND(0.025)	
Chrysene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benz(a)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(b+k)fluoranthene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(a)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Indeno(1,2,3-c,d)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Dibenz(a,h)anthracene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Benzo(g,h,i)perylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
<u>Volatile Organics</u>	<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>		
Gas Sample Volume, Nm^3	0.047	0.018	0.019		
Formaldehyde	1.25	0.88	0.87	1.31	0.61
<u>Natural Gas Firing</u>					
<u>Volatile Organics</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm^3	0.096	0.039	0.023		
Formaldehyde	2.75	0.78	0.64	1.31	0.61

Appendix B
Individual Stream Concentrations

This appendix presents the results from the Site 108 sampling event in March 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 108 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented in the Carnot report, which are shown in Appendix A. These concentrations were corrected for the reagent or field blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis and the field blank analysis.

The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration is presented as the detection limit.

Site 108 was sampled for lead by two different methods--Draft EPA Metals Method and CARB Method 12. The results for the CARB Method 12 test are presented as "emitted gas, alternate."

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography (GC)	ppbv	< 1	< 1	< 1	
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3	B< 1.4	B< 1.3	B< 1.3	
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3	1.4	5.6	3.9	
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Emitted gas, alternate <<<<						
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			3.6	13
Benzo(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzene	Gas chromatography (GC)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.04	0.04
Chromium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			2.7	8.2
Chromium, hexavalent	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chrysene	Ion chromatography (IC)	ug/Nm3				
Copper	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Dibenz(a,h)anthracene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	8	19	8	21
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	24	23		
Lead	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	8<		
Manganese	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	8	11	8	20
Naphthalene	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3		20		
Nickel	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3		26		38
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Pyrene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		1490		1850
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		19	23	23
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		270	160	160
>>>> Emitted gas, alternate <<<<						
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			7.2	9.6

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	B<	B<	0.01
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	B<	B<	0.01
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	7.6			
Benzo(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Benzene	Gas chromatography (GC)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	<	0.04		
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	3.3			
Chromium	Atomic absorption spectrophotometry (AAS), flame	ug/Nm3				
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	B			
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	B<	B<	0.01
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	0.01	B<	0.01
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.01	<	0.01
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	B			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	15			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3	34			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	1.2	B<	0.01
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	1600			
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.055	0.01	B<	0.01
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.01	0.01	<	0.015
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	12			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	5.8			
>>>> Emitted gas, alternate <<<<						
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	8.5			

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	0.3	2.2	2.6	
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3	1.4	3.4	1.3	
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Ultimate analysis	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Gross alpha	Not specified	pCi/g				
Gross beta	Not specified	pCi/g				
Hydrogen	Ultimate analysis	wt %				

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			3.6	8.3
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 0.03	< 0.03
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.7	4
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			7.2	4.9
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			8	12
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			8.9	
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 26	< 38
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			30	28
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			9.9	15
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			9.4	11
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			1.9	4.5
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			< 0.04	< 0.04
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			2	4.2
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			12	16
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			2.6	8.1
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			11	13
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			< 0.9	< 0.8
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			1460	1860
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			8.8	7.5
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			260	150
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l			< 1.2	
Beryllium	EPA method 6010	mg/l			< 0.2	
Cadmium	EPA method 6010	mg/l			< 0.2	
Carbon	Ultimate analysis	wt %			84.63	
Chloride	ASTM D808-87	mg/l			130	
Chromium	EPA method 6010	mg/l			0.3	
Chromium, hexavalent	EPA method 6010	mg/l			< 0.2	
Copper	EPA method 6010	mg/l			< 0.7	
Gross alpha	Not specified	pCi/g			0.795	
Gross beta	Not specified	pCi/g				
Hydrogen	Ultimate analysis	wt %			9.5	

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	7.6			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 0.03			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	0.9			
Chromium, hexavalent	Ion chromatography (IC)	ug/nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	3.1			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	4.5			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	5.8			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3	< 34			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	17			
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	3.8			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	5.8			
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	B<			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 0.04			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	2.4			
Chromium, hexavalent	Ion chromatography (IC)	ug/nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	B			
Lead	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	B<			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	9.3			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3	< 1.3			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	1580			
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	8.3			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 0.3			
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l	< 1.21			
Beryllium	EPA method 6010	mg/l	< 0.2			
Cadmium	EPA method 6010	mg/l	< 0.2			
Carbon	Ultimate analysis	wt %	85.02			
Chloride	ASTM D808-87	mg/l	< 50			
Chromium	EPA method 6010	mg/l	0.4			
Chromium, hexavalent	EPA method 6010	mg/l	< 0.2			
Copper	EPA method 6010	mg/l	< 0.6			
Gross alpha	Not specified	pCi/g	0.831			
Gross beta	Not specified	pCi/g	0.067			
Hydrogen	Ultimate analysis	wt %	9.49			

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				
Oxygen	Ultimate analysis	wt %				
Phosphorus	EPA method 6010	mg/kg				
Selenium	EPA method 6010	mg/l				
Sulfur	Ultimate analysis	wt %				
Zinc	EPA method 6010	mg/l				

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Lead	EPA method 6010	mg/l			<	1.2
Manganese	EPA method 6010	mg/l				0.2
Mercury	EPA method 6010	mg/l			<	0.1
Nickel	EPA method 6010	mg/l				28
Oxygen	Ultimate analysis	wt %				1.85
Phosphorus	EPA method 6010	mg/kg				10
Selenium	EPA method 6010	mg/l			<	1.2
Sulfur	Ultimate analysis	wt %				1.49
Zinc	EPA method 6010	mg/l				4.1

Table B-1 Site 108 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run
Lead	EPA method 6010	mg/l	< 1.2			
Manganese	EPA method 6010	mg/l	0.2			
Mercury	EPA method 6010	mg/l	< 0.1			
Nickel	EPA method 6010	mg/l	27			
Oxygen	Ultimate analysis	wt %	0.02			
Phosphorus	EPA method 6010	mg/kg	7.3			
Selenium	EPA method 6010	mg/l	< 1.2			
Sulfur	Ultimate analysis	wt %	1.54			
Zinc	EPA method 6010	mg/l	1			

Table B-2 Site 103 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run
>>>> Emitted gas <<<<						
Benzene	Gas chromatography (GC)	ppbv	1	<	1	1
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	22	B<	B<	19
>>>> Natural gas <<<<						
Benzene	Not specified	vol %	0.028			
Butane	Not specified	vol %	0.026			
Carbon dioxide	Not specified	vol %	0.21			
Ethane	Not specified	vol %	1.12			
Isobutane	Not specified	vol %	0.015			
Isopentane	Not specified	vol %	0.006			
Methane	Not specified	vol %	97.64			
Nitrogen	Not specified	vol %	0.83			
Pentane	Not specified	vol %	0.003			
Propane	Not specified	vol %	0.124			

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Table C-1

Reference Table for Sampling Methods - By Sample Stream

<u>Sampling Stream</u>	<u>Collection Method</u>	<u>Substance Measured</u>
Stack Gas	Draft EPA Metals Method	Metals
	CARB Method 12	Lead
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410A	Benzene
	CARB Method 429	PAH
	CARB Method 430	Formaldehyde
Oil	Grab	Metals

Table C-2

**Summary of Preparation Procedures and Analytical Methods
Used to Measure Inorganic Components Measured in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>FCEM Target Elements by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by GFAAS	
Arsenic	EPA Method 7060
Lead ^a	EPA Method 7421
<u>FCEM Target Elements by Flame Atomic Absorption Spectrophotometry (AAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by Flame AAS	
Chromium	EPA Method 7190
<u>FCEM Target Elements by Cold Vapor Atomic Absorption Spectrophotometry (CVAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by CVAAS	
Mercury	EPA Method 7470
<u>FCEM Target Elements by Inductively Coupled Argon Plasma Emissions Spectrophotometry (ICP-AES)</u>	
Preparation	
Acid Digestion for Filters	EPA Draft Metals Method
Analysis by ICP-AES	EPA Method 6010
Beryllium	
Cadmium	
Copper	
Lead ^b	
Manganese	
Nickel	
Selenium	
<u>FCEM Target Elements by Ion Chromatography (IC)</u>	
Preparation	
Extraction by Aikaline Solution	CARB Method 425
Analysis by IC	
Hexavalent Chromium	

^aImpinger analysis for multi-metals sampling train; total analysis for CARB Method 12 sampling train.

^bFilter analysis for the multi-metals sampling train.

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>Benzene</u>	
Sample Collection	
Tedlar Bags	CARB Method 410A
Analysis by Gas Chromatography/Mass Spectroscopy (GC/PID)	CARB Method 410A
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by High Performance Liquid Chromatography (HPLC)	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>	
Sample Collection	
Modified Method 5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by GC/MS	CARB Method 429
Naphthalene	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Chrysene	
Benz(a)anthracene	
Benzo(b+k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-c,d)pyrene	
Dibenz(a,h)anthracene	
Benzo(g,h,i)perylene	

Table C-4

**Preparation Methods and Chemical Analysis
Methods Applied to Oil for Site 108**

<u>Substance</u>	<u>Method Reference</u>
Arsenic	EPA Method 6010, ICP-AES
Beryllium	EPA Method 6010, ICP-AES
Cadmium	EPA Method 6010, ICP-AES
Chloride	ASTM D808-87
Chromium	EPA Method 6010, ICP-AES
Chromium, hexavalent	EPA Method 6010, ICP-AES
Copper	EPA Method 6010, ICP-AES
Lead	EPA Method 6010, ICP-AES
Manganese	EPA Method 6010, ICP-AES
Mercury	EPA Method 6010, ICP-AES
Nickel	EPA Method 6010, ICP-AES
Selenium	EPA Method 6010, ICP-AES
Sulfur	ASTM D129-64

Table C-5
Sampling Periods for Flue Gas and Oil

<u>Stack Gas</u>	<u>3/14/90</u>	<u>3/15/90</u>	<u>3/16/90</u>	<u>3/17/90</u>	<u>3/18/90</u>	<u>3/19/90</u>
Multi-metals			0809-1046 1255-1519	0840-1119		
Lead			0936-1209 1355-1617	1051-1319		
Chromium	1024-1243 1435-1652 1619-1841					
Semi-VOST				1402-1732	0800-1121 1205-1527	
Benzene	1322-1429					0813-0917 ^a
Formaldehyde		1754-1937				0913-1059 ^a
<u>Oil</u>						
Grab Sample			1200	1200		
<u>Natural Gas</u>						
Grab Sample Analysis						1200

^aNatural gas firing.

Appendix D
Process Stream Information

Table D-1
Natural Gas Analysis - March 19, 1990

Substance	Volume %
CH_4	97.640
C_2H_6	1.120
C_3H_8	0.124
$\text{C}_4\text{H}_{10}\text{-I}$	0.015
$\text{C}_4\text{H}_{10}\text{-N}$	0.026
$\text{C}_5\text{H}_{12}\text{-I}$	0.006
$\text{C}_5\text{H}_{12}\text{-N}$	0.003
C_6H_6	0.028
CO_2	0.210
N_2	0.830

Table D-2

**Process Stream Flow Rates, Stack Gas Characterization Data,
Unit Operating Load, and the Degree of Isokinetic Sampling**

<u>Stream</u>	<u>Units of Measure</u>				<u>Average</u>
Residual Oil Firing					
<u>Oil</u>	lb/hr L/hr				32,800 ^a 15,100 ^a
<u>Stack Gas</u>					
<u>Multi-Metals</u>		<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	144,293 229,000	146,413 232,000	145,422 230,000	145,000 230,000
Unit Load	MW	54	56	53	54
Isokinetic Rate	%	93.57	95.77	92.15	93.8
Moisture	%	7.8	10.0	8.5	8.8
Oxygen	%	3.86	3.75	3.79	3.8
Carbon Dioxide	%	12.64	12.80	12.79	12.7
Stack Temperature	° F	295.5	303.1	301.7	300
<u>Chromium</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	139,307 221,000	140,744 223,000	145,634 231,000	142,000 225,000
Unit Load	MW	54	55	53	54
Isokinetic Rate	%	94.65	97.04	96.52	96.1
Moisture	%	9.5	8.9	9.9	9.4
Oxygen	%	3.47	3.86	3.75	3.7
Carbon Dioxide	%	13.12	12.76	12.60	12.8
Stack Temperature	° F	275.8	305.2	307.3	296
<u>Lead</u>					
		<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	137,265 217,000	143,104 227,000	143,162 227,000	141,000 224,000
Unit Load	MW	54	53	53	53
Isokinetic Rate	%	98.48	96.95	97.71	97.7
Moisture	%	10.2	9.8	10.0	10.0
Oxygen	%	4.76	3.76	3.56	4.0
Carbon Dioxide	%	11.99	12.81	12.96	12.6
Stack Temperature	° F	299.4	302.5	305.2	302
<u>PAHs</u>					
		<u>Run 9</u>	<u>Run 10</u>	<u>Run 11</u>	
Flow Rate	dscfm ^b Nm ³ /hr ^c	146,226 232,000	140,943 223,000	139,556 221,000	142,000 225,000
Unit Load	MW	53.5	53	54	53.5
Isokinetic Rate	%	92.50	98.33	101.62	97.5
Moisture	%	8.3	8.8	9.8	9.0
Oxygen	%	3.79	4.76	4.08	4.2
Carbon Dioxide	%	12.76	11.86	12.57	12.4
Stack Temperature	° F	310.8	304.1	305.6	307

Table D-2 (Continued)

<u>Stream</u>	<u>Units of Measure</u>	<u>Average</u>			
<u>Formaldehyde</u>					
		<u>Run 4</u>	<u>Run 5</u>	<u>Run 6</u>	
Flow Rate	dscfm ^b	145,634	145,634	145,634	146,000
	Nm ³ /hr ^c	231,000	231,000	231,000	231,000
Unit Load	MW	53	53	53	53
O ₂	%	3.75	3.75	3.75	3.75
<u>Benzene</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Flow Rate	dscfm ^b				139,307 ^d
	Nm ³ /hr ^c				221,000
Unit Load	MW				53 ^d
O ₂	%				3.47 ^d
<u>Natural Gas Firing</u>					
<u>Natural Gas</u>					
		<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	
Heat Input	10 ⁶ Btu/hr				740 ^{d,e}
Flow Rate	scf/hr				728,000 ^f
<u>Formaldehyde</u>					
Flow Rate	dscfm ^b	131,696	131,696	131,696	132,000
	Nm ³ /hr ^c	209,000	209,000	209,000	209,000
Unit Load	MW				53 ^d
O ₂	%	3.76	3.76	3.76	3.76
<u>Benzene</u>					
Flow Rate	dscfm ^b				131,696 ^d
	Nm ³ /hr ^c				209,000
Unit Load	MW				53 ^d
O ₂	%				4.08 ^d

^aAverage of 16 measurements.

^bStandard conditions: 1 atm, 68° F.

^cNormal conditions: 1 atm, 32° F.

^dOne value was presented in the Carnot report for all runs.

^eEstimated by Carnot in their report.

^fCalculated from the heat input to the boiler and the natural gas HHV (10¹⁶ Btu/scf).

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 108 are included here.

Emission Factor Results

Oil Firing

Elements

Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	6.836473	3.18E-01	9.86E+00	9.9E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Arsenic conc	uo/Nm3	8.100001	PREC	9.71E+01	8.44E-01	2.02E+01	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	1.01E-01	-1.99E-04	1.60E+03	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	1.23E-02	2.97E-05	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	4.11E-03	-1.99E-04	1.29E+03	14

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Beryllium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	3.376036E-02	1.70E-02	4.08E-04	1.7E-02	2.78E+00	3.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Beryllium conc	uo/Nm3	.04	BIAS	2.85E-04	8.44E-01	2.00E-02	-
2) oil	Oil flow rate	lb/hr	32800	BIAS	2.47E-06	-9.81E-07	1.60E+03	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	1.25E-07	1.47E-07	4.16E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	4.18E-08	-9.81E-07	8.33E+02	14

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	3.966842	1.85E-01	6.29E+00	6.3E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Cadmium conc	uo/Nm3	4.7	PREC	3.96E+01	8.44E-01	1.29E+01	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	3.40E-02	-1.15E-04	1.60E+03	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	4.13E-03	1.72E-05	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	1.38E-03	-1.15E-04	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	1.155925	5.80E-01	6.85E-02	5.8E-01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Chromium conc	uo/Nm3	1.4	BIAS	3.34E-01	8.26E-01	7.00E-01	-
2) gas	Stack gas flow rate	Nm3/hr	225000	PREC	4.58E-03	5.14E-06	2.28E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	2.89E-03	-3.36E-05	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	1.18E-04	-3.36E-05	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Chromium, hexavalent

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	2.972379	1.38E-01	4.11E+00	4.1E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Hex. chromium conc	uo/Nm3	3.6	PREC	1.68E+01	8.26E-01	8.61E+00	3
2) gas	Stack gas flow rate	Nm3/hr	225000	PREC	3.03E-02	1.32E-05	2.28E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	1.91E-02	-8.64E-05	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	7.78E-04	-8.64E-05	1.29E+03	16

* PRECISION COMPONENT = $t \cdot \bar{S}_r$

** $(B_0 \cdot \text{SIGMA}_p)^2$ FOR BIAS ERRORS; $(t \cdot \bar{S}_p \cdot \text{SIGMA}_p)^2$ FOR PRECISION ERRORS
 -WHERE $\bar{S}_p$ = PRECISION INDEX OF THE MEAN, $\bar{S}_p / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $\bar{S}_p \cdot t$ FOR PRECISION ERRORS

Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	15.19216	7.07E-01	8.81E+00	8.8E+00	4.30E+00	2.0E+00

INPUT - VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Copper conc	uo/Nm3	18	PREC	7.76E+01	8.44E-01	1.81E+01	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	4.99E-01	-4.42E-04	1.60E+03	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	6.06E-02	6.61E-05	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	2.03E-02	-4.42E-04	1.29E+03	16

* PRECISION COMPONENT = $t \cdot \bar{S}_r$

** $(B_0 \cdot \text{SIGMA}_p)^2$ FOR BIAS ERRORS; $(t \cdot \bar{S}_p \cdot \text{SIGMA}_p)^2$ FOR PRECISION ERRORS
 -WHERE $\bar{S}_p$ = PRECISION INDEX OF THE MEAN, $\bar{S}_p / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $\bar{S}_p \cdot t$ FOR PRECISION ERRORS

Appendix E

Lead

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	10.12811	4.71E-01	1.64E+01	1.6E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Lead conc	uo/Na3	12	PREC	2.67E+02	8.44E-01	3.36E+01	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	2.22E-01	-2.94E-04	1.60E+03	-
3) gas	Stack gas flow rate	Na3/hr	230000	PREC	2.69E-02	4.40E-05	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	9.03E-03	-2.94E-04	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_p \cdot SIGMA_p)^2$ FOR BIAS ERRORS; $(t \cdot S_{pbar} \cdot SIGMA_p)^2$ FOR PRECISION ERRORS

-WHERE S_{pbar} = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	15.19216	7.07E-01	3.03E+01	3.0E+01	1.27E+01	1.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Manganese conc	uo/Na3	18	PREC	9.20E+02	8.44E-01	5.08E+01	2
2) gas	Stack gas flow rate	Na3/hr	230000	PREC	5.28E-01	6.61E-05	1.91E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	4.99E-01	-4.42E-04	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	1.77E-01	-4.42E-04	3.81E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_p \cdot SIGMA_p)^2$ FOR BIAS ERRORS; $(t \cdot S_{pbar} \cdot SIGMA_p)^2$ FOR PRECISION ERRORS

-WHERE S_{pbar} = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Mercury

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	32.07234	1.61E+01	3.87E-01	1.6E+01	2.78E+00	3.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Mercury conc	uo/Nm3	38	BIAS	2.57E+02	8.44E-01	1.90E+01	-
2) oil	Oil flow rate	lb/hr	32800	BIAS	2.23E+00	-9.32E-04	1.60E+03	-
3) oas	Stack gas flow rate	Nm3/hr	230000	PREC	1.12E-01	1.39E-04	4.16E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	3.77E-02	-9.32E-04	8.33E+02	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ = PRECISION INDEX OF THE MEAN. $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $Sp \cdot t$ FOR PRECISION ERRORS

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	1401.055	6.52E+01	4.41E+02	4.5E+02	4.30E+00	2.0E+00

INPUT - VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Nickel conc	uo/N3	1660	PREC	1.94E+05	8.44E-01	9.04E+02	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	4.25E+03	-4.07E-02	1.60E+03	-
3) oas	Stack gas flow rate	Nm3/hr	230000	PREC	5.15E+02	6.09E-03	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	1.73E+02	-4.07E-02	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ = PRECISION INDEX OF THE MEAN. $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $Sp \cdot t$ FOR PRECISION ERRORS

Appendix E

Selenium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	15.19216	7.07E-01	1.26E+01	1.3E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Selenium conc	ug/Nm3	18	PREC	1.58E+02	8.44E-01	2.58E+01	3
2) oil	Oil flow rate	lb/hr	32800	BIAS	4.99E-01	-4.42E-04	1.60E+03	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	6.06E-02	6.61E-05	6.45E+03	3
4) oil	Oil flow rate	lb/hr	32800	PREC	2.03E-02	-4.42E-04	1.29E+03	16

* PRECISION COMPONENT = $t \cdot s_{\bar{r}}$

** $(B_p \cdot \text{SIGMA}_p)^2$ FOR BIAS ERRORS; $(t \cdot s_{\bar{r}} \cdot \text{SIGMA}_p)^2$ FOR PRECISION ERRORS

-WHERE $s_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $s_{\bar{r}} = (s^2 / \text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_p FOR BIAS ERRORS; $s_{\bar{r}}$ FOR PRECISION ERRORS

Organic Compounds

Acenaphthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	8.25661E-03	4.15E-03	5.43E-04	4.2E-03	4.30E+00	2.1E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Acenaphthene conc	uo/Nm3	.01	BIAS	1.70E-05	8.26E-01	5.00E-03	-
2) gas	Stack gas flow rate	Nm3/hr	225000	PREC	2.89E-07	3.67E-08	2.54E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	1.47E-07	-2.40E-07	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	6.00E-09	-2.40E-07	1.29E+03	16
=====								
* PRECISION COMPONENT = t*Srbar								
** (Bp*SIGMAp)^2 FOR BIAS ERRORS; (t*Spbar*SIGMAp)^2 FOR PRECISION ERRORS								
-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** Bp FOR BIAS ERRORS; Sp*t FOR PRECISION ERRORS								

Anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	8.25661E-03	4.15E-03	5.43E-04	4.2E-03	4.30E+00	2.1E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Anthracene conc	uo/Nm3	.01	BIAS	1.70E-05	8.26E-01	5.00E-03	-
2) gas	Stack gas flow rate	Nm3/hr	225000	PREC	2.89E-07	3.67E-08	2.54E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	1.47E-07	-2.40E-07	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	6.00E-09	-2.40E-07	1.29E+03	16
=====								
* PRECISION COMPONENT = t*Srbar								
** (Bp*SIGMAp)^2 FOR BIAS ERRORS; (t*Spbar*SIGMAp)^2 FOR PRECISION ERRORS								
-WHERE Spbar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** Bp FOR BIAS ERRORS; Sp*t FOR PRECISION ERRORS								

Appendix E

Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	8.25661E-03	4.15E-03	5.43E-04	4.2E-03	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Fluoranthene conc	ug/Mu3	.01	BIAS	1.70E-05	8.26E-01	5.00E-03	-
2) gas	Stack gas	Mu3/hr	225000	PREC	2.89E-07	3.67E-08	2.54E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	1.47E-07	-2.40E-07	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	6.00E-09	-2.40E-07	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	8.25661E-03	4.15E-03	5.43E-04	4.2E-03	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Fluorene conc	ug/Mu3	.01	BIAS	1.70E-05	8.26E-01	5.00E-03	-
2) gas	Stack gas flow rate	Mu3/hr	225000	PREC	2.89E-07	3.67E-08	2.54E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	1.47E-07	-2.40E-07	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	6.00E-09	-2.40E-07	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE Spbar=PRECISION INDEX OF THE MEAN, $Sp/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	.5201664	2.43E-02	3.08E+00	3.1E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Naphthalene conc	ug/Nm3	.63	PREC	9.47E+00	8.26E-01	6.45E+00	3
2) gas	Stack gas flow rate	Nm3/hr	225000	PREC	1.15E-03	2.31E-06	2.54E+04	3
3) oil	Oil flow rate	lb/hr	32800	BIAS	5.85E-04	-1.51E-05	1.60E+03	-
4) oil	Oil flow rate	lb/hr	32800	PREC	2.38E-05	-1.51E-05	1.29E+03	16
5) conc	Naphthalene conc	ug/Nm3	.63	BIAS	2.73E-06	8.26E-01	2.00E-03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} \cdot SIGMAp)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} =PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	1.651322E-02	1.82E-03	1.44E-01	1.4E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Phenanthrene conc	ug/Nm3	.02	PREC	2.06E-02	8.26E-01	3.01E-01	3
2) conc	Phenanthrene conc	ug/Nm3	.02	BIAS	2.73E-06	8.26E-01	2.00E-03	-
3) gas	Stack gas flow rate	Nm3/hr	225000	PREC	1.16E-06	7.34E-08	2.54E+04	3
4) oil	Oil flow rate	lb/hr	32800	BIAS	5.90E-07	-4.80E-07	1.60E+03	-
5) oil	Oil flow rate	lb/hr	32800	PREC	2.40E-08	-4.80E-07	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} \cdot SIGMAp)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} =PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Appendix E

Pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/1E12 B	8.25661E-03	1.70E-03	1.03E-02	1.0E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) conc	Pyrene conc	ug/M ³	.01	PREC	1.05E-04	8.26E-01	2.15E-02	3
2) conc	Pyrene conc	ug/M ³	.01	BIAS	2.73E-06	8.26E-01	2.00E-03	-
3) gas	Stack gas flow rate	M ³ /hr	225000	PREC	2.89E-07	3.67E-08	2.54E+04	3
4) oil	Oil flow rate	lb/hr	32800	BIAS	1.47E-07	-2.40E-07	1.60E+03	-
5) oil	Oil flow rate	lb/hr	32800	PREC	6.00E-09	-2.40E-07	1.29E+03	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_p \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{pbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{pbar} = PRECISION INDEX OF THE MEAN. $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Material Balance Closure Results

Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	137.0861	6.57E+00	2.74E+02	2.7E+02	1.27E+01	1.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) mboc	Manganese gas conc	ug/Nm3	18	PREC	7.49E+04	7.62E+00	5.08E+01	2
2) oilvol	Oil flow rate	L/hr	15100	BIAS	4.32E+01	-8.64E-03	7.60E+02	-
3) gas	Stack gas flow rate	Nm3/hr	230000	PREC	4.30E+01	5.96E-04	1.91E+04	3
4) oilvol	Oil flow rate	L/hr	15100	PREC	3.69E+00	-8.64E-03	8.89E+02	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ = PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $Sp \cdot t$ FOR PRECISION ERRORS

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
closure	Total closure	%	90.30274	4.33E+00	3.00E+01	3.0E+01	4.30E+00	2.4E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMAp)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) mbgc	Nickel gas conc	ug/Nm3	1660	PREC	8.05E+02	5.44E-02	9.04E+02	3
2) mboc	Nickel oil conc	mg/L	28	PREC	9.16E+01	-3.15E+00	4.30E+00	2
3) oilvol	Oil flow rate	L/hr	15100	BIAS	1.87E+01	-5.69E-03	7.60E+02	-
4) gas	Stack gas flow rate	Nm3/hr	230000	PREC	2.14E+00	3.93E-04	6.45E+03	3
5) oilvol	Oil flow rate	L/hr	15100	PREC	1.84E-01	-5.69E-03	3.01E+02	16

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMAp)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMAp)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ = PRECISION INDEX OF THE MEAN, $Sp / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bp FOR BIAS ERRORS; $Sp \cdot t$ FOR PRECISION ERRORS

Appendix F
Quality Assurance/Quality Control Data

This section presents QA/QC results for the stack gas and fuel samples. The blank and duplicate analyses are presented, as well as the sample spike results and detection limits.

Table F-1 presents the results of the blank analyses for the stack gas samples. Reagent blank and field blank analyses were performed for the metals (solid phase and vapor phase). A field blank consisting of a complete semi-VOST sampling train was analyzed for PAHs. A trip blank, field blank, and method blank were analyzed for formaldehyde.

Table F-2 presents matrix spike recovery data performed for one of the multi-metals stack gas samples. A duplicate analysis was run on one of the flue gas samples for metals. Table F-2 presents the relative percent difference (RPD) between the duplicate analyses for this sample.

Table F-3 presents the matrix spike recovery results for the oil samples. The relative percent difference between the matrix spike and the matrix spike duplicate is also presented. Table F-4 presents the results for the lab spike recoveries for the PAH analyses.

Table F-1
Summary of Blank Sample Results

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected (μg)</u>	<u>Detection Limit (μg)</u>
PAHs				
<u>Field Blank</u>				
Naphthalene	1	1	20	0.025
Acenaphthylene	1	0		0.025
Acenaphthene	1	1	2	0.025
Fluorene	1	1	0.089	0.025
Phenanthrene	1	1	0.14	0.025
Anthracene	1	1	0.068	0.025
Fluoranthene	1	1	0.035	0.025
Pyrene	1	0		0.025
Chrysene	1	0		0.025
Benz(a)anthracene	1	0		0.025
Benzo(b+k)fluoranthene	1	0		0.025
Benzo(a)pyrene	1	0		0.025
Indeno(1,2,3-c,d)pyrene	1	0		0.025
Dibenz(a,h)anthracene	1	0		0.025
Benzo(g,h,i)perylene	1	0		0.025
Volatile Organics				
<u>Method Blank</u>				
Formaldehyde	1	1	0.61	0.44
Benzene	0	0		
<u>Field Blank</u>				
Formaldehyde	1	1	1.31	0.44
Benzene	0	0		
Metals - Solid Phase *				
<u>Field Blank</u>				
Arsenic	1	1	3.0	1.9 $\mu\text{g}/\text{Nm}^3$
Beryllium	1	1	0.22	0.07
Cadmium	1	0		0.3
Copper	1	1	40	0.7
Lead	1	1	66	3.0
Manganese	1	1	8.0	0.6
Mercury	1	0		1.5
Nickel	1	1	23	0.6
Selenium	1	1	5.4	3.0
<u>Reagent Blank</u>				
Arsenic	1	1	20	1.9 $\mu\text{g}/\text{Nm}^3$
Beryllium	1	1	0.22	0.07
Cadmium	1	0		0.3
Copper	1	1	33	0.7
Lead	1	1	41	3.0

Table F-1 (Continued)

<u>Sample</u>	<u>Number of Blank Samples Analyzed</u>	<u>Number of Detects</u>	<u>Mass Detected (μg)</u>	<u>Detection Limit (μg)</u>
Manganese	1	1	7.3	0.6
Mercury	1	0		2.0
Nickel	1	1	4.8	0.6
Selenium	1	1	4.2	3.0
Metals - Vapor Phase ^a				
<u>Field Blank</u>				
Arsenic	1	1	0.4	--
Beryllium	1	0		0.07
Cadmium	1	0		0.3
Copper	1	1	3.7	0.6
Lead	1	1	0.9	--
Manganese	1	0		0.6
Mercury ^b	1	0		2.3, 19
Nickel	1	1	6.8	0.6
Selenium	1	0		3.0
<u>Reagent Blank</u>				
Arsenic	1	1	0.5	--
Beryllium	1	0		0.07
Cadmium	1	0		0.3
Copper	1	1	1.3	0.6
Lead	1	1	0.7	--
Manganese	1	0		0.6
Mercury ^b	1	0		1.0, 20
Nickel	1	1	1.6	0.6
Selenium	1	0		3.0
Chromium ^c				
<u>Field Blank</u>				
Chromium	1	1	59.0	1.25
Chromium, hexavalent	1	0		0.3
Lead ^c				
<u>Field Blank</u>				
Lead	1	1	9.2	1.5
<u>Reagent Blank</u>				
Lead	1	1	0.40	0.15

^aMulti-metals sampling train.^bTwo impinger analyses, including a potassium permanganate impinger.^cIndividual metal sampling trains.

Table F-2
Summary of Quality Control Results for Stack Gas

<u>Substance</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
<u>Stack Gas - Solid Phase</u>		
Beryllium	56	<1
Cadmium	83	2
Copper	96	<1
Lead	88	2
Manganese	88	<1
Mercury	90	<1
Nickel	99	<1
Selenium	84	<1
<u>Stack Gas - Vapor Phase</u>		
Beryllium	90	<1
Cadmium	74	<1
Copper	82	1
Manganese	79	4
Mercury ^b	89, 86	3 ^c , <1
Nickel	84	3
Selenium	128	<1
<u>Stack Gas - Total</u>		
Chromium	116	9
Chromium, hexavalent	102	—
Lead	86	8
Formaldehyde	116,93	22 ^c

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

^bResults from both impingers.

^cMatrix spike duplicate RPD.

Table F-3

Summary of Quality Control Results for Fuel Oil

<u>Substance</u>	<u>Detection Limit (mg/L)</u>	<u>Matrix Spike Recovery %</u>	<u>Duplicate Analysis RPD ^a</u>
Arsenic	1.2	105	<1
Beryllium	0.2	98	<1
Cadmium	0.2	86	5
Chromium	0.2	114	5
Copper	--	118	11
Lead	1.2	111	5
Manganese	--	104	4
Mercury	0.1	95	3
Nickel	--	80	<1
Phosphorus	2.5 mg/kg	98	4
Selenium	1.2	97	14

^a

$$RPD = \left[\frac{A-B}{\left[\frac{A+B}{2} \right]} \right] * 100$$

where A, B are individual values and RPD is the relative percent difference between the values.

Table F-4

Summary of Surrogate Recoveries for Semivolatile Organic Analysis

<u>Substance</u>	<u>Number of Analyses</u>	<u>Mean Spike Recovery (%)</u>	<u>Std. Dev. (% Rec.)</u>	<u>No. Below Limits ^a</u>	<u>No. Above Limits ^b</u>
d10 Acenaphthene	4	96	14	0	0
d10 Anthracene	3	57	13	3	0
d12 Chrysene	3	130	17	0	1
d12 Benzo(a)pyrene	3	58	24	2	0

^aLower limit is 75 percent.

^bUpper limit is 125 percent.

Appendix A
Analytical Data from the Carnot Report

Table A-1 presents the test results for each run, as well as the results of the blank analyses. Blanks were analyzed for metals in both the solid phase and vapor phase fractions. A field blank analysis was performed for PAHs.

Table A-1

**Results of the Sample, Field Blank, and
Reagent Blank Analyses for FCEM Site 107**

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>		
Oil Firing					
Elements					
<u>Multi-Metal Sampling Train</u>					
Gas Sample Volume, Nm^3	1.43	1.40	1.49		
<u>Vapor Phase</u>					
Arsenic	4.1	2.5	4.5	0.65	0.36
Beryllium	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)	ND(0.06)
Cadmium	0.31	1.1	0.54	1.2	0.02
Copper	5.0	6.2	6.7	14	1.6
Lead	1.9	13	3.2	7.3	14
Manganese	5.3	0.7	1.1	1.6	1.2
Mercury ^a	ND(46)	ND(45)	ND(38)	ND(41)	ND(20)
	ND(1.6)	ND(2.8)	ND(2.7)	ND(1.0)	ND(2.0)
Nickel	21	2.4	2.3	2.9	ND(0.63)
Selenium	ND(2.8)	2.9	ND(2.8)	ND(2.8)	ND(3.1)
<u>Solid Phase</u>					
Arsenic	16	11	14	2.9	1.4
Beryllium	0.22	0.27	0.10	0.15	0.28
Cadmium	0.81	0.88	1.7	ND(0.36)	ND(0.32)
Copper	19	23	40	120	7.6
Lead	43	41	46	47	46
Manganese	16	20	15	6.6	6.7
Mercury	ND(2.1)	ND(2.7)	ND(3.2)	ND(1.7)	ND(2.2)
Nickel	430	470	590	6.9	4.8
Selenium	8.5	5.7	5.0	15	7.9
	<u>Run 1</u>	<u>Run 2</u>	<u>Run 5</u>		
<u>Individual Metal Sampling Train</u>					
Gas Sample Volume, Nm^3	2.24	2.14	2.15		
Chromium	26.68	16.88	12.44	--	3.06
Chromium, hexavalent	3.79	3.98	1.76	--	ND(0.28)
	<u>Run 3</u>	<u>Run 4</u>	<u>Run 5</u>		
Gas Sample Volume, Nm^3	1.41	1.37	1.42		
Arsenic	1.3	3.1	4.9	0.42	0.43

^aTwo impingers were analyzed for mercury--the standard multi-metals train impinger and the potassium permanganate impinger.

Table A-1 (Continued)

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
<u>PAHs</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 5</u>		
Gas Sample Volume, Nm^3	3.30	3.34	3.08		
Naphthalene	11	0.26	72	29	
Acenaphthylene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Acenaphthene	0.19	ND(0.025)	ND(0.025)	0.48	
Fluorene	0.075	ND(0.025)	ND(0.025)	0.07	
Phenanthrene	0.84	ND(0.025)	0.32	0.11	
Anthracene	0.11	ND(0.025)	ND(0.025)	0.058	
Fluoranthene	0.73	ND(0.025)	0.12	0.057	
Pyrene	0.66	ND(0.025)	0.11	0.055	
Chrysene	0.44	ND(0.025)	0.051	ND(0.025)	
Benz(a)anthracene	0.97	ND(0.025)	0.15	ND(0.025)	
Benzo(b+k)fluoranthene	ND(0.025)	ND(0.025)	0.31	ND(0.025)	
Benzo(a)pyrene	ND(0.025)	ND(0.025)	ND(0.025)	ND(0.025)	
Indeno(1,2,3-c,d)pyrene	0.53	ND(0.025)	0.14	0.31	
Dibenz(a,h)anthracene	0.21	ND(0.025)	0.042	0.15	
Benzo(g,h,i)perylene	0.61	ND(0.025)	0.14	0.36	
<u>Volatile Organics</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
Gas Sample Volume, Nm^3	0.038	0.019	0.038		
Formaldehyde	15.7	16.2	15.0	16.3	ND(0.89)
<u>Natural Gas Firing</u>					
<u>Volatile Organics</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm^3	0.038	0.028	0.038		
Formaldehyde	30.2	23.7	23.6	16.3	ND(0.89)

Appendix B
Individual Stream Concentrations

This appendix presents the results from the Site 107 sampling event in February 1990. Tables B-1 and B-2 present the concentrations of the substances measured at Site 107 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented in the Carnot report, which are shown in Appendix A. These concentrations were corrected for the reagent or field blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis and the field blank analysis.

The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection limit. In this case, the concentration is presented as the detection limit.

Site 107 was sampled for arsenic by two different methods--Draft EPA Metals Method and CARB Method 423. The results for the CARB Method 423 test are presented as "emitted gas, alternate."

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.008	B<	0.007
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.008	<	0.007
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.016	B<	0.007
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			13.5	8.8
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.29	0.007	B<	0.007
Benzene	Gas chromatography (GC)	ppbv				
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.008	<	0.007
Benzo(b,k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	<	0.008	<	0.007
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.076	B<	0.007
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			B<	0.09
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			1.02	1.5
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3	10.5	6.46		
Chromium, hexavalent	Ion chromatography (IC)	ug/Nm3	1.69	1.86		
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.13	<	0.007	15.1
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			10.9	
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.018	B<	0.007
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.2	B<	0.007	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.0015	B<	0.007
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B	0.067	B<	0.007
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			B<	2.3
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			9.8	10
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3			<	32
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	B<	0.008	B<	0.007
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			328	352
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.22	<	0.007	
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.18	B<	0.007	
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			B	0.44
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			26.4	36.5
>>>> Emitted gas, alternate <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			0.58	1.9

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	<			
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/m ³	11.8			
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	0.049			
Benzene	Gas chromatography (GC)	ppbv	<	1	<	1
Benzo(a)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	<			
Benzo(b+k)fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	0.1			
Benzo(g,h,i)perylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	B<			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	1.57			
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/m ³	4.36			
Chromium, hexavalent	Ion chromatography (IC)	ug/m ³	0.81			
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	0.017			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	26.4			
Dibenz(a,h)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	0.02			
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Formaldehyde	High performance liquid chromatography (HPLC)	ug/m ³	413			
Indeno(1,2,3-c,d)pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B<			
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	B<	853		395
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	B<			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/m ³	5.85			
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	26			
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	14			
Phenanthrene	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	414			
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	0.068			
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/m ³	B			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	0.018			
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	B<			
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/m ³	2.2			
>>>> Emitted gas, alternate <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/m ³	3.1			

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			2.8	1.6
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		<	0.04	<
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.21	0.81
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			2.5	3.5
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.44	0.5
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			3	0.4
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3		<	32	32
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			15	1.8
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		<	2.1	2.2
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			4.26	4.89
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			10.7	7.22
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		B<	0.09	B<
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			0.81	0.66
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			8.38	11.6
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		B<	2.3	B<
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			6.84	10
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3		<	1.5	<
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			313	350
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3		B	0.44	B<
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3			22.1	31.6
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l				
Beryllium	EPA method 6010	mg/l				
Cadmium	EPA method 6010	mg/l				
Carbon	Ultimate analysis	wt %				
Chloride	ASTM D808-87	mg/l				
Chromium	EPA method 6010	mg/l				
Chromium, hexavalent	EPA method 6010	mg/l				
Copper	EPA method 6010	mg/l				
Hydrogen	Ultimate analysis	wt %				
Lead	EPA method 6010	mg/l				
Manganese	EPA method 6010	mg/l				
Mercury	EPA method 6010	mg/l				
Nickel	EPA method 6010	mg/l				

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run
>>>> Emitted gas, gas phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	2.9			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	<			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	<			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	3.6			
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	0.4			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	8<			
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	8<			
Nickel	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3	<			
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	1.6			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	2			
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	4.36			
>>>> Emitted gas, solid phase <<<<						
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	8.87			
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	8<			
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	1.2			
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	22.8			
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	2.3			
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	5.85			
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3	<			
Nickel	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	412			
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	2.2			
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/l	<	1.1	<	1.1
Beryllium	EPA method 6010	mg/l	<	0.22	<	0.22
Cadmium	EPA method 6010	mg/l	<	0.22	<	0.22
Carbon	Ultimate analysis	wt %	84.53	86.38		
Chloride	ASTM D808-87	mg/l	107	156		
Chromium	EPA method 6010	mg/l	0.22	0.21		
Chromium, hexavalent	EPA method 6010	mg/l	<	0.5	<	0.5
Copper	EPA method 6010	mg/l	0.47	0.41		
Hydrogen	Ultimate analysis	wt %	12.4	12.75		
Lead	EPA method 6010	mg/l	<	1.1	<	1.1
Manganese	EPA method 6010	mg/l	<	0.43	<	0.43
Mercury	EPA method 6010	mg/l	<	0.1	<	0.1
Nickel	EPA method 6010	mg/l	10	10		

Table B-1 Site 107 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Nitrogen	Ultimate analysis	wt %				
Oxygen	Ultimate analysis	wt %				
Selenium	EPA method 6010	mg/l				
Sulfur	Ultimate analysis	wt %				
Zinc	EPA method 6010	mg/l				

PART VII: SITE 109 EMISSIONS REPORT

PRELIMINARY DRAFT REPORT

Test Contractor:

**KVB - Analect
(formerly R-C Environmental)
9342 Geronimo
Irvine, California 92718**

3 March 1993

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Section 1

INTRODUCTION

This part of the document summarizes data gathered by KVB - Analect (formerly R-C Environmental) at a California power plant, designated Site 109, during a sampling program sponsored by the electric utility. The power plant was tested during both residual fuel oil and natural gas-firing. The opposed-burner boiler was sampled in late 1990 and early 1991.

The test matrix shown in Table 1-1 lists the substances of interest at this site. Samples were collected during three load conditions: 100%, 75%, and 50% of full load. Benzene, formaldehyde and PAHs were the only substances measured in the stack gas during the reduced load, oil-fired tests. Formaldehyde was the only substance measured in the stack gas during the natural gas-fired tests. The primary emphasis of the sampling effort was collecting valid stack emissions data; less emphasis was placed on collecting oil and natural gas samples.

Section 2 of this report briefly describes the power plant and sampling locations. Section 3 discusses the analytical results for the fuel oil, natural gas, and flue gas streams sampled at the plant. Section 4 contains an evaluation of the sampling and analytical data according to traditional QA/QC techniques and engineering calculations. Section 5 contains example calculations. The appendices contain raw data, stream concentrations, information on sampling and analytical methods, measured and calculated stream flow rates, error propagation equations and examples, and quality assurance/quality control (QA/QC) results.

Table 1-1
Summary of Test Matrix for Site 109^a

<u>Substance</u>	<u>Process Streams Sampled^b</u>		
	<u>Oil</u>	<u>Natural Gas</u>	<u>Stack Gas</u>
<u>Inorganic</u>			
Arsenic	X		X
Beryllium	X		X
Cadmium	X		X
Chlorine	X		
Chromium	X		X
Chromium, hexavalent	X		X
Copper	X		X
Lead	X		X
Manganese	X		X
Mercury	X		X
Nickel	X		X
Selenium	X		X
<u>Organic</u>			
Benzene			X
Formaldehyde			X ^c
Polynuclear Aromatic Hydrocarbons (15)			X
<u>Additional</u>			
Heating Value	X	X	
Ultimate/Proximate	X		
Sulfur Content	X		

^aTesting conducted at 100%, 75% and 50% load conditions.

^bOnly organic compounds were measured during 75% and 50% load tests.

^cOnly formaldehyde was measured during natural gas tests.

Section 2

SITE DESCRIPTION

This section provides a description of the test site, Site 109, and gives the locations of the sampling points.

Facility Information

At Site 109, a steam electric generating unit with a capacity of approximately 230 megawatts (MW) was tested. Testing for PAHs, benzene, and formaldehyde was conducted under three load conditions (100%, 75%, and 50% of full load) during both 100% residual oil firing and 100% natural gas firing. Metals were sampled only during 100% residual oil firing with a load condition of 100 percent.

Figure 2-1 is a process flow diagram of the unit at Site 109. Steam is generated in an opposed-fired, high-pressure boiler designed to burn either natural gas or low-sulfur residual fuel oil. Nitrogen oxide emissions are controlled by flue gas recirculation and off-stoichiometric firing. This unit has two stacks. During oil firing, an additive is injected into the boiler to reduce acid fallout. No analyses are available for this additive.

The residual fuel oil at this site has a sulfur content of 0.2%, a higher heating value (HHV) of approximately 18,900 Btu/lb, and an ash content of 0.04 percent. The natural gas fired at Site 109 has an HHV of approximately 21,900 Btu/lb (1,000 Btu/scf).

Sampling Locations

The fuel to the boiler and the flue gas emitted through the stack were the two streams sampled in this study. Figure 2-1 shows the locations of the sampling points. Brief descriptions of the sampling locations are given below.

- The oil grab samples were collected from a fuel storage tank.
- The natural gas was not analyzed during the test period.
- Stack gas samples were collected from ports installed in both exhaust stacks at 138 feet.

Except for chromium, two tests were conducted in the east stack, and one test was conducted in the west stack. For chromium, two samples were collected from the west stack, and one sample was collected from the east stack.

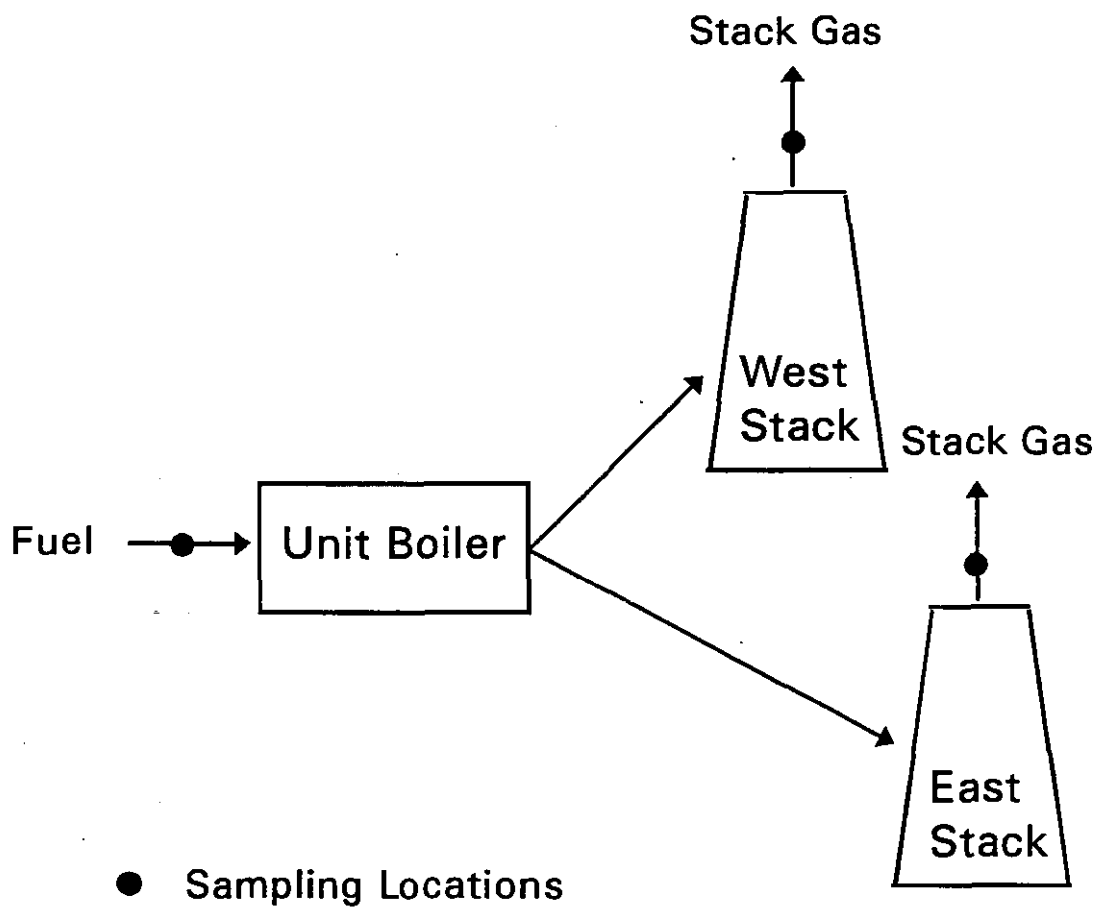


Figure 2-1. Process Flow Diagram for Site 109

Section 3

RESULTS

This section summarizes the fuel and emitted gas stream data collected at Site 109 during oil firing. These results were calculated from laboratory and field data reported by KVB - Analect. Only formaldehyde emissions were measured during the firing of natural gas; metals, PAHs, benzene and formaldehyde emissions were measured during fuel oil-firing.

Appendix A contains the raw analytical data generated by KVB - Analect and their contracting laboratories during the project. Data processed by Radian Corporation for this report can be found in Appendix B.

Sampling Schedule

Site 109 was sampled in late 1990 and early 1991. Figure 3-1 shows the sequence of tests performed at this site. The sample runs are numbered in chronological order. Each fuel type has its own unique set of run numbers, which are shown in Figure 3-1 and the summary tables.

Four collection trains were used to sample the stack gas during oil firing. These trains include an EPA Modified Method 5 train for multi-metals, a CARB Method 433 train for nickel, a CARB Method 425 train for total and hexavalent chromium, and a semi-VOST (Modified Method 5) train for polynuclear aromatic hydrocarbons (PAHs). Benzene was collected by CARB Method 410A, and formaldehyde was sampled using CARB Method 430 for the comparison of emissions produced during natural gas firing and oil firing. Two grab samples of the fuel oil were collected twelve days after the stack gas sampling was completed.

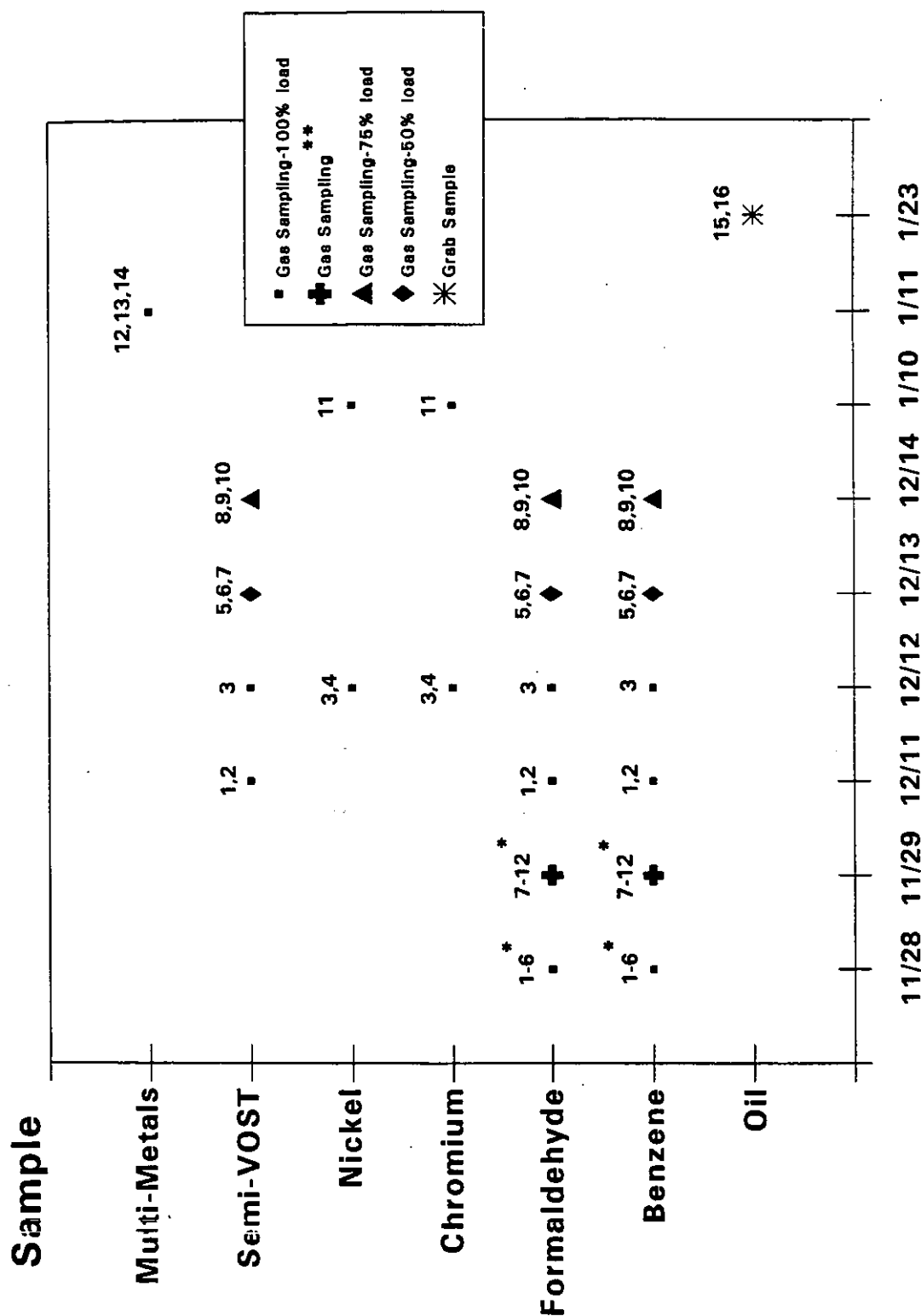
Appendix C presents details of the analytical and sampling methods used at this site.

Data Treatment

Several conventions were developed for treating the test data and developing average concentrations of substances in the oil and stack gas streams.

Blank Corrections

The convention for using blanks to correct the data in this group of reports was to use the reagent blank analytical results when they were available. If a reagent blank analysis



*Natural gas firing.

**Runs 7-9 pertain to 75% load operating conditions; Runs 10-12 pertain to 50% load conditions.

Figure 3-1. Summary of the Stack Gas Stream and Fuel Sampling Schedule for Site 109, Including Run Numbers. (This site was sampled in late 1990 and early 1991.)

was not performed, the field blank results were used to correct the sample results. If neither a reagent nor field blank was analyzed, no corrections were made. At Site 109, the individual run measurements for PAHs, benzene, and formaldehyde were corrected for the reagent blank measurements. No blanks were analyzed for any metals. When the blank concentration was equal to or greater than 50% of the uncorrected measurement, the corrected concentration was flagged with a "B." When the blank correction resulted in a value less than the detection limit, the corrected concentration is presented as ND(DL), which means that the concentration is below the detection limit (DL), which is given in parentheses. Similarly, NR(RL) means that the concentration is below the reporting limit (RL).

Total Concentrations

Both solid and vapor fractions were sampled to obtain data on their metal and PAH levels. However, the fractions were combined for analysis and the data were presented as total concentrations in the KVB - Analect report, hence only total concentrations are presented in this report.

Average Concentrations

The following criteria were used to average data from the individual runs.

- When all concentrations are above the detection limit (or reporting limit), the arithmetic mean concentration is calculated using the reported quantities.
- To calculate the mean result from individual concentrations that are both above and below the detection limit, one-half of the DL is used for values below the detection limit. For example:

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

By our convention, the calculated mean cannot be smaller than the largest detection limit value. In the following example, the calculated mean is 2.8, which is less than the largest detection limit, so the reported mean becomes ND(4).

<u>Analytical Values</u>	<u>Mean Value</u>
5, ND(4), ND(3)	ND(4)

- When all analytical results are less than the detection limit, the mean is reported as ND (the largest detection limit value).

Fuel Oil

Table 3-1 presents the results of the two residual fuel oil analyses. An assumed specific gravity of 0.98 for fuel oil was used to convert from mg/kg to mg/L. For each reported

Table 3-1
Oil Composition Data for Site 109

	<u>Run 15</u>	<u>Run 16</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Mass Flow Rate (klb/hr)</u>				
100% of Full Load (222MW)			110 ^b	--
75% of Full Load (159 MW)			80 ^c	--
50% of Full Load (109 MW)			57 ^b	--
<u>Elements (mg/L)</u>				
Arsenic	1.5	1.1	1.3	2.3
Beryllium	ND(0.08) ^d	ND(0.08)	ND(0.08)	--
Cadmium	ND(0.14)	ND(0.14)	ND(0.14)	--
Chloride (%)	ND(0.09)	ND(0.09)	ND(0.09)	--
Chromium	ND(0.17)	ND(0.17)	ND(0.17)	--
Copper	0.23	0.11	0.18	0.75
Lead	0.81	1.8	1.3	6.1
Manganese	ND(0.8)	ND(0.8)	ND(0.8)	--
Mercury	ND(0.9)	ND(0.9)	ND(0.9)	--
Nickel	5.1	5.5	5.3	2.3
Selenium	ND(5)	ND(5)	ND(5)	--
Sulfur (%)	0.20	0.19	0.20	0.09
Higher Heating Value (Btu/lb)			18,900 ^e	--

^aCI = Confidence Interval.

^bAverage flow rate presented in the KVB - Analect report.

^cFlow rate estimated in the KVB - Analect report from full and half load measurements.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eOnly one measurement for HHV.

substance, a mean concentration has been calculated, along with the 95% confidence interval about the mean. The confidence interval (CI) is the range about the mean in which the true mean lies with a given probability [e.g., it is 95% certain that the true mean nickel concentration in the oil is 5.3 ± 2.3 mg/L (between 3.0 and 7.6 mg/L) according to the two results shown in Table 3-1]. The confidence interval calculation is discussed in Section 5.

Stack Gas

Tables 3-2a, 3-2b, and 3-2c present concentration data for the emitted gas at Site 109. The data are presented for each operating condition--100%, 75%, and 50% of full load. For each sampling train, the particulate filter, probe and nozzle rinse, and impinger fractions were combined and analyzed. The measured concentrations for each of the three sampling runs are presented, as well as the mean and the 95% confidence interval associated with the mean. The concentrations in the two stacks are not expected to differ significantly since they are generated by the same boiler. Although it is not possible to determine which sample came from which stack, there seems to be no correlation of concentration and sampling location in Tables 3-2 through 3-3.

The metals concentrations in the stack gas were measured only during operation at 100% ✓ of full load. Because a filter blank analysis was not performed, measured concentrations were not adjusted. At other sites, blank concentrations have been significant for some substances. *what substances?*

The PAH levels in the stack gas were measured during all three load conditions. The PAH measurements are corrected for the reagent blank results. The field blank PAH levels were much higher than the levels in the reagent blank, as shown in Appendix A. Several of the PAHs were not detected in the stack gas at levels above the reporting limits given in the KVB - Analect report.

Tables 3-3a, 3-3b, and 3-3c show the concentrations of volatile organic compounds in the stack gas. During oil firing, benzene was not detected in the stack gas. These tables also compare formaldehyde emissions from the same boiler during the firing of two different fuels--residual oil and natural gas. During full-load conditions, the formaldehyde emissions were higher during oil firing than during natural gas firing. At 50% of full-load conditions, the formaldehyde emissions during oil firing and natural gas firing were similar.

Appendix D, Table D-1 presents additional sampling information, including stream flow rates, stack gas characterization data, stack temperature, unit load, and the degree of isokinetic sampling.

Tables 3-4a, 3-4b, and 3-4c show the average unit-energy-based emission factors in pounds of substance emitted per 10^{12} Btu input to the boiler. The emission factors were

Table 3-2a
Stack Gas Composition Data at Site 109
Residual Oil Firing
100% of Full Load ($\mu\text{g}/\text{Nm}^3$)

<u>Elements</u>	<u>Substance</u>	<u>Run 12</u>	<u>Run 13</u>	<u>Run 14</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Multi-Metal Sampling Train^b</u>						
Sample Date		1/11/91	1/11/91	1/11/91		
Stream Flow Rate (Nm^3/hr) ^c		926,000	752,000	914,000	864,000	240,000
Arsenic		ND(1.0) ^d	ND(1.2)	ND(1.0)	ND(1.2)	--
Beryllium		ND(0.5)	ND(0.6)	ND(0.5)	ND(0.6)	--
Cadmium		2.5	6.6	1.0	3.4	7.2
Chromium		12	16	7.8	12	10
Copper		14	27	11	17	22
Lead		49	ND(6)	8.3	20	62
Manganese		43	--	83	63	250
Mercury		ND(0.3)	ND(0.3)	6.4	2	10
Nickel		360	110	300	260	330
Selenium		ND(1.0)	12	ND(1.0)	4	17
<u>Individual Metal Sampling Trains^b</u>						
Sample Date		<u>Run 3</u>	<u>Run 4</u>	<u>Run 11</u>	<u>Mean</u>	<u>95% CI</u>
Stream Flow Rate (Nm^3/hr) ^c		12/12/90	12/12/90	1/10/91		
Chromium		892,000	802,000	768,000	821,000	160,000
Chromium, hexavalent		ND(1.1)	ND(6)	ND(6)	ND(1.1)	--
Nickel		ND(2.2)	ND(1.2)	ND(1.2)	ND(2.2)	--
		940	370	290	530	880

Table 3-2a (Continued)

Substance		Run 1	Run 2	Run 3	Mean	95% CI ^a
<u>Polynuclear Aromatic Hydrocarbons^f</u>						
Sample Date		12/11/90	12/11/90	12/12/90		
Stream Flow Rate (Nm ³ /hr) ^c		860,000	742,000	892,000	831,000	200,000
Acenaphthene		0.087 ^g	0.057 ^g	0.038 ^g	0.061	0.062
Acenaphthylene		0.023 ^g	0.020 ^g	0.014 ^g	0.019	0.012
Anthracene		0.025 ^g	0.023 ^g	0.019 ^g	0.022	0.007
Benz(a)anthracene		0.011 ^g	0.011 ^g	0.0066 ^g	0.010	0.007
Chrysene		0.034 ^g	0.021 ^g	0.018 ^g	0.024	0.022
Fluoranthene		0.14	0.058	0.043	0.080	0.13
Fluorene		0.24 ^g	0.15 ^g	0.15 ^g	0.18	0.13
Naphthalene		27	62	21	37	55
Phenanthrene		0.66	0.16	0.24	0.35	0.67
Pyrene		0.11	0.042	0.044	0.065	0.097

^aCI = Confidence interval.

^bNeither a reagent nor a field blank analysis was performed.

^cThis is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate measurement). Appendix D presents the individual stack flow rates.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eSample was contaminated with KMnO₄ because of reagent carryover from the KMnO₄ impinger solution to the nitric acid impinger solution (from the KVB - Analect report).

^fA method (reagent) blank analysis was performed and used to correct the sample results.

^gA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-2b
Stack Gas Composition Data at Site 109
Residual Oil Firing
75% of Full Load ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons^b</u>					
Sample Date	12/14/90 ^c	12/14/90	12/14/90		
Stream Flow Rate (Nm^3/hr) ^e	766,000	712,000	762,000	747,000	75,000
Acenaphthene	0.015 ^d	0.052 ^d	0.02 ^d	0.029	0.050
Acenaphthylene	0.018 ^d	0.021 ^d	0.0087 ^d	0.016	0.015
Anthracene	0.0056 ^d	0.013 ^d	0.0091 ^d	0.0092	0.0099
Benz(a)anthracene	NR(0.0029) ^{d,e}	0.0064 ^d	NR(0.0028) ^d	0.0031	0.0074
Chrysene	0.0078 ^d	0.013 ^d	0.012 ^d	0.011	0.0074
Fluoranthene	0.012	0.053	0.022	0.029	0.052
Fluorene	0.13 ^d	0.22 ^d	0.13 ^d	0.16	0.13
Naphthalene	22	31	36	30	18
Phenanthrene	0.066	0.26	0.067	0.13	0.28
Pyrene	0.007 B ^f	0.054	0.026	0.029	0.060

^aCI = Confidence interval.

^bA method (reagent) blank analysis was performed and used to correct the sample results.

^cThis is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate). Appendix D presents the individual stack flow rates.

^dA blank correction is not applied since the substance was not detected in the blank sample.

^eNR indicates that the concentration is below the reporting limit, which is shown in parentheses.

^fB indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. Refer to Table A-1 in Appendix A for a comparison of sample and blank results.

Table 3-2c
Stack Gas Composition Data at Site 109
Residual Oil Firing
50% of Full Load ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons^b</u>					
Sample Date	12/13/90	12/13/90	12/13/90		
Stream Flow Rate (Nm^3/hr) ^c	596,000	566,000	548,000	570,000	60,000
Acenaphthene	0.031 ^d	0.0048 ^d	0.013 ^d	0.016	0.033
Acenaphthylene	0.034 ^d	0.019 ^d	0.014 ^d	0.022	0.026
Anthracene	0.0093 ^d	0.0085 ^d	0.0091 ^d	0.0090	0.0010
Benz(a)anthracene	0.0051 ^d	0.0051 ^d	NR(0.0024) ^{d,e}	0.0038	0.0057
Chrysene	0.015 ^d	0.0089 ^d	0.0091 ^d	0.011	0.0087
Fluoranthene	0.045	0.028	0.022	0.032	0.030
Fluorene	0.18 ^d	0.12 ^d	0.058 ^d	0.12	0.15
Naphthalene	22	25	20	22	6
Phenanthrene	0.19	0.10	0.06	0.12	0.16
Pyrene	0.039	0.019	0.031	0.030	0.025

^aCI = confidence interval.

^bA method (reagent) blank analysis was performed and used to correct the sample results.

^cThis is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate). Appendix D presents the individual stack flow rates.

^dA blank correction is not applied since the substance was not detected in the blank sample.

^eNR indicates that the concentration is below the reporting limit, which is shown in parentheses.

Table 3-3a
Volatile Organic Stack Emissions at Site 109
Residual Oil and Natural Gas Firing
100% of Full Load ($\mu\text{g}/\text{Nm}^3$)

<u>Substance</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Residual Oil Firing</u>					
Sample Date	12/11/90	12/11/90	12/12/90		
Stack Flow Rate (Nm^3/hr) ^b	860,000	742,000	892,000	831,000	200,000
Benzene ^c	ND(11) ^{d,e}	ND(11) ^e	ND(11) ^e	ND(11)	--
Formaldehyde ^e	520 ^e	320 ^e	530 ^e	460	290
<u>Natural Gas Firing</u>					
Sample Date	11/28/90	11/28/90	11/28/90		
Stack Flow Rate (Nm^3/hr) ^b	860,000	860,000	742,000	831,000	175,000
Formaldehyde ^e	46 ^e	55 ^e	41 ^e	50	8

^aCI = Confidence interval.

^bThis is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate). Appendix D presents the individual stack flow rate measurements.

^cA reagent blank analysis was performed and used to correct the sample results.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eA blank correction is not applied since the substance was not detected in the blank sample.

Table 3-3b

**Volatile Organic Stack Emissions at Site 109
Residual Oil and Natural Gas Firing
75% of Full Load ($\mu\text{g}/\text{Nm}^3$)**

<u>Volatile Organic Compounds</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Residual Oil Firing</u>					
Stack	East	West	East		
Sample Date	12/14/90	12/14/90	12/14/90		
Stack Flow Rate (Nm^3/hr) ^b	766,000	712,000	762,000	747,000	75,000
Benzene ^c	ND(11) ^{d,e}	ND(11) ^e	ND(11) ^e	ND(11)	--
Formaldehyde ^c	650 ^e	300 ^e	430 ^e	460	440
<u>Natural Gas Firing</u>					
	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>		
Stack	East	West	East		
Sample Date	11/29/90	11/29/90	11/29/90		
Stack Flow Rate (Nm^3/hr) ^b	596,000	566,000	548,000	570,000	60,000
Formaldehyde	-- ^f	-- ^f	-- ^f	--	--

^aCI = Confidence interval.

^bThis is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate). Appendix D presents the individual stack flow rate measurements.

^cA reagent blank analysis was performed and used to correct the sample results.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eA blank correction is not applied since the substance was not detected in the blank sample.

^fConcentrations are not presented because the analytical report for formaldehyde at 75% of full-load operating conditions is not available.

Table 3-3c

**Volatile Organic Stack Emissions at Site 109
Residual Oil and Natural Gas Firing
50% of Full Load ($\mu\text{g}/\text{Nm}^3$)**

<u>Volatile Organic Compounds</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>	<u>Mean</u>	<u>95% CI ^a</u>
<u>Residual Oil Firing</u>					
Sample Date	12/13/90	12/13/90	12/13/90		
Stack Flow Rate (Nm^3/hr) ^b	596,000	566,000	548,000	570,000	60,000
Benzene ^c	ND(11) ^{d,e}	ND(11) ^c	ND(11) ^c	ND(11)	--
Formaldehyde ^c	-- ^f	130 ^c	150 ^c	140	130
<u>Natural Gas Firing</u>					
	<u>Run 10</u>	<u>Run 11</u>	<u>Run 12</u>		
Sample Date	11/29/90	11/29/90	11/29/90		
Stack Flow Rate (Nm^3/hr) ^b	766,000	712,000	762,000	747,000	75,000
Formaldehyde ^c	170 ^c	190 ^c	180 ^c	180	25

^aCI = Confidence interval.

^b This is the total-unit stack gas flow rate (i.e., two times the individual stack flow rate). Appendix D presents the individual stack flow rate measurements.

^cA reagent blank analysis was performed and used to correct the sample results.

^dND indicates that the concentration is below the detection limit, which is shown in parentheses.

^eA blank correction is not applied since the substance was not detected in the blank sample.

^f Missing sample, according to the KVB - Analect report.

Table 3-4a
Stack Gas Emission Factors at Site 109
100% of Full Load (lb/10¹² Btu)
Elements

<u>Substance</u>	<u>Residual Oil Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>
<u>Multi-Metals Sampling Train</u>		
Arsenic	ND(1.1) ^b	--
Beryllium	ND(0.5)	--
Cadmium	3.1	6.9
Chromium	11	10
Copper	16	21
Lead	17	59
Manganese	58	240
Mercury	1.8	9.1
Nickel	240	300
Selenium	3.7	16
<u>Individual Metal Sampling Trains</u>		
Chromium	ND(9.6)	--
Chromium, hexavalent	ND(1.9)	--
Nickel	460	760

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Btu), which is shown in parentheses.

Table 3-4b
Stack Gas Emissions Factors at Site 109
(lb/10¹² Btu)
PAHs, Benzene, and Formaldehyde

	<u>100% Load</u>		<u>75% Load</u>		<u>50% Load</u>	
	<u>Residual Oil Firing</u>		<u>Residual Oil Firing</u>		<u>Residual Oil Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>	<u>Mean</u>	<u>95% CI^a</u>	<u>Mean</u>	<u>95% CI^a</u>
<u>Polynuclear Aromatic Hydrocarbons</u>						
Acenaphthene	0.054	0.056	0.032	0.054	0.019	0.096
Acenaphthylene	0.0017	0.0086	0.017	0.016	0.026	0.029
Anthracene	0.019	0.0052	0.0098	0.011	0.010	0.001
Benz(a)anthracene	0.0088	0.0069	0.0033	0.0081	0.0047	0.0058
Chrysene	0.021	0.020	0.012	0.008	0.013	0.009
Fluoranthene	0.075	0.11	0.032	0.057	0.037	0.035
Fluorene	0.16	0.12	0.17	0.14	0.14	0.17
Naphthalene	33	50	33	20	26	6
Phenanthrene	0.33	0.60	0.14	0.30	0.14	0.20
Pyrene	0.066	0.085	0.032	0.65	0.035	0.029
<u>Volatile Organic Compounds</u>						
Benzene	ND(9.7)	--	ND(12) ^b	--	ND(13) ^b	--
Formaldehyde	400	210	-- ^c	--	160	160

Table 3-4b (Continued)

<u>Volatile Organic Compounds</u>	<u>100% Load</u>		<u>75% Load</u>		<u>50% Load</u>	
	<u>Natural Gas Firing</u>		<u>Natural Gas Firing</u>		<u>Natural Gas Firing</u>	
	<u>Mean</u>	<u>95% CI^a</u>	<u>Mean</u>	<u>95% CI^a</u>	<u>Mean</u>	<u>95% CI^a</u>
Formaldehyde	46	9	330	160	330	39

^aCI = Confidence interval.

^bND indicates that the concentration is below the detection limit (expressed as lb/10¹² Bu), which is shown in parentheses.

^cNo analytical data for formaldehyde were available in the KVB - Analyt report.

calculated from the total mean emitted gas concentrations presented in Tables 3-2a, 3-2b, and 3-2c. The mean stack gas flow rate must be consistent with the inlet fuel flow rate; therefore, the total-unit stack gas flow rate, rather than the single-stack flow rate, was used to calculate the emission factor. The total-unit stack gas flow rate was estimated to be two times the single-stack flow rate measurement. These results are organized by load condition. Section 5 contains an example calculation.

Section 4

DATA EVALUATION

Several procedures can be used to evaluate the information developed during a field sampling program. In the case of Site 109, two methods were used to evaluate the quality of the data. First, and most important, was evaluation of the traditional QA/QC protocol for sampling and analytical procedures used at Site 109, i.e., equipment calibration and leak checks, duplicates, blanks, spikes, etc. Site 109 QA/QC data are compared with FCEM project objectives for similar QA/QC procedures. The second data evaluation tool involves calculating material balances around the entire plant for various substances. Material balances involve the summation and comparison of mass flow rates in several streams that are often sampled and analyzed by different methods. Good agreement, i.e., closure within an acceptable range, can be used as an indicator of accurate results for streams that contribute significantly to the overall inlet or outlet mass rate.

Evaluation of Measurement Data Quality

An evaluation of the quality of the measurement data is based on quality control data obtained experimentally during the sampling and analysis process. Generally, the type of quality information obtained pertains to measurement precision, accuracy, and blank effects, determined using various types of replicate, spiked, and blank samples. The specific characteristics evaluated depend on the type of quality control checks performed. For example, blanks may be prepared at different stages in the sampling and analysis process to isolate the source of a blank effect. Similarly, replicate samples may be generated at different stages to isolate and measure the sources of variability. Table 4-1 summarizes the QA/QC measures commonly used as part of the FCEM data evaluation protocol and the characteristic information obtained. The absence of any of these types of quality control checks does not necessarily reflect poorly on the quality of the data but does limit the ability to measure the various components of measurement error.

As indicated in the table, different QC checks provide different types of information, particularly pertaining to the source of inaccuracy, imprecision, and blank effects. As part of FCEM, measurement precision and accuracy are typically estimated from QC indicators that cover as much of the total sampling and analytical process as feasible. Estimates of measurement precision and accuracy are based on the actual sample matrix. For purposes of comparability, the actual precision and accuracy estimates obtained experimentally during the test programs are compared with data quality objectives (DQOs) established for the FCEM project.

Table 4-1
Types of Quality Control Samples

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

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

Analytical Quality Control Results

Table 4-2 presents the types of quality control data reported for this site. The analytical results appear in Appendix H. Table 4-3 summarizes the precision and accuracy estimates.

According to the quality control data evaluated, there is no reason to conclude that the data reported are unacceptable; however, not enough information is available to unequivocally validate the data. The QC indicators reported are generally good; accepted methods were used for sampling and analysis, and stack gas sample collection records are strongly supportive. Confidence in some measurements is low because of the relatively high blank results. In particular, high levels of PAHs in the field and trip blanks make the PAH measurements suspect, except for the results for benzo(a)anthracene. No quality control measurements were reported for metals or for proximate and ultimate analyses. No natural gas samples were collected.

A discussion of precision and accuracy is presented below for each measurement type, followed by a review of stack gas sampling quality control data. This review includes a discussion of representativeness, comparability, and completeness.

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

Accuracy is a measure of the deviation from a measurement result and the "true" or expected value. In a single measurement, accuracy includes components of both random error, or imprecision, and systematic error, or bias. The average of several accuracy values tends toward a limiting mean, which is a measure of the bias, or persistent positive or negative deviation from the "true" value.

The efficiency of the analytical procedure as used on the sample matrix is quantified by the analysis of spiked samples containing target or indicator analytes and other quality assurance measures, as necessary. Although spiked samples usually provide a measure of

Table 4-2
Types of Quality Control Data Reported

Analysis	Precision				Accuracy			Blank				
	Replicate Runs	Dup Field Samples	Dup Lab Analysis	Matrix or Media Spiked Dup	Lab Control Sample Dup	Matrix or Media Spike	Surrogate Spike	Lab Control Sample	Field Blank	Trip Blank	Method Blank	Reagent Blank
<u>Fuel Oil</u>												
Metals by ICP/AAS ^a	✓		✓			✓						
Ultimate and Proximate ^b	✓											
<u>Fuel - Natural Gas</u>												
Composition & HHV												
<u>Stack Gas</u>												
Metals by ICP ^c	✓		✓			✓			✓			✓
Arsenic by GFAAS	✓								✓			✓
Lead by GFAAS	✓					✓			✓			✓
Mercury by CVAAS	✓		✓			✓			✓			✓
Hexavalent Chromium by IC	✓		✓			✓			✓			
Total Chromium by AAS	✓		✓			✓			✓			✓
Benzene by GC/PID	✓											
Formaldehyde by HPLC	✓			✓		✓			✓		✓	
Polynuclear Aromatic Hydrocarbons by GC/MS ^d	✓							✓				✓

^aIncludes As, Be, Cd, Cr, Cr(VI), Cu, Pb, Hg, Mn, Ni, P, Se, Zn by EPA SW-846 Methods 6010 (ICP-AES) AND 7000 series (AAS).

^bAsh, carbon, hydrogen, nitrogen, oxygen, sulfur, specific gravity, and chlorine.

^cIncludes Be, Cd, Cu, Pb, Mn, Ni, Se, and Zn by ICP-AES.

^dIncludes acenaphthene, anthracene, fluoranthene, phenanthrene, and pyrene.

Table 4-3

Summary of Precision and Accuracy Estimates

Measurement Parameter	How Measured ^a	Objectives		Measured		Data Evaluation
		Precision ^b	Accuracy ^c	Precision	Accuracy	
Metals in Fuel Oil	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	<1% RPD	97%	
Beryllium		20% RPD	75-125%	<1% RPD	89%	
Cadmium		20% RPD	75-125%	<1% RPD	91%	
Chromium		20% RPD	75-125%	5% RPD	88%	
Copper		20% RPD	75-125%	14% RPD	91%	
Lead		20% RPD	75-125%	2% RPD	99%	
Manganese		20% RPD	75-125%	2% RPD	87%	
Mercury		20% RPD	75-125%	2% RPD	88%	
Nickel		20% RPD	75-125%	<1% RPD	103%	
Selenium		20% RPD	75-125%	7% RPD	96%	
Metals in Stack Gas - Vapor Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	<1% RPD	90%	
Beryllium		20% RPD	75-125%	<1% RPD	96%	
Cadmium		20% RPD	75-125%	<1% RPD	77%	
Copper		20% RPD	75-125%	1% RPD	95%	
Lead		20% RPD	75-125%	8% RPD	81%	
Manganese		20% RPD	75-125%	4% RPD	92%	
Mercury		20% RPD	75-125%	<1% RPD	94-100%	
Nickel		20% RPD	75-125%	3% RPD	97%	
Selenium		20% RPD	75-125%	<1% RPD	109%	
Metals in Stack Gas - Solid Phase	Precision - Duplicate Analysis Accuracy - Matrix Spike					
Arsenic		20% RPD	75-125%	10% RPD	112%	
Beryllium		20% RPD	75-125%	<1% RPD	94%	
Cadmium		20% RPD	75-125%	<1% RPD	100%	
Copper		20% RPD	75-125%	3% RPD	101%	
Lead		20% RPD	75-125%	<1% RPD	92%	

Table 4-3 (Continued)

<u>Measurement Parameter</u>	<u>How Measured^a</u>	<u>Objectives</u>		<u>Measured</u>	
		<u>Precision^b</u>	<u>Accuracy^c</u>	<u>Precision</u>	<u>Accuracy</u>
Manganese		20% RPD	75-125%	<1% RPD	96%
Mercury		20% RPD	75-125%	<1% RPD	109%
Nickel		20% RPD	75-125%	<1% RPD	101%
Selenium		20% RPD	75-125%	4% RPD	85%
Total Chromium in Stack Gas	Precision - Duplicate Analysis Accuracy - Matrix Spike	20% RPD	75-125%	6% RPD	79%
Hexavalent Chromium in Stack Gas	Precision - Not performed Accuracy - Matrix Spike	20% RPD	75-125%	--	96%
PAHs in Stack Gas	Precision & Accuracy - Surrogate Spikes	35% CV	50-150%	32% CV	49-95%
d10-Acenaphthene		35% CV	50-150%	33% CV	18-67%
d10-Anthracene		35% CV	50-150%	21% CV	98-150%
d12-Chrysene		35% CV	50-150%	69% CV	10-71%
d12-Benzo(a)pyrene		40% RPD	50-150%	3% RPD	104-107%
Formaldehyde in Stack Gas	Precision and Accuracy - Matrix Spike Duplicates				

^aRefers to the type of QC samples used to estimate precision and accuracy.

^bPrecision is expressed according to the type of measurement. For surrogate spikes, precision is expressed as the percent coefficient of variation (% CV) for the set of surrogate recovery results. For objectives estimated from duplicate measurements, whether matrix spike duplicate, media spike duplicates, or field sample duplicates, precision is expressed as the relative percent difference (RPD) between the duplicate results. The objectives cited are intended to include components of both sampling and analytical variability, although, in most cases, only analytical variability data were available; consequently, the sample variability component is not incorporated into the comparison with the stated objectives.

^cAccuracy is expressed as the range of recoveries expected for individual analytical results.

accuracy or bias at medium concentration levels, expressed as percent recovery, blank samples also provide a measure of bias, although at low or near-detection levels.

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

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

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

Metals

Precision. Precision estimates for metals analyses could not be evaluated. Although replicate runs were performed, not enough samples were taken to appropriately characterize the variability associated with the process, sampling and analytical systems. Analytical variability could not be estimated because no duplicate matrix or method spikes were performed, nor was a duplicate injection performed. Replicate runs were performed and analyzed, but the variability indicates that the 95% confidence interval (CI) is greater than the mean for the three runs for all metals but chromium in the stack gas and nickel in the oil. Although this variability does not suggest that field sample concentrations are unusable, it does suggest low confidence in the average emission estimates.

Accuracy. The accuracy of the metals analyses could not be evaluated because no method or matrix spikes were performed.

Blanks. Contamination associated with laboratory and field practices could not be evaluated because no field blanks or laboratory blanks were analyzed.

PAHs

Precision. Precision estimates for PAH analyses in stack gas samples, as shown in Table 4-3, are based on the scatter of surrogate spike recoveries in the nine replicate sample analyses, expressed as the percent coefficient of variation (%CV). These data show precision within expected limits. CVs for 12 of 16 surrogate compounds were within the 35% objective, and the other four were slightly higher at 41%, 37%, 57%, and 56%. The

results for PAHs are equally consistent, although half of the target analytes were not detected.

Accuracy. Accuracy estimates for PAHs in the stack gas, based on surrogate spike recoveries in nine samples, were biased slightly high for most compounds and were widely scattered for two, benzo(g,h,i)perylene-d₁₂ (25-141%) and dibenzo(a,h)anthracene-d₄ (28-142%). Overall, these data point to effective, although biased slightly high, analyses.

Blanks. Ten of the PAHs analyzed were reported in the stack gas stream during oil firing, as shown in Tables 3-2a, 3-2b, and 3-2c. Generally, the levels in the reagent blank were insignificant, compared with the levels in the test samples. On the other hand, field blank results were not substantially different from the concentrations reported in the field samples. Two field blanks, a trip blank and a blank train, were analyzed. For all compounds but benz(a)anthracene, the concentrations in the field blank were not substantially different from the measured mean concentration in the stack gas. In some cases, the field blank concentration was higher than the reported mean stack gas concentration. Benz(a)anthracene was not detected in the field blank or the trip blank. The high levels of PAHs in the field blank make the PAH measurements suspect, except for test results for benz(a)anthracene. Since the concentrations in the field and trip blanks are so much higher than that of the method blank, the contamination is assumed to be due to the XAD resin.

Formaldehyde

Precision. Precision for formaldehyde analyses, expressed in terms of the relative percent difference (RPD) for analytical duplicate analyses, is 58% RPD. At low concentrations, the absolute differences between the analytical duplicates are typically small, whereas the relative differences are large, which would be expected as the measured values approach zero. At such low levels the results should be considered semi-quantitative or qualitative.

Accuracy. Accuracy estimates for formaldehyde, based on matrix spike and method spike sample results were within the 50-150% objective.

Blanks. Nothing was detected in the water blank, the three laboratory blanks, the two trip blanks or the field blank. No problems are indicated by these results.

Benzene

Neither precision nor accuracy could be estimated for this substance. Three blanks were collected. Nothing was detected in the blanks or in the samples.

Stack Gas Sampling Quality Control

Sampling quality control was addressed with process schematic forms, including location description, traverse point guidelines and calculations, nozzle selection calculations, velocity traverse information, and isokinetic variation calculations. Also included were calibration records for the dry gas meters.

Sampling precision can be estimated by comparing the results for various parameters of the replicate samples, notably velocity, moisture content, and gas composition. These were fairly constant for each sample location. Although there was some variation in the moisture content, volumetric flow results were fairly uniform.

Sampling accuracy is usually assumed from the calibration and proper operation of the equipment and from historical validation of the methods. Field blanks are used to correct for any biases that may be caused by contamination of the equipment or location, or by operator errors. Blanks were included for all tests except the CARB 410 benzene samples, which were collected in bags by grab sampling.

Sampling representativeness depends on the testing precision and accuracy and also on the characteristics of the sampling locations. The sampling locations on the stacks were not ideal in terms of undisturbed flow distances upstream of the ports (about four diameters), but the maximum required number of traverse points were used to ensure sample representativeness. The isokinetic variation is a measure of the operational performance of sampling for particulate matter; it can be used as an indicator of precision, with consequences for representativeness. All of the sampling runs met the acceptance criteria for isokinetic variation.

Sampling comparability depends on the representativeness of the samples and on the use of standard methods consistently applied. The CARB 430 method for aldehydes is a single-point, nonisokinetic, midjet impinger procedure analogous to the EPA Boilers and Industrial Furnaces (BIF) Method 0011. It uses the same acidified 2,4-dinitrophenylhydrazine reagent for collection and HPLC for analysis. The CARB 429-EPA MM5/M23 method for semivolatile organic compounds, dioxins, and furans is well established for both sampling and analysis. The EPA multimetals procedure is still in the evaluation process, but it is becoming widely accepted and is documented enough to be considered a standard method. CARB 425 for total and hexavalent chromium is somewhat similar to the current EPA/BIF hexavalent chromium method in terms of the collection medium and analytical procedures, although in this case, water was used as the impinger solution. CARB 433 for nickel is nearly identical with EPA Method 12 for inorganic lead and should be applicable to most acid soluble metals. CARB 410 for benzene is the same as the EPA Method 18 procedure for sampling with a rigid container that is evacuated to fill a bag.

Sampling completeness is mainly a function of providing the requisite number of samples and of proper documentation. In particular, the data necessary for calculating the results, including calibrating the equipment and all pertinent entries on the run data

sheets, should be present. The calibration data provided in this report were adequate and sampling sheets were acceptably filled out. The necessary number of samples were successfully taken and sample custody was transferred properly to the analytical laboratories. No significant data losses were reported. Four formaldehyde results could not be located and one manganese result was not available because of a contaminated impinger solution. Triplicate runs were performed for stack gas measurements, consistent with the standard FCEM approach. Only two samples were collected for fuel oil. The natural gas was not sampled.

Material Balance Results

Material balance closures were not calculated for Site 109. The oil samples were collected twelve days after the stack gas sampling was completed. Since the oil samples were not collected in sequence with the flue gas samples, material balances were not considered appropriate for evaluating the data.

The average flow rate for oil is consistent with the generating capacity of the unit (i.e., nominal heat rates of 9400, 9500, and 9900 Btu/kW hr for 100%, 75%, and 50% of full load operating conditions, respectively).

Section 5

EXAMPLE CALCULATIONS

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

Concentration Calculations

The concentrations presented in this report were calculated from raw data presented in the R-C Environmental report. The gas concentration is calculated as follows:

$$C = \frac{(M - B)}{SV} * 35.3 * \frac{520}{492} \quad (5-1)$$

where:

- C = Concentration, $\mu\text{g}/\text{Nm}^3$
- M = Mass measured in the sample, μg
- B = Mass measured in the reagent blank, μg
- SV = Sample volume (at 60° F), dscf
- 35.3 = Conversion of ft^3 to m^3 (standard)
- $\frac{520}{492}$ = Temperature correction to normal conditions, i.e., 32° F (60° F to 32° F)

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

Unit Energy Calculations

The unit-energy-based emission factors (Tables 3-4a, 3-4b, and 3-4c) were determined by dividing the mass flow rate of a substance being emitted by the fuel heat input to the boiler during testing.

Example Calculations

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

$$E = \frac{g * c}{HHV * oil} * 2202.6 \quad (5-2)$$

where:

E = Mean stack emission factor, lb/10¹² Btu

g = Mean flue gas flow rate, Nm³/hr

c = Mean total flue gas concentration, μg/Nm³

HHV = Mean oil higher heating value, Btu/lb

oil = Mean oil feed rate, lb/hr

2202.6 = Unit conversion coefficient, lb Btu/μg 10¹² Btu

For this unit, the mean flue gas flow rate was calculated as the average of the individual runs, which were estimated as two times the single-stack flow rate. The mean flue gas flow rate must be consistent with the inlet fuel flow rate.

Nickel, collected by the multi-metals train during full-load conditions, will be used for this example. The following mean values were taken from Tables 3-1 and 3-2a:

g = 864,000 Nm³/hr

c = 260 μg/Nm³

HHV = 18,900 Btu/lb

oil = 110,000 lb/hr

The emission factor for nickel during 100% of full load conditions is calculated from Equation 5-2:

$$E = \frac{864,000 * 260 * 2202.6}{18,900 * 110,000} = 240 \text{ lb}/10^{12} \text{ Btu}$$

During natural gas firing, the emission factor equation is:

$$E = \frac{g * c}{HHV_g * gas} * 2202.6 \quad (5-3)$$

where:

HHV_g = Mean natural gas higher heating value, Btu/scf

gas = Mean natural gas feed rate, scf/hr

Confidence Interval Calculations

Confidence intervals (CIs) were calculated for the total mean concentrations in the stack gas and fuel oil. In addition, confidence intervals were determined for the stack gas emission factors presented in Tables 3-4a, 3-4b, and 3-4c. Additional information on the CI calculation can be found in Appendix E.

CIs for Stream Concentrations

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

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

where:

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

β_r = Bias component

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

S_r = Standard deviation of the individual run measurements

N = Number of measurements

Example Calculations

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

$$\beta_r = \sqrt{\sum_{m=1}^n (\beta_{pm} * \theta_{pm})^2} \quad (5-5)$$

where:

β_{pm} = Individual bias for run m

θ_{pm} = Sensitivity to run m = $1/N$

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

The following stack gas concentrations ($\mu\text{g}/\text{Nm}^3$), taken from Table 3-2a, will be used to demonstrate the method for calculating the 95% CI. The mean total concentration and standard deviation are also calculated.

<u>Substance</u>	<u>Fraction</u>	<u>Run 12</u>	<u>Run 13</u>	<u>Run 14</u>	<u>Mean</u>	<u>Standard Deviation</u>
Copper	Total	14	27	11	17	9
Lead	Total	49	ND(6)	8.3	20	25

The 95% confidence interval associated with the total copper concentration is calculated using the following values inserted into Equation 5-4:

β_r = 0 (no values below the detection limit)

t = 4.3

S_r = 9

N = 3

The 95% CI (U_{TOT}) for the total copper concentration is $22 \mu\text{g}/\text{Nm}^3$.

The 95% confidence interval for lead is calculated the same way. Since the concentration for Run 13 is below the detection limit, the bias component is not zero. The individual bias, β_p , for each run is:

	<u>Run 12</u>	<u>Run 13</u>	<u>Run 14</u>
β_p	0	3	0

Using these values, the bias component is then calculated from Equation 5-5. In this example, the sensitivity is 0.33 or 1/3.

$$\beta_r = \sqrt{\left(\frac{0}{3}\right)^2 + \left(\frac{3}{3}\right)^2 + \left(\frac{0}{3}\right)^2}$$

$$= 1$$

The standard deviation (S_r) calculated from the three individual lead concentrations is 25. Substituting these values into Equation 5-4,

$$U_{TOT} = \sqrt{(1)^2 + \left(\frac{4.3 * 25}{\sqrt{3}}\right)^2}$$

$$= 62 \mu\text{g}/\text{Nm}^3$$

CIs for Emission Factors

The 95% CIs for the emission factors were calculated using the equations presented in Appendix E. Appendix E also contains a sample calculation for the 95% CI around an emission factor.

Appendix A

Analytical Data from the KVB Analect Report

Table A-1 presents the stack gas test results for each run, as well as the results of the blank analyses. No blank analyses were performed for metals. Blanks were analyzed for PAHs and volatile organics.

Table A-1

**Results of the Sample, Field Blank, and
Reagent Blank Analyses for FCEM Site 109**

	<u>Mass Measured in the Sample (μg)</u>			<u>Field Blank (μg)</u>	<u>Reagent Blank (μg)</u>
	<u>Run 12</u>	<u>Run 13</u>	<u>Run 14</u>		
Oil Firing					
<u>Multi-Metals Sampling Train</u> ^a					
Gas Sample Volume, Nm ³	2.03	1.66	2.04		
Arsenic	ND(2) ^b	ND(2)	ND(2)		
Beryllium	ND(1)	ND(1)	ND(1)		
Cadmium	5	11	2		
Chromium	24	26	16		
Copper	28	44	22		
Lead	100	ND(10)	17		
Manganese	87	590,000 ^c	170		
Mercury	ND(0.5)	ND(0.5)	13		
Nickel	730	180	620		
Selenium	ND(2)	20	ND(2)		
<u>Individual Metal Sampling Trains</u> ^a					
	<u>Run 3</u>	<u>Run 4</u>	<u>Run 11</u>		
Gas Sample Volume, Nm ³	0.91	1.66	1.70		
Chromium	ND(10)	ND(10)	ND(10)		
Chromium, hexavalent	ND(2)	ND(2)	ND(2)		
Gas Sample Volume, Nm ³	0.92	1.66	2.03		
Nickel	870	610	450		

Table A-1 (Continued)

	<u>Mass Detected (μg)</u>			<u>Field</u> <u>Blank (μg)</u>	<u>Method</u> <u>(Reagent)</u> <u>Blank (μg)</u>
<u>PAHs</u>					
<u>100% of Full Load</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm ³	2.64	2.27	2.86		
Naphthalene	70	140	61	100	0.062
Acenaphthylene	0.069	0.046	0.040	0.018	NR(0.013) ^d
Acenaphthene	0.23	0.13	0.11	0.036	NR(0.0041)
Fluorene	0.64	0.34	0.43	0.073	NR(0.0051)
Phenanthrene	1.8	0.41	0.74	0.15	0.048
Anthracene	0.066	0.052	0.053	0.022	NR(0.0029)
Fluoranthene	0.38	0.15	0.14	0.048	0.018
Pyrene	0.31	0.12	0.15	0.070	0.024
Benz(a)anthracene	0.030	0.025	0.019	0.011	NR(0.0015)
Chrysene	0.095	0.048	0.051	0.013	NR(0.0023)
Benzo(b)fluoranthene	NR(0.022)	NR(0.026)	NR(0.013)	NR(0.0089)	NR(0.0041)
Benzo(k)fluoranthene	NR(0.027)	NR(0.022)	NR(0.016)	NR(0.0077)	NR(0.0039)
Benzo(a)pyrene	NR(0.011)	NR(0.021)	NR(0.0085)	NR(0.0072)	NR(0.0042)
Dibenz(a,h)anthracene	NR(0.010)	NR(0.0063)	NR(0.0099)	NR(0.0011)	NR(0.0044)
Benzo(g,h,i)perylene	NR(0.024)	NR(0.035)	NR(0.015)	NR(0.0086)	NR(0.0048)
Indeno(1,2,3-c,d)pyrene	NR(0.017)	NR(0.018)	NR(0.012)	NR(0.0059)	NR(0.0036)
<u>PAHs</u>					
<u>75% of Full Load</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>		
Gas Sample Volume, Nm ³	2.32	2.51	2.41		
Naphthalene	50	78	86	100	0.062
Acenaphthylene	0.041	0.052	0.021	0.018	NR(0.013)
Acenaphthene	0.034	0.13	0.049	0.036	NR(0.0041)
Fluorene	0.31	0.56	0.31	0.073	NR(0.0051)
Phenanthrene	0.20	0.69	0.21	0.15	0.048
Anthracene	0.013	0.033	0.022	0.022	NR(0.0029)
Fluoranthene	0.045	0.15	0.071	0.048	0.018
Pyrene	0.040	0.16	0.086	0.070	0.024
Benz(a)anthracene	NR(0.0067)	0.016	NR(0.012)	0.011	NR(0.0015)
Chrysene	0.018	0.032	0.029	0.013	NR(0.0023)
Benzo(b)fluoranthene	NR(0.0066)	NR(0.018)	NR(0.014)	NR(0.0089)	NR(0.0041)
Benzo(k)fluoranthene	NR(0.0059)	NR(0.015)	NR(0.018)	NR(0.0077)	NR(0.0039)
Benzo(a)pyrene	NR(0.0035)	NR(0.013)	NR(0.010)	NR(0.0072)	NR(0.0042)
Dibenz(a,h)anthracene	NR(0.0024)	NR(0.0024)	NR(0.0037)	NR(0.0011)	NR(0.0044)
Benzo(g,h,i)perylene	NR(0.0078)	NR(0.012)	NR(0.011)	NR(0.0086)	NR(0.0048)
Indeno(1,2,3-c,d)pyrene	NR(0.0038)	NR(0.0068)	NR(0.0067)	NR(0.0059)	NR(0.0036)

Table A-1 (Continued)

	<u>Mass Detected (μg)</u>			<u>Field</u> <u>Blank (μg)</u>	<u>Method</u> <u>(Reagent)</u> <u>Blank (μg)</u>
<u>PAHs</u>					
<u>50% of Full Load</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
Gas Sample Volume, Nm ³	2.95	2.93	2.76		
Naphthalene	66	72	56	100	0.062
Acenaphthylene	0.10	0.056	0.038	0.018	NR(0.013)
Acenaphthene	0.091	0.014	0.036	0.036	NR(0.0041)
Fluorene	0.52	0.35	0.16	0.073	NR(0.0051)
Phenanthrene	0.60	0.34	0.22	0.15	0.048
Anthracene	0.027	0.025	0.025	0.022	NR(0.0029)
Fluoranthene	0.15	0.10	0.080	0.048	0.018
Pyrene	0.14	0.080	0.11	0.070	0.024
Benz(a)anthracene	0.015	0.015	NR(0.013)	0.011	NR(0.0015)
Chrysene	0.044	0.026	0.025	0.013	NR(0.0023)
Benzo(b)fluoranthene	NR(0.014)	NR(0.014)	NR(0.019)	NR(0.0089)	NR(0.0041)
Benzo(k)fluoranthene	NR(0.014)	NR(0.012)	NR(0.016)	NR(0.0077)	NR(0.0039)
Benzo(a)pyrene	NR(0.010)	NR(0.0091)	NR(0.099)	NR(0.0072)	NR(0.0042)
Dibenz(a,h)anthracene	NR(0.0034)	NR(0.0045)	NR(0.0038)	NR(0.0011)	NR(0.0044)
Benzo(g,h,i)perylene	NR(0.0074)	NR(0.014)	NR(0.034)	NR(0.0086)	NR(0.0048)
Indeno(1,2,3-c,d)pyrene	NR(0.0055)	NR(0.0072)	NR(0.015)	NR(0.0059)	NR(0.0036)
<u>Volatile Organics</u>					
<u>100% of Full Load</u>	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>		
Gas Sample Volume, Nm ³	0.0031	0.0047	0.0047		
Benzene, mg/m ³	ND(0.010)	ND(0.010)	ND(0.010)		ND(0.010)
Gas Sample Volume, Nm ³	0.029	0.022	0.018		
Formaldehyde	15	7	9.6	ND(1)	ND(1)
<u>75% of Full Load</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>		
Gas Sample Volume, Nm ³	0.0047	0.0047	0.0047		
Benzene, mg/m ³	ND(0.010)	ND(0.010)	ND(0.010)		ND(0.010)
Gas Sample Volume, Nm ³	0.023	0.023	0.023		
Formaldehyde	-- ^e	-- ^e	-- ^e	ND(1)	ND(1)
<u>50% of Full Load</u>	<u>Run 5</u>	<u>Run 6</u>	<u>Run 7</u>		
Gas Sample Volume, Nm ³	0.0047	0.0047	0.0047		
Benzene, 1 mg/m ³	ND(0.010)	ND(0.010)	ND(0.010)		ND(0.010)
Gas Sample Volume, Nm ³	-- ^f	0.022	0.020		
Formaldehyde	-- ^f	2.8	3.1	ND(1)	ND(1)

Table A-1 (Continued)

	<u>Mass Detected (μg)</u>			<u>Field Blank (μg)</u>	<u>Method (Reagent) Blank (μg)</u>
Natural Gas Firing					
<u>Volatile Organics</u>					
<u>100% of Full Load-East Stack</u>	<u>Run 1</u>	<u>Run 3</u>	<u>Run 5</u>		
Gas Sample Volume, Nm ³	0.024	0.024	0.026		
Formaldehyde	1.1	1.0	1.6	ND(1)	ND(1)
<u>100% of Full Load-West Stack</u>	<u>Run 2</u>	<u>Run 4</u>	<u>Run 6</u>		
Gas Sample Volume, Nm ³	0.024	0.023	0.023		
Formaldehyde	1.3	1.1	1.1	ND(1)	ND(1)
<u>75% of Full Load</u>	<u>Run 7</u>	<u>Run 8</u>	<u>Run 9</u>		
Gas Sample Volume, Nm ³	0.023	0.022	0.023		
Formaldehyde	10	6.8	7.7	ND(1)	ND(1)
<u>50% of Full Load</u>	<u>Run 10</u>	<u>Run 11</u>	<u>Run 12</u>		
Gas Sample Volume, Nm ³	0.020	0.021	0.021		
Formaldehyde	3.4	3.9	3.9	ND(1)	ND(1)

*100% load test conditions; neither a field blank nor a reagent blank analyses was performed for metals.

^bND indicates that the concentration is below the detection limit, which is shown in parenthesis.

^cSample was contaminated by KMnO_4 , according to the KVB Analect report.

^dNR indicates that the concentration is below the reporting limit, which is shown in parentheses.

^eAnalytical data could not be found in the laboratory reports under conditions at 75% of full load.

^fSample was not taken.

Appendix B
Individual Stream Concentrations

This appendix present the results from the Site 109 sampling event in late 1990 and early 1991. Tables B-1 and B-2 present the concentrations of the substances measured at Site 109 during residual oil firing and natural gas firing, respectively. The analytical methods used to determine these results are also given.

The concentrations were calculated from the raw analytical data presented in the KVB Analect report, which are shown in Appendix A. These concentrations were corrected for the reagent blank analysis, when appropriate. Section 3 presents details of which samples were corrected for the reagent blank analysis.

The "B" flag indicates that the blank measurement is equal to or greater than 50% of the uncorrected sample measurement. The "<" flag indicates that the concentration is below the detection (or reporting) limit. In this case, the concentration is presented as the detection (or reporting) limit.

Site 109 was sampled for chromium and nickel by two different methods--EPA Modified Method 5 (multi-metals sampling train) and CARB Method 425 for chromium and CARB Method 433 for nickel (individual metal sampling trains). The individual metal sampling train results are identified by Runs 3, 4, and 11.

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.087	0.057	0.038	
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.023	0.02	0.014	
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.025	0.023	0.019	
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.011	0.011	0.0066	
Benzene	Gas chromatography (GC)	ug/nm3	11	11	11	
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3				
Chromium, hexavalent	Spectrophotometry	ug/nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.034	0.021	0.018	
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.14	0.058	0.043	
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.24	0.15	0.15	
Formaldehyde	High performance liquid chromatography (HPLC)	ug/nm3	520	320	530	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3				
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	27	62	21	
Nickel	Atomic absorption spectrophotometry (AAS)	ug/nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.66	0.16	0.24	370
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3	0.11	0.042	0.044	
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3				
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/kg				
Beryllium	EPA method 6010	mg/kg				
Cadmium	EPA method 6010	mg/kg				
Chromium	EPA method 6010	mg/kg				
Copper	EPA method 6010	mg/kg				
Lead	EPA method 6010	mg/kg				
Manganese	EPA method 6010	mg/kg				
Mercury	EPA method 6010	ppm				
Nickel	EPA method 6010	mg/kg				
Selenium	EPA method 6010	ppm				

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emittid gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.013	0.0048	0.031	0.015
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.034	0.019	0.014	0.018
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0093	0.0085	0.0091	0.0056
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0051	0.0051	< 0.0024	< 0.0029
Benzene	Gas chromatography (GC)	ug/Nm3	11	11	< 11	< 11
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				
Chromium, hexavalent	Spectrophotometry	ug/Nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.015	0.0089	0.0091	0.0078
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.045	0.028	0.022	0.012
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.18	0.12	0.058	0.13
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3		130	150	
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3	22	25	20	22
Naphthalene	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3				
Phenanthrene	Atomic absorption spectrophotometry (AAS)	ug/Nm3				
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.19	0.1	0.06	0.066
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.039	0.019	0.031	0.007
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/kg				
Beryllium	EPA method 6010	mg/kg				
Cadmium	EPA method 6010	mg/kg				
Chromium	EPA method 6010	mg/kg				
Copper	EPA method 6010	mg/kg				
Lead	EPA method 6010	mg/kg				
Manganese	EPA method 6010	mg/kg				
Mercury	EPA method 6010	ppm				
Nickel	EPA method 6010	mg/kg				
Selenium	EPA method 6010	ppm				

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run 12
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.052	0.02		
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.021	0.0087		
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.013	0.0091		
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3				< 1
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.0064	< 0.0028		
Benzene	Gas chromatography (GC)	ug/Nm3	< 11	< 11		
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				< 0.5
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				2.5
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/Nm3			< 6	12
Chromium, hexavalent	Spectrophotometry	ug/Nm3			< 1.2	
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.013	0.012		14
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.053	0.022		
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.22	0.13		
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3				
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				49
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				43
Mercury	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/Nm3				< 0.3
Naphthalene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	31	36		
Nickel	Atomic absorption spectrophotometry (AAS)	ug/Nm3				
Phenanthrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.26	0.067	290	360
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/Nm3	0.054	0.026		
Selenium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				< 1
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/Nm3				270
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/kg				
Beryllium	EPA method 6010	mg/kg				
Cadmium	EPA method 6010	mg/kg				
Chromium	EPA method 6010	mg/kg				
Copper	EPA method 6010	mg/kg				
Lead	EPA method 6010	mg/kg				
Manganese	EPA method 6010	mg/kg				
Mercury	EPA method 6010	ppm				
Nickel	EPA method 6010	mg/kg				
Selenium	EPA method 6010	ppm				

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 13	Run 14	Run 15	Run 16
>>>> Emitted gas <<<<						
Acenaphthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Acenaphthylene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Arsenic	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	< 1.2	< 1		
Benz(a)anthracene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Benzene	Gas chromatography (GC)	ug/nm3				
Beryllium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 0.6	< 0.5		
Cadmium	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	6.6	1		
Chromium	Atomic absorption spectrophotometry, graphite furnace (GFAAS)	ug/nm3	16	7.8		
Chromium, hexavalent	Spectrophotometry	ug/nm3				
Chrysene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Copper	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	27	11		
Fluoranthene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Fluorene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Formaldehyde	High performance liquid chromatography (HPLC)	ug/nm3				
Lead	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 6	8.3		
Manganese	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3		83		
Mercury	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	< 0.3	6.4		
Naphthalene	Atomic absorption spectrophotometry, cold vapor (CVAAS)	ug/nm3				
Nickel	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Phenanthrene	Atomic absorption spectrophotometry (AAS)	ug/nm3	110	300		
Pyrene	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Selenium	Gas chromatography-mass spectroscopy (GC-MS)	ug/nm3				
Zinc	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	12	< 1		
	Inductively coupled argon plasma emission spectrophotometry (ICP-AES)	ug/nm3	1500	250		
>>>> Oil <<<<						
Arsenic	EPA method 6010	mg/kg			1.6	1.2
Beryllium	EPA method 6010	mg/kg	<	<	0.09	0.09
Cadmium	EPA method 6010	mg/kg	<	<	0.15	0.15
Chromium	EPA method 6010	mg/kg	<	<	0.18	0.18
Copper	EPA method 6010	mg/kg			0.25	0.12
Lead	EPA method 6010	mg/kg			0.87	1.9
Manganese	EPA method 6010	mg/kg	<	<	0.91	0.91
Mercury	EPA method 6010	ppm	<	<	1	1
Nickel	EPA method 6010	mg/kg			5.5	5.9
Selenium	EPA method 6010	ppm	<	<	5	5

Appendix B

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
Zinc	EPA method 6010	mg/kg				

Table 8-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
Zinc	EPA method 6010	mg/kg				

Table 8-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run 12
Zinc	EPA method 6010	mg/kg				

Table B-1 Site 109 Stream Concentrations During Oil-Fired Tests

Substance	Method	Units	Run 13	Run 14	Run 15	Run 16
Zinc	EPA method 6010	mg/kg			0.9	0.9

Table B-2 Site 109 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 1	Run 2	Run 3	Run 4
>>>> Emitted gas <<<< Formaldehyde	High performance liquid chromatography (HPLC)	ug/m ³	46	55	41	48

Table B-2 Site 109 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 5	Run 6	Run 7	Run 8
>>>> Emitted gas <<<<						
Formaldehyde	High performance liquid chromatography (HPLC)	ug/Nm3	63	47	440	300

Table B-2 Site 109 Stream Concentrations During Gas-Fired Tests

Substance	Method	Units	Run 9	Run 10	Run 11	Run 12
>>>> Emitted gas <<<< Formaldehyde	High performance liquid chromatography (HPLC)	ug/lm3	330	170	190	180

Appendix C

Detailed Sample Collection, Preparation, and Analysis Information

Table C-1

Reference Table for Sampling Methods - By Sample Stream

<u>Sampling Stream</u>	<u>Collection Method</u>	<u>Substance Measured</u>
Stack Gas	EPA Modified Method 5	Metals (including nickel and chromium)
	CARB Method 433	Nickel
	CARB Method 425	Total and Hexavalent Chromium
	CARB Method 410A	Benzene
	CARB Method 429	PAH
	CARB Method 430	Formaldehyde
Oil	Grab	Metals

Table C-2

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Inorganic Components in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>FCEM Target Elements by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Modified Method 5
Analysis by GFAAS	
Arsenic	EPA Method 7041
Chromium	EPA Method 7191
<u>FCEM Target Elements by Cold Vapor Atomic Absorption Spectrophotometry (CVAAS)</u>	
Preparation	
Acid Digestion for Filters	EPA Modified Method 5
Analysis by CVAAS	
Mercury	EPA Method 7470
<u>FCEM Target Elements by Inductively Coupled Argon Plasma Emissions Spectrophotometry (ICP-AES)</u>	
Preparation	
Acid Digestion for Filters	EPA Modified Method 5
Analysis by ICP-AES	EPA Method 6010
Beryllium	
Cadmium	
Copper	
Lead	
Manganese	
Nickel	
Selenium	
<u>FCEM Target Elements by Spectrophotometry</u>	
Preparation	
Extraction by Alkaline Solution	CARB Method 425
Analysis with Spectrophotometer	
Chromium, hexavalent	

Table C-3

**Summary of Preparation Procedures and Analytical
Methods Used to Measure Organic Compounds in the Flue Gas**

<u>Component</u>	<u>Method Reference</u>
<u>Benzene</u>	
Sample Collection	
Tedlar Bags	CARB Method 410A
Analysis by Gas Chromatography/Photo Ionization Detector (GC/PID)	CARB Method 410A
<u>Formaldehyde</u>	
Sample Collection	
DNPH Impinger	CARB Method 430
Analysis by High Performance Liquid Chromatography (HPLC)	CARB Method 430
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>	
Sample Collection	
Modified Method 5	CARB Method 429
Preparation	
Soxhlet Extraction	CARB Method 429
Analysis by Gas Chromatography/Mass Spectroscopy (GC/MS)	CARB Method 429
Naphthalene	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Chrysene	
Benz(a)anthracene	
Benzo(b)fluoranthene	
Benzo(k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-c,d)pyrene	
Dibenz(a,h)anthracene	
Benzo(g,h,i)perylene	

Table C-4

**Preparation Methods and Chemical Analysis
Methods Applied to Oil for Site 109**

<u>Component</u>	<u>Method Reference</u>
<u>FCEM Target Elements</u>	
Arsenic	EPA Method 6010, ICP-AES
Beryllium	EPA Method 6010, ICP-AES
Cadmium	EPA Method 6010, ICP-AES
Chloride	ASTM D808-87
Chromium	EPA Method 6010, ICP-AES
Copper	EPA Method 6010, ICP-AES
Lead	EPA Method 6010, ICP-AES
Manganese	EPA Method 6010, ICP-AES
Mercury	EPA Method 6010, ICP-AES
Nickel	EPA Method 6010, ICP-AES
Selenium	EPA Method 6010, ICP-AES

Appendix D
Process Stream Flow Rates

Table D-1
Process Stream Flow Rates, Stack Gas Characterization
Data, Unit Load, and the Isokinetic Rate

<u>Load</u>	<u>Stream</u>	<u>Component</u>	<u>Units of Measure</u>	<u>Run 12</u>	<u>Run 13</u>	<u>Run 14</u>	<u>Average</u>
<u>Residual Oil Firing</u> 100% of Full Load (222 MW)	Oil Stack Gas - Metals	Flow Rate	klb/hr	288,100	233,520	284,480	110 ^a
		Single-Stack Flow Rate ^b	dscfm ^c	926,000	752,000	914,000	269,000
		Total Flow Rate ^d	Nm ³ /hr ^e	691	703	700	864,000
		Temperature	°R	10,293	13.89	10,246	698
		Moisture	%	102.778	102.778	103.973	11.5
		Isokinetic Rate	%				103.2
	Stack Gas - Cr	Flow Rate	klb/hr	277,270	249,570	238,690	262,000
		Single-Stack Flow Rate ^b	dscfm ^c	892,000	802,000	768,000	821,000
		Total Flow Rate ^d	Nm ³ /hr ^e	684	700	700	695
		Temperature	°R	9,367	10,625	12,041	10.7
		Moisture	%	99.032	96.257	103.136	99.5
	Stack Gas - Ni	Flow Rate	klb/hr	277,270	249,570	238,690	262,000
		Single-Stack Flow Rate ^b	dscfm ^c	892,000	802,000	768,000	821,000
		Total Flow Rate ^d	Nm ³ /hr ^e	684	700	698	694
		Temperature	°R	11,632	10,391	8,001	10.0
		Moisture	%	107.104	97.804	100.029	101.6
	Stack Gas - PAH	Flow Rate	klb/hr	267,170	230,710	277,270	258,000
		Single-Stack Flow Rate ^b	dscfm ^c	860,000	742,000	892,000	831,000
		Total Flow Rate ^d	Nm ³ /hr ^e	683	696	686	688
		Temperature	°R	10,339	9,752	7,892	9.3
		Moisture	%	95.411	94.997	99.689	96.7
		Isokinetic Rate	%				

Table D-1 (Continued)

<u>Load</u>	<u>Stream</u>	<u>Component</u>	<u>Units of Measure</u>	<u>Run 8</u>	<u>Run 9</u>	<u>Run 10</u>	<u>Average</u>
75% of Full Load (159 MW)	Oil Stack Gas	Flow Rate	klb/hr				
		Single-Stack Flow Rate ^b	dscfm ^c	238,090	221,280	236,870	80 ^f
		Total Flow Rate ^d	Nm ³ /hr ^e	766,000	712,000	762,000	232,000
		Temperature	°R	670	685	674	747,000
		Moisture	%	4.043	5.94	3.897	676
		Isokinetic Rate	%	94.357	109.639	98.168	100.7
50% of Full Load (109 MW)	Oil Stack Gas	Flow Rate	klb/hr				
		Single-Stack Flow Rate ^b	dscfm ^c	185,560	176,080	170,280	57 ^a
		Total Flow Rate ^d	Nm ³ /hr ^e	596,000	566,000	548,000	177,000
		Temperature	°R	648	660	649	570,000
		Moisture	%	5.854	7.879	5.852	
		Isokinetic Rate	%	97.951	97.817	99.959	
Natural Gas Firing 100% of Full Load (222 MW)	Natural Gas Stack Gas	Flow Rate	MSCFH				
		Single-Stack Flow Rate ^b	dscfm ^c	267,170	230,71	277,270	1,985 ^a
		Total Flow Rate ^d	Nm ³ /hr ^e	860,000	742,000	892,000	258,000
		Single-Stack Flow Rate ^b	MSCFH				
		Total Flow Rate ^d	Nm ³ /hr ^e	185,560	176,08	170,280	1,365 ^a
75% of Full Load (159 MW)	Natural Gas Stack Gas	Single-Stack Flow Rate ^b	dscfm ^c	596,000	566,000	548,000	177,000
		Total Flow Rate ^d	Nm ³ /hr ^e				570,000
50% of Full Load (109 MW)	Natural Gas Stack Gas	Flow Rate	MSCFH				
		Single-Stack Flow Rate ^b	dscfm ^c	238,090	221,280	236,870	0.911 ^a
		Total Flow Rate ^d	Nm ³ /hr ^e	766,000	712,000	762,000	232,000
		Single-Stack Flow Rate ^b	MSCFH				
		Total Flow Rate ^d	Nm ³ /hr ^e				747,000

^a Fuel flow rates were presented as averages in the report.

^b This flow rate was measured in one of the stacks.

^c Standard conditions: 1 atm, 60° F.

^d The total-unit flow rate was estimated as two times the single-stack flow rate.

^e Normal conditions: 1 atm, 32° F.

^f Fuel flow rate was estimated from the oil flow rates at 100% and 50% of full load operating conditions.

Appendix E

Error Propagation for Emission Factors and Material Balance Closures

The text for Appendix E can be found in the Site 103 section. The computer-generated results from the emission factor and material balance calculations and error propagation analyses for Site 109 are included here.

Emission Factor Results

Oil Firing

100% of Full Load

Multi-Metal Sampling Train

Arsenic

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.098461	5.52E-01	3.07E-01	6.3E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Arsenic conc	uo/Nm3	1.2	BIAS	3.02E-01	9.15E-01	6.00E-01	-
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	9.43E-02	1.27E-06	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.74E-03	-9.51E-03	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Beryllium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.5492305	2.76E-01	1.54E-01	3.2E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Beryllium conc	uo/Nm3	.6	BIAS	7.54E-02	9.15E-01	3.00E-01	-
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	2.36E-02	6.36E-07	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	6.84E-04	-4.76E-03	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Cadmium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.112306	1.48E-01	6.88E+00	6.9E+00	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Cadmium conc	ug/Na3	3.4	PREC	4.65E+01	9.15E-01	1.29E+01	3
2) oas	Stack gas flow rate	Na3/hr	864000	PREC	7.57E-01	3.60E-06	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.20E-02	-2.69E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{obar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	10.98461	5.23E-01	9.60E+00	9.6E+00	4.30E+00	2.4E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium conc	ug/Na3	12	PREC	8.27E+01	9.15E-01	1.72E+01	3
2) oas	Stack gas flow rate	Na3/hr	864000	PREC	9.43E+00	1.27E-05	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.74E-01	-9.51E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{obar} =PRECISION INDEX OF THE MEAN. $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Copper

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	15.56153	7.41E-01	2.09E+01	2.1E+01	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Copper conc	uo/Nm3	17	PREC	4.19E+02	9.15E-01	3.87E+01	3
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	1.89E+01	1.80E-05	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	5.49E-01	-1.35E-01	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Lead

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	17.3923	1.23E+00	5.93E+01	5.9E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Lead conc	uo/Nm3	19	PREC	3.50E+03	9.15E-01	1.12E+02	3
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	2.36E+01	2.01E-05	4.18E+05	3
3) baconc	Lead conc	uo/Nm3	19	BIAS	8.38E-01	9.15E-01	1.00E+00	-
4) oil	Oil flow rate	Klb/hr	110	BIAS	6.86E-01	-1.51E-01	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Manganese

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	57.6692	2.75E+00	2.35E+02	2.4E+02	1.27E+01	1.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Manganese conc	ug/M ³	63	PREC	5.30E+04	9.15E-01	3.56E+02	2
2) gas	Stack gas flow rate	M ³ /hr	864000	PREC	2.27E+03	6.67E-05	1.24E+06	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	7.54E+00	-4.99E-01	5.50E+00	-

* PRECISION COMPONENT = $t \cdot s_{\bar{r}}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\bar{r}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE $s_{\bar{r}}$ = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Mercury

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.830768	1.08E-01	9.11E+00	9.1E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Mercury conc	ug/M ³	2	PREC	8.27E+01	9.15E-01	1.72E+01	3
2) gas	Stack gas flow rate	M ³ /hr	864000	PREC	2.62E-01	2.12E-06	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	7.60E-03	-1.59E-02	5.50E+00	-
4) baconc	Mercury conc	ug/M ³	2	BIAS	4.11E-03	9.15E-01	7.00E-02	-

* PRECISION COMPONENT = $t \cdot s_{\bar{r}}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\bar{r}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE $s_{\bar{r}}$ = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	237.9999	1.13E+01	3.03E+02	3.0E+02	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Nickel conc	ud/Nm3	260	PREC	8.74E+04	9.15E-01	5.59E+02	3
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	4.42E+03	2.75E-04	4.18E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	1.28E+02	-2.06E+00	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} =PRECISION INDEX OF THE MEAN, $S_D/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Selenium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.661536	2.80E-01	1.60E+01	1.6E+01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Selenium conc	ud/Nm3	4.000001	PREC	2.53E+02	9.15E-01	3.01E+01	3
2) gas	Stack gas flow rate	Nm3/hr	864000	PREC	1.05E+00	4.24E-06	4.18E+05	3
3) baconc	Selenium conc	ud/Nm3	4.000001	BIAS	4.83E-02	9.15E-01	2.40E-01	-
4) oil	Oil flow rate	Klb/hr	110	BIAS	3.04E-02	-3.17E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_D \cdot SIGMA_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{Dbar} \cdot SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{Dbar} =PRECISION INDEX OF THE MEAN, $S_D/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Individual Metal Sampling Trains

Chromium

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.568095	4.81E+00	1.86E+00	5.2E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chromium conc	uo/Nm3	11	BIAS	2.29E+01	8.70E-01	5.50E+00	-
2) gas	Stack gas flow rate	Nm3/hr	821000	PREC	3.44E+00	1.17E-05	2.76E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.08E-01	-8.28E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Chromium, hexavalent

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.913619	9.61E-01	3.71E-01	1.0E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Hex. chromium conc	uo/Nm3	2.2	BIAS	9.15E-01	8.70E-01	1.10E+00	-
2) gas	Stack gas flow rate	Nm3/hr	821000	PREC	1.38E-01	2.33E-06	2.76E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	8.30E-03	-1.66E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Nickel

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	461.0083	2.20E+01	7.62E+02	7.6E+02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Nickel conc	uo/N#3	530	PREC	5.72E+05	8.70E-01	1.51E+03	3
2) gas	Stack gas flow rate	N#3/hr	821000	PREC	8.00E+03	5.62E-04	2.76E+05	3
3) oil	Dil flow rate	Klb/hr	110	BIAS	4.82E+02	-3.99E+00	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(S_{00} \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix E

Benzene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.684637	4.86E+00	2.29E+00	5.4E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benzene conc	uo/M ₀ 3	11	BIAS	2.34E+01	8.80E-01	5.50E+00	-
2) oas	Stack gas flow rate	M ₀ 3/hr	831000	PREC	5.23E+00	1.17E-05	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.13E-01	-8.38E-02	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	404.9939	1.93E+01	2.07E+02	2.1E+02	3.18E+00	2.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	uo/M ₀ 3	460	PREC	3.77E+04	8.80E-01	3.82E+02	3
2) oas	Stack gas flow rate	M ₀ 3/hr	831000	PREC	5.00E+03	4.87E-04	2.51E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	3.72E+02	-3.51E+00	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Acenaphthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	5.370572E-02	2.56E-03	5.61E-02	5.6E-02	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthene conc	ug/M ³	6.100001E-02	PREC	2.99E-03	8.80E-01	1.08E-01	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	1.61E-04	6.46E-08	3.40E+05	3
3) oil	Dil flow rate	Klb/hr	110	BIAS	6.54E-06	-4.65E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Acenaphthylene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.672801E-02	7.97E-04	8.60E-03	8.6E-03	3.18E+00	2.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthylene conc	ug/M ³	.019	PREC	6.54E-05	8.80E-01	1.59E-02	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	8.54E-06	2.01E-08	2.51E+05	3
3) oil	Dil flow rate	Klb/hr	110	BIAS	6.35E-07	-1.45E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN. $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.936927E-02	9.22E-04	5.16E-03	5.2E-03	2.78E+00	3.6E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Anthracene conc	ug/M ³	.022	PREC	1.79E-05	8.80E-01	8.33E-03	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	8.71E-06	2.33E-08	2.19E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	8.51E-07	-1.68E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(S_{00} \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Benz(a)anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	8.804215E-03	4.19E-04	6.88E-03	6.9E-03	4.30E+00	2.4E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benz(a)anthracene conc	ug/M ³	.01	PREC	4.31E-05	8.80E-01	1.29E-02	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	4.32E-06	1.06E-08	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	1.76E-07	-7.62E-05	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(S_{00} \cdot SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER\ OF\ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** S_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Chrysene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	2.113012E-02	1.01E-03	2.03E-02	2.0E-02	4.30E+00	2.3E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chrysene conc	ug/Nm ³	.024	PREC	3.88E-04	8.80E-01	3.87E-02	3
2) gas	Stack gas flow rate	Nm ³ /hr	831000	PREC	2.49E-05	2.54E-08	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	1.01E-06	-1.83E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	7.483583E-02	3.56E-03	1.11E-01	1.1E-01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluoranthene conc	ug/Nm ³	.085	PREC	1.20E-02	8.80E-01	2.15E-01	3
2) gas	Stack gas flow rate	Nm ³ /hr	831000	PREC	3.12E-04	9.01E-08	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	1.27E-05	-6.48E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1584759	7.55E-03	1.16E-01	1.2E-01	4.30E+00	2.5E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluorene conc	ug/M ³	.18	PREC	1.20E-02	8.80E-01	2.15E-01	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	1.40E-03	1.91E-07	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	5.69E-05	-1.37E-03	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE S_{obar} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	32.5756	1.55E+00	4.87E+01	4.9E+01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Naphthalene conc	ug/M ³	37	PREC	2.32E+03	8.80E-01	9.47E+01	3
2) gas	Stack gas flow rate	M ³ /hr	831000	PREC	5.92E+01	3.92E-05	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.41E+00	-2.82E-01	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE S_{obar} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.325756	1.55E-02	5.96E-01	6.0E-01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Phenanthrene conc	ug/Mu3	.37	PREC	3.49E-01	8.80E-01	1.16E+00	3
2) gas	Stack gas flow rate	Mu3/hr	831000	PREC	5.92E-03	3.92E-07	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	2.41E-04	-2.82E-03	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{obars} + SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{obars} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_D \cdot t$ FOR PRECISION ERRORS

Pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	6.603162E-02	3.14E-03	8.46E-02	8.5E-02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Pyrene conc	ug/Mu3	.075	PREC	6.91E-03	8.80E-01	1.64E-01	3
2) gas	Stack gas flow rate	Mu3/hr	831000	PREC	2.43E-04	7.95E-08	3.40E+05	3
3) oil	Oil flow rate	Klb/hr	110	BIAS	9.89E-06	-5.72E-04	5.50E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_D)^2$ FOR BIAS ERRORS: $(t \cdot S_{obars} + SIGMA_D)^2$ FOR PRECISION ERRORS

-WHERE S_{obars} = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_D \cdot t$ FOR PRECISION ERRORS

75% of Full Load

Benzene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	11.97032	6.01E+00	1.20E+00	6.1E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benzene conc	uo/M ₀ 3	11	BIAS	3.58E+01	1.09E+00	5.50E+00	-
2) gas	Stack gas flow rate	M ₀ 3/hr	747000	PREC	1.44E+00	1.60E-05	1.30E+05	3
3) oil	Dil flow rate	Klb/hr	80	BIAS	3.25E-01	-1.43E-01	4.00E+00	-

* PRECISION COMPONENT = t*Srbar

** (B₀*SIGMA₀)² FOR BIAS ERRORS; (t*S₀bar*SIGMA₀)² FOR PRECISION ERRORS-WHERE S₀bar=PRECISION INDEX OF THE MEAN. S₀/(NUMBER OF SAMPLES)^{.5}

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B₀ FOR BIAS ERRORS; S₀*t FOR PRECISION ERRORS

Acenaphthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.155811E-02	1.50E-03	5.42E-02	5.4E-02	4.30E+00	2.0E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthene conc	ug/M ³	.029	PREC	2.92E-03	1.09E+00	8.61E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	9.98E-06	4.22E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.26E-06	-3.76E-04	4.00E+00	-
=====								
* PRECISION COMPONENT = t*Srbar								
** (S _D *SIGMA _D) ² FOR BIAS ERRORS: (t*S _o bar*SIGMA _D) ² FOR PRECISION ERRORS								
-WHERE S _o bar=PRECISION INDEX OF THE MEAN. S _D /(NUMBER OF SAMPLES) ^{.5}								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** S _D FOR BIAS ERRORS: S _D *t FOR PRECISION ERRORS								

Acenaphthylene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.741137E-02	8.29E-04	1.63E-02	1.6E-02	4.30E+00	2.0E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthylene conc	ug/M ³	.016	PREC	2.63E-04	1.09E+00	2.58E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	3.04E-06	2.33E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	6.87E-07	-2.07E-04	4.00E+00	-
=====								
* PRECISION COMPONENT = t*Srbar								
** (S _D *SIGMA _D) ² FOR BIAS ERRORS: (t*S _o bar*SIGMA _D) ² FOR PRECISION ERRORS								
-WHERE S _o bar=PRECISION INDEX OF THE MEAN. S _D /(NUMBER OF SAMPLES) ^{.5}								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** S _D FOR BIAS ERRORS: S _D *t FOR PRECISION ERRORS								

Anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	9.793895E-03	4.66E-04	1.09E-02	1.1E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Anthracene conc	ug/M ³	8.999999E-03	PREC	1.17E-04	1.09E+00	1.72E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	9.61E-07	1.31E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.18E-07	-1.17E-04	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$ ** $(B_0 \cdot \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{\bar{r}} \cdot \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Benz(a)anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.264632E-03	1.55E-04	8.12E-03	8.1E-03	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benz(a)anthracene conc	ug/M ³	.003	PREC	6.58E-05	1.09E+00	1.29E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	1.07E-07	4.37E-09	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.42E-08	-3.89E-05	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$ ** $(B_0 \cdot \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{\bar{r}} \cdot \text{SIGMA}_D)^2$ FOR PRECISION ERRORS-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $S_D / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_D \cdot t$ FOR PRECISION ERRORS

Chrysene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.197032E-02	5.70E-04	8.20E-03	8.2E-03	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chrysene conc	ug/M ³	.011	PREC	6.58E-05	1.09E+00	1.29E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	1.44E-06	1.60E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	3.25E-07	-1.43E-04	4.00E+00	-

* PRECISION COMPONENT = t*Srbar

** (Bo+SIGMA_D)^2 FOR BIAS ERRORS: (t*Sobar+SIGMA_D)^2 FOR PRECISION ERRORS

-WHERE Sobar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bo FOR BIAS ERRORS: Sp*t FOR PRECISION ERRORS

Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.155811E-02	1.50E-03	5.69E-02	5.7E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluoranthene conc	ug/M ³	.029	PREC	3.22E-03	1.09E+00	9.04E-02	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	9.98E-06	4.22E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.26E-06	-3.76E-04	4.00E+00	-

* PRECISION COMPONENT = t*Srbar

** (Bo+SIGMA_D)^2 FOR BIAS ERRORS: (t*Sobar+SIGMA_D)^2 FOR PRECISION ERRORS

-WHERE Sobar=PRECISION INDEX OF THE MEAN, Sp/(NUMBER OF SAMPLES)^.5

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** Bo FOR BIAS ERRORS: Sp*t FOR PRECISION ERRORS

Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1741137	8.29E-03	1.36E-01	1.4E-01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluorene conc	uo/Nm3	.16	PREC	1.83E-02	1.09E+00	2.15E-01	3
2) oas	Stack gas flow rate	Nm3/hr	747000	PREC	3.04E-04	2.33E-07	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	6.87E-05	-2.07E-03	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	32.64632	1.55E+00	1.92E+01	1.9E+01	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Naphthalene conc	uo/Nm3	30	PREC	3.58E+02	1.09E+00	3.01E+01	3
2) oas	Stack gas flow rate	Nm3/hr	747000	PREC	1.07E+01	4.37E-05	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.42E+00	-3.89E-01	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} =PRECISION INDEX OF THE MEAN, $S_0/(\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1414674	6.74E-03	2.98E-01	3.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Phenanthrene conc	uo/Na3	.13	PREC	8.84E-02	1.09E+00	4.73E-01	3
2) gas	Stack gas flow rate	Na3/hr	747000	PREC	2.01E-04	1.89E-07	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	4.54E-05	-1.68E-03	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

Pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.155811E-02	1.50E-03	6.50E-02	6.5E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Pyrene conc	uo/Na3	.029	PREC	4.21E-03	1.09E+00	1.03E-01	3
2) gas	Stack gas flow rate	Na3/hr	747000	PREC	9.98E-06	4.22E-08	1.30E+05	3
3) oil	Oil flow rate	Klb/hr	80	BIAS	2.26E-06	-3.76E-04	4.00E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS: $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS: $S_0 \cdot t$ FOR PRECISION ERRORS

50% of Full Load

Benzene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	12.81962	6.44E+00	1.36E+00	6.6E+00	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benzene conc	uo/Nm3	11	BIAS	4.11E+01	1.17E+00	5.50E+00	-
2) oas	Stack gas flow rate	Nm3/hr	570000	PREC	1.84E+00	2.25E-05	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	3.85E-01	-2.14E-01	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{obar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	163.1588	7.90E+00	1.55E+02	1.6E+02	1.27E+01	1.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	uo/Nm3	140	PREC	2.15E+04	1.17E+00	1.78E+02	2
2) oas	Stack gas flow rate	Nm3/hr	570000	PREC	2.60E+03	2.86E-04	3.09E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	6.24E+01	-2.72E+00	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{obar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS-WHERE S_{obar} =PRECISION INDEX OF THE MEAN, $S_0/(NUMBER OF SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Acenaphthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
factor	Emission Factor	lb/MMBTU	1.864672E-02	8.88E-04	9.57E-02	9.6E-02	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMap)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	emitted Acenaphthene	ug/m3	.016	PREC	9.13E-03	1.17E+00	1.42E-01	3
2) gas	stack gas	m3/hr	570000	PREC	2.38E-05	3.27E-08	2.58E+05	3
3) oil	oil FLOW RATE	lb/hr	57000	BIAS	7.88E-07	-3.12E-07	2.85E+03	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(Bp \cdot SIGMap)^2$ FOR BIAS ERRORS; $(t \cdot Spbar \cdot SIGMap)^2$ FOR PRECISION ERRORS

-WHERE $Spbar$ =PRECISION INDEX OF THE MEAN, $Sp/(NUMBER \ OF \ SAMPLES)^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

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

Acenaphthylene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	2.563924E-02	1.24E-03	2.91E-02	2.9E-02	4.30E+00	2.0E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Acenaphthylene conc	ug/M ³	.022	PREC	8.38E-04	1.17E+00	4.30E-02	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	7.37E-06	4.50E-08	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	1.54E-06	-4.28E-04	2.90E+00	-
=====								
* PRECISION COMPONENT = t*Srbar								
** (B ₀ *SIGMA _D) ² FOR BIAS ERRORS; (t*S ₀ bar*SIGMA _D) ² FOR PRECISION ERRORS								
-WHERE S ₀ bar=PRECISION INDEX OF THE MEAN. S ₀ /(NUMBER OF SAMPLES) ^{.5}								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** B ₀ FOR BIAS ERRORS; S ₀ *t FOR PRECISION ERRORS								

Anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.048878E-02	5.08E-04	1.04E-03	1.2E-03	2.78E+00	4.0E+00
=====								
INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Anthracene conc	ug/M ³	8.999999E-03	PREC	5.58E-07	1.17E+00	1.11E-03	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	5.14E-07	1.84E-08	6.75E+04	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	2.58E-07	-1.75E-04	2.90E+00	-
=====								
* PRECISION COMPONENT = t*Srbar								
** (B ₀ *SIGMA _D) ² FOR BIAS ERRORS; (t*S ₀ bar*SIGMA _D) ² FOR PRECISION ERRORS								
-WHERE S ₀ bar=PRECISION INDEX OF THE MEAN. S ₀ /(NUMBER OF SAMPLES) ^{.5}								
-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY								
*** B ₀ FOR BIAS ERRORS; S ₀ *t FOR PRECISION ERRORS								

Benz(a)anthracene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	4.661679E-03	5.18E-04	5.81E-03	5.8E-03	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Benz(a)anthracene conc	ug/M ³	.004	PREC	3.35E-05	1.17E+00	8.61E-03	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	2.44E-07	8.18E-09	1.05E+05	3
3) baconc	Benz(a)anthracene conc	ug/M ³	.004	BIAS	2.17E-07	1.17E+00	4.00E-04	-
4) oil	Oil flow rate	Klb/hr	57	BIAS	5.09E-08	-7.78E-05	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_p)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} + \text{SIGMA}_p)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Chrysene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	1.281962E-02	6.21E-04	8.79E-03	8.8E-03	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _p)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Chrysene conc	ug/M ³	.011	PREC	7.54E-05	1.17E+00	1.29E-02	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	1.84E-06	2.25E-08	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	3.85E-07	-2.14E-04	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$ ** $(B_0 + \text{SIGMA}_p)^2$ FOR BIAS ERRORS; $(t \cdot S_{rbar} + \text{SIGMA}_p)^2$ FOR PRECISION ERRORS-WHERE S_{rbar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluoranthene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.729343E-02	1.81E-03	3.50E-02	3.5E-02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluoranthene conc	ug/M ³	.032	PREC	1.21E-03	1.17E+00	5.16E-02	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	1.56E-05	6.54E-08	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	3.26E-06	-6.23E-04	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$
 ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS
 -WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY
 *** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Fluorene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1398504	6.77E-03	1.74E-01	1.7E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Fluorene conc	ug/M ³	.12	PREC	3.02E-02	1.17E+00	2.58E-01	3
2) gas	Stack gas flow rate	M ³ /hr	570000	PREC	2.19E-04	2.45E-07	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	4.58E-05	-2.33E-03	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$
 ** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS
 -WHERE S_{0bar} = PRECISION INDEX OF THE MEAN, $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$
 -THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY
 *** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Naphthalene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	25.63923	1.24E+00	5.72E+00	5.9E+00	3.18E+00	2.6E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Naphthalene conc	uo/M ₃	22	PREC	2.87E+01	1.17E+00	7.96E+00	3
2) oas	Stack gas flow rate	M ₃ /hr	570000	PREC	4.03E+00	4.50E-05	7.73E+04	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	1.54E+00	-4.28E-01	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$

** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{\bar{r}} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS

-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Phenanthrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	.1398504	6.77E-03	2.03E-01	2.0E-01	4.30E+00	2.0E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Phenanthrene conc	uo/M ₃	.12	PREC	4.11E-02	1.17E+00	3.01E-01	3
2) oas	Stack gas flow rate	M ₃ /hr	570000	PREC	2.19E-04	2.45E-07	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	4.58E-05	-2.33E-03	2.90E+00	-

* PRECISION COMPONENT = $t \cdot S_{\bar{r}}$

** $(B_0 + \text{SIGMA}_D)^2$ FOR BIAS ERRORS; $(t \cdot S_{\bar{r}} + \text{SIGMA}_D)^2$ FOR PRECISION ERRORS

-WHERE $S_{\bar{r}}$ = PRECISION INDEX OF THE MEAN, $S_p / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_p \cdot t$ FOR PRECISION ERRORS

Pyrene

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	3.496259E-02	1.69E-03	2.92E-02	2.9E-02	4.30E+00	2.1E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA _D)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Pyrene conc	ug/Nm ³	.03	PREC	8.38E-04	1.17E+00	4.30E-02	3
2) oas	Stack oas flow rate	Nm ³ /hr	570000	PREC	1.37E-05	6.13E-08	1.05E+05	3
3) oil	Oil flow rate	Klb/hr	57	BIAS	2.87E-06	-5.84E-04	2.90E+00	-

* PRECISION COMPONENT = t*Srbar

** (B_D*SIGMA_D)² FOR BIAS ERRORS; (t*S_obar*SIGMA_D)² FOR PRECISION ERRORS-WHERE S_obar=PRECISION INDEX OF THE MEAN, S_D/(NUMBER OF SAMPLES)^{.5}

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_D FOR BIAS ERRORS; S_o*t FOR PRECISION ERRORS

Natural Gas Firing

100% of Full Load

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	46.1057	2.19E+00	8.91E+00	9.2E+00	2.37E+00	6.8E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	ug/M ³	50	PREC	5.07E+01	9.22E-01	1.89E+01	6
2) oas	Stack gas flow rate	M ³ /hr	831000	PREC	2.87E+01	5.55E-05	1.67E+05	3
3) oil	Natural gas flow rate	kcfh	1985	BIAS	4.80E+00	-2.21E-02	9.90E+01	-

* PRECISION COMPONENT = $t \cdot s_{\text{bar}}$

** $(B_0 \cdot \text{SIGMA}_0)^2$ FOR BIAS ERRORS; $(t \cdot s_{\text{bar}} \cdot \text{SIGMA}_0)^2$ FOR PRECISION ERRORS

-WHERE s_{bar} = PRECISION INDEX OF THE MEAN. $s_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $s_0 \cdot t$ FOR PRECISION ERRORS

75% of Full Load

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	331.1226	1.57E+01	1.64E+02	1.6E+02	4.30E+00	2.2E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	ug/Mm3	360	PREC	2.56E+04	9.20E-01	3.01E+02	3
2) gas	Stack gas flow rate	Mm3/hr	570000	PREC	1.23E+03	5.81E-04	1.05E+05	3
3) oil	Natural gas flow rate	kcfh	1365	BIAS	2.47E+02	-2.31E-01	6.80E+01	-

PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 + SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} + SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

50% of Full Load

Formaldehyde

OUTPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ABSOLUTE BIAS COMPONENT	ABSOLUTE PRECISION COMPONENT*	ABSOLUTE TOTAL UNC	STUDENT t	DEGREES OF FREEDOM
emis	Emission factor	lb/MMBTU	325.1014	1.56E+01	3.58E+01	3.9E+01	2.78E+00	3.6E+00

INPUT VARIABLE NAME	DESCRIPTION	UNITS	AVERAGE VALUE	ERROR TYPE	ABSOLUTE CONTRIBUTION **	ABSOLUTE SENSITIVITY (SIGMA ₀)	ABSOLUTE ERROR OF INPUT***	NUMBER OF SAMPLES
1) baconc	Formaldehyde conc	ug/M ³	180	PREC	8.38E+02	1.81E+00	2.78E+01	3
2) gas	Stack gas flow rate	M ³ /hr	747000	PREC	4.41E+02	4.35E-04	8.36E+04	3
3) oil	Natural gas flow rate	kcfh	911	BIAS	2.44E+02	-3.40E-01	4.60E+01	-

* PRECISION COMPONENT = $t \cdot S_{rbar}$

** $(B_0 \cdot SIGMA_0)^2$ FOR BIAS ERRORS; $(t \cdot S_{0bar} \cdot SIGMA_0)^2$ FOR PRECISION ERRORS

-WHERE S_{0bar} = PRECISION INDEX OF THE MEAN. $S_0 / (\text{NUMBER OF SAMPLES})^{.5}$

-THE SQUARE ROOT OF THE SUM OF THE ABSOLUTE CONTRIBUTIONS IS EQUAL TO THE TOTAL UNCERTAINTY

*** B_0 FOR BIAS ERRORS; $S_0 \cdot t$ FOR PRECISION ERRORS

Appendix F
Quality Assurance/Quality Control Data