DEVELOPMENT OF FINE PARTICULATE EMISSION FACTORS AND SPECIATION PROFILES FOR OIL- AND GAS-FIRED COMBUSTION SYSTEMS

TOPICAL REPORT: TEST RESULTS FOR A DUAL FUEL-FIRED COMMERCIAL BOILER (SITE DELTA)

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TOPICAL REPORT: TEST RESULTS FOR A DUAL FUEL-FIRED COMMERCIAL BOILER (SITE DELTA)

Prepared by:
Stephanie Wien, Thomas P. McGrath, Glenn C. England, and M.C. Oliver Chang
GE Energy and Environmental Research Corporation
18 Mason
Irvine, CA 92618

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GE ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION PROJECT TEAM MEMBERS

Glenn England, Project Manager
Stephanie Wien, Project Engineer
Thomas P. McGrath, Senior Scientist
Dr. Oliver M.C. Chang, Project Engineer
Prof. Judith Chow, Desert Research Institute
Prof. John Watson, Desert Research Institute
Prof. Barbara Zielinska, Desert Research Institute
Prof. Lynn Hildemann, Stanford University
Prof. Philip Hopke, Clarkson University

AD HOC COMMITTEE MEMBERS

Dr. Karl Loos, Shell Global Solutions
Prof. James Schauer, University of Wisconsin-Madison
Dr. Praveen Amar, NESCAUM
Thomas Logan, U.S. EPA
Ron Myers, U.S. EPA
Karen Magliano, California Air Resources Board

PROJECT SPONSORS

Kathy Stirling, U.S. Department of Energy
Marla Mueller, California Energy Commission
Dr. Paul Drayton, Gas Research Institute
Karin Ritter, American Petroleum Institute
Barry Liebowitz, New York State Energy Research and Development Authority
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FOREWORD

In 1997, the United States Environmental Protection Agency (EPA) promulgated new National Ambient Air Quality Standards (NAAQS) for particulate matter, including for the first time particles with aerodynamic diameter smaller than 2.5 micrometers (PM2.5). PM2.5 in the atmosphere also contributes to reduced atmospheric visibility, which is the subject of existing rules for siting emission sources near Class 1 areas and new Regional Haze rules. There are few existing data regarding emissions and characteristics of fine aerosols from oil, gas and power generation industry combustion sources, and the information that is available is generally outdated and/or incomplete. Traditional stationary source air emission sampling methods tend to underestimate or overestimate the contribution of the source to ambient aerosols because they do not properly account for primary aerosol formation, which occurs after the gases leave the stack. These deficiencies in the current methods can have significant impacts on regulatory decision-making. The current program was jointly funded by the U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL), California Energy Commission (CEC), Gas Research Institute (GRI), New York State Energy Research and Development Authority (NYSERDA) and the American Petroleum Institute (API) to provide improved measurement methods and reliable source emissions data for use in assessing the contribution of oil, gas and power generation industry combustion sources to ambient PM2.5 concentrations. More accurate and complete emissions data generated using the methods developed in this program will enable more accurate source apportionment and source receptor analysis for PM2.5 NAAQS implementation and streamline the environmental assessment of oil, gas and power production facilities.

The goals of this program were to:

- Develop emission factors and speciation profiles for emissions of fine particulate matter, especially organic aerosols, for use in source receptor and source apportionment analysis;

- Identify and characterize PM2.5 precursor compound emissions that can be used in source receptor and source apportionment analysis; and

- Develop improved dilution sampling technology and test methods for PM2.5 mass emissions and speciation measurements, and compare results obtained with dilution and traditional stationary source sampling methods.

This report is part of a series of progress, topical and final reports presenting the findings of the program.

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EXECUTIVE SUMMARY

In 1997, the United States Environmental Protection Agency (EPA) promulgated new National Ambient Air Quality Standards (NAAQS) for particulate matter, including for the first time particles with aerodynamic diameter smaller than 2.5 micrometers (PM2.5). PM2.5 in the atmosphere also contributes to reduced atmospheric visibility, which is the subject of existing rules for siting emission sources near Class 1 areas and new Regional Haze rules. There are few existing data regarding emissions and characteristics of fine aerosols from oil, gas and power industry combustion sources, and the information that is available is generally outdated and/or incomplete. Traditional stationary source air emission sampling methods tend to underestimate or overestimate the contribution of the source to ambient aerosols because they do not properly account for primary aerosol formation, which occurs after the gases leave the stack. These deficiencies in the current methods can have significant impacts on regulatory decision-making. The current program was jointly funded by the U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL), California Energy Commission (CEC), Gas Research Institute (GRI), New York State Energy Research and Development Authority (NYSERDA) and the American Petroleum Institute (API) to provide improved measurement methods and reliable source emissions data for use in assessing the contribution of oil, gas and power generation industry combustion sources to ambient PM2.5 concentrations. More accurate and complete emissions data generated using the methods developed in this program will enable more accurate source apportionment and source receptor analysis for PM2.5 NAAQS implementation and streamline the environmental assessment of oil, gas and power production facilities.

The overall goals of this research program are to:

- Develop emission factors and speciation profiles for emissions of fine particulate matter, especially organic aerosols, for use in source receptor and source apportionment analysis;
- Identify and characterize PM2.5 precursor compound emissions that can be used in source receptor and source apportionment analysis; and
- Develop improved dilution sampling technology and test methods for PM2.5 mass emissions and speciation measurements, and compare results obtained with dilution and traditional stationary source sampling methods.

This report is part of a series of progress, topical and final reports presenting the findings of the research program. The research program includes field tests at several different types of gas- and oil-fired combustion sources, pilot-scale tests to help develop an improved measurement technology and methods, and technology transfer activities designed to disseminate results and incorporate scientific peer review into project plans and results. The reports present results and identify issues, procedures, methods and results that can be useful for future studies.

This report presents emissions data from testing performed on a dual fuel-fired commercial boiler with no pollution controls. Testing was performed first firing No. 6 oil, then firing natural gas. Average firing rates were 78 percent of capacity during No. 6 oil tests and 35 percent of capacity during natural gas tests. The flue gas temperature at the sampling location was approximately 415°F for oil and 314°F for natural gas firing during the tests.

Emission measurements at the stack were made using both a dilution sampler research test method for PM2.5 (primary emissions, secondary particle precursors, size-classified chemical composition, etc.) and the controlled condensation method for sulfur trioxide (SO_3) emissions, the principal component of condensable particulate matter from oil combustion. The dilution sampler method is attractive for PM2.5 characterization because the sample collection media and analysis methods are identical to those used for ambient air sampling. Thus, the results are directly comparable with ambient air data. Also, the dilution sampler method is believed to provide representative PM2.5 results including condensable aerosols. These test data along with a subsequent pilot scale evaluation of the test methods and additional testing of other combustion units will advance the understanding of differences noted between the dilution sampler and other measurement methods.

Emission factors for primary PM including: PM2.5 mass; elements; ionic species; and organic and elemental carbon are presented in Tables ES-1a and ES-1b. Emission factors are expressed in pounds of pollutant per million British thermal units of fuel fired (lb/MMBtu). Four test runs were performed for each fuel (four-hour runs for oil, six-hour runs for gas) on separate, consecutive days. As a measure of the bias, measurement precision, process variability, and other sources of uncertainty inherent in the results, the uncertainty (at the 95 percent confidence level) and 95 percent confidence upper bound are also presented. Tables ES-1a through ES-2b include only those substances that were detected in at least two of the four test runs, with an uncertainty of less than 100 percent and an average concentration greater than those measured in the dilution sampler blank and the field blank. Emission factors for particulate carbon and semivolatile organic species (SVOCs) are presented in Tables ES-2a and ES-2b. The carbon equivalent of the sum of speciated SVOCs reported in the tables is approximately 1.5 percent of the organic carbon for oil firing and 14 percent for natural gas firing (although results indicate the organic carbon results are probably biased high due to a significant measurement artifact). The carbon equivalent of the sum of speciated SVOCs that includes SVOCs that were detected but with uncertainties greater than 100 percent or high blanks is approximately 13 percent of the organic carbon for oil firing 27 percent for natural gas firing.

Table ES-1a. Summary of Primary PM Emission Factors (Delta – NG).

Substance		Emission Factor (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Elements (DS)	S	5.0E-5	B	69	7.6E-5	4
	Si	7.0E-6	B	49	9.7E-6	4
	Fe	5.1E-6	B	75	8.0E-6	4
	Zn	1.9E-6	B	49	2.7E-6	4
	K	1.8E-6	B	56	2.6E-6	4
	Mn	9.4E-8	B	61	1.4E-7	4
	Br	7.2E-8	B	71	1.1E-7	4
Ions (DS)	SO4=	1.2E-4	B	99	2.0E-4	3
	NH4+	3.1E-5	B	99	5.2E-5	3
	Soluble Na	1.7E-6	B	67	2.6E-6	3

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank and/or Field Blank.

DS - Dilution Sampler

Table ES-1b. Summary of Primary PM Emission Factors (Delta – Oil).

Substance		Emission Factor (lb/MMBtu)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Particulate Mass	PM2.5 mass (DS)	1.6E-2	40	2.1E-2	4
	SO3 (CCT)	2.1E-2	43	2.8E-2	4
Elements (DS)	S	1.2E-3	30	1.5E-3	4
	Ni	3.4E-4	20	4.0E-4	4
	Si	2.1E-4	18	2.5E-4	4
	Zn	1.8E-4	45	2.5E-4	4
	Fe	1.6E-4	24	2.0E-4	4
	Ca	1.5E-4	30	1.9E-4	4
	Al	7.8E-5	18	9.1E-5	4
	V	5.5E-5	26	6.7E-5	4
	Co	2.1E-5	21	2.5E-5	4
	K	1.8E-5	35	2.3E-5	4
	P	1.7E-5	97	2.9E-5	4
	La	1.6E-5	20	1.9E-5	4
	Sb	1.4E-5	25	1.7E-5	4
	Cu	1.1E-5	40	1.5E-5	4
	Pb	9.7E-6	44	1.3E-5	4
	Ti	7.0E-6	22	8.4E-6	4
	Mo	5.4E-6	49	7.4E-6	4
	Ba	4.7E-6	45	6.4E-6	4
	Sn	2.7E-6	53	3.8E-6	4
	Cr	2.5E-6	29	3.2E-6	4
	Mn	1.9E-6	23	2.3E-6	4
	Sr	1.1E-6	22	1.3E-6	4
	Ga	8.2E-7	46	1.1E-6	4
	Zr	2.5E-7	25	3.0E-7	4
	Y	< 1.4E-7	53	1.9E-7	3
Ions (DS)	Cl-	1.7E-5 B	36	2.2E-5	4
	SO4=	6.2E-3	48	8.5E-3	4
	NH4+	3.3E-4 B	39	4.4E-4	4
	Soluble Na	1.7E-5 B	65	2.7E-5	4

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank, and/or Field Blank.

CCT - Controlled Condensation Train

DS - Dilution Sampler

In addition to inorganic and organic primary PM species, the tests measured a variety of secondary PM precursors including volatile organic compounds, sulfur dioxide, ammonia, and aldehydes, such as formaldehyde and acetaldehyde.

Substances of interest not present above the minimum detection limit for these tests are listed in Tables ES-3a and ES-3b.

Table ES-2a. Summary of Particulate Carbon and SVOCs Emission Factors (Delta – NG).

Substance	Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Semi-Volatile Organic Compounds					
1,3+1,6+1,7-dimethylnaphthalene	2.5E-5	B	73	3.8E-5	4
2-methylnaphthalene	7.7E-6	B	68	1.2E-5	4
1-methylnaphthalene	4.4E-6	B	68	6.6E-6	4
2,6+2,7-dimethylnaphthalene	4.3E-6	B	73	6.6E-6	4
1+2-ethylnaphthalene	3.1E-6	B	95	5.3E-6	4
A-trimethylnaphthalene	2.0E-6	B	86	3.4E-6	4
1,4+1,5+2,3-dimethylnaphthalene	2.0E-6	B	84	3.3E-6	4
C-trimethylnaphthalene	1.9E-6	B	98	3.2E-6	4
B-trimethylnaphthalene	1.7E-6	B	92	2.8E-6	4
1,2-dimethylnaphthalene	1.1E-6	B	75	1.7E-6	4
2,3,5+I-trimethylnaphthalene	1.0E-6	B	87	1.7E-6	4
F-trimethylnaphthalene	8.8E-7	B	94	1.5E-6	4
Biphenyl	4.0E-7	B	62	6.0E-7	4

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions. 0.0000552

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Table ES-2b. Summary of Particulate Carbon and SVOCs Emission Factors (Delta – Oil).

Substance		Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Organic Carbon (OC) **		7.2E-4	B	40	9.5E-4	4
Elemental Carbon		6.7E-4		63	9.8E-4	4
Total Carbon*		1.4E-3		32	1.7E-3	4
Semi-Volatile Organic Compounds						
A-trimethylnaphthalene		2.2E-6	B	92	3.9E-6	4
Phenanthrene		1.8E-6		66	2.7E-6	4
2,3,5+I-trimethylnaphthalene		1.1E-6	B	99	2.1E-6	4
B-MePy/MeFl		9.7E-7		80	1.6E-6	4
9-fluorenone		9.0E-7	B	41	1.2E-6	4
F-trimethylnaphthalene		8.9E-7	B	76	1.4E-6	4
Fluoranthene		7.0E-7		81	1.1E-6	4
Dibenzofuran		4.8E-7	B	51	6.8E-7	4
Anthrone		4.5E-7		84	7.3E-7	4
Anthraquinone		4.1E-7		83	6.6E-7	4
C-MePy/MeFl		3.5E-7		89	5.8E-7	4
2,4,5-trimethylnaphthalene		3.2E-7	B	90	5.3E-7	4
Benzo(a)pyrene	<	1.2E-7	B	99	2.3E-7	3
Fluorene	<	5.8E-7		56	7.8E-7	2
Backup Filter OC ***		1.2E-4	B	57	1.8E-4	4

* TC Average calculated as average of TC runs, not OC Average + EC Average.

** OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote *** and Sections 6 & 7 for further discussion.

*** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion. Note, Dilution System Blank > Sample Average; it is likely the reporte emission factor value is not representative of actual emissions. Data users should exercise appropriate caution

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Table ES-3a. Substances of Interest Not Detected in Stack Emissions from Site Delta (NG).

Inorganic

- Ag
- Au
- Ba
- Cd
- Ga
- Hg
- In
- La
- Mo
- P
- Pd
- Rb
- Sb
- Se
- Sn
- Tl
- U
- Y
- Zr

Carbonyl

- Acrolein
- Propionaldehyde
- Crotonaldehyde
- Butyraldehyde
- Hexanaldehyde

VOC (>C2)

- F 114
- 1-butene&i-butene
- 1 & 2-butyne
- Acetonitrile
- tert-butanol
- 2-methylpropanal
- Methacrolein

VOC (>C2)

- 3-methyl-1-pentene
- Butanal
- Butanone
- 2,2-dimethylpentane
- Mechloroform
- 3,3-dimethylheptane
- n-butylbenzene
- 1,3-dimethyl-4-ethylbenzene
- 2-methylindan

VOC (>C7)

- 2-heptanone
- alpha-Pinene
- beta-pinene
- 2-pentylfuran
- t-butylbenzene
- 4-methylstyrene
- Isobutylbenzene
- Sec-butylbenzene
- 1,2,3-trimethylbenzene
- Indene
- o-isopropyltoluene
- o-methylphenol
- m-tolualdehyde
- Butylbenzene
- 1,2-diethylbenzene
- 2-n-propyltoluene
- 4-tert-butyltoluene
- 2-methylbenzofuran
- 5-isopropyl-m-xylene
- 1,3-diisopropylbenzene
- Pentylbenzene
- 1,2,3,4-tetrahydronaphthalene
- 1,2-dihydronaphthalene
- 1,4-diisopropylbenzene

VOC (>C7)

- C-dimethylindane
- 2-decanone
- Biphenyl
- 1+2-ethylnaphthalene
- Acenaphthylene
- 1,2-dimethylnaphthalene
- Acenaphthene
- Fluorene
- Propylene glycol
- hexyl acetate
- 2-butoxyethyl acetate
- Benzoic acid
- 2-(2-butoxyethoxy) ethanol
- Hexadecanoic acid
- Pentamethylbenzene

SVOC

- 1,4,5-trimethylnaphthalene
- B-methylfluorene
- Acenaphthenequinone
- Perinaphthenone
- B-methylphenanthrene
- 2,3-Benzofluorene
- 1,7-dimethylphenanthrene
- Retene
- 1-MeFl+C-MePy/Fl
- Benzo(c)phenanthrene
- Benz(a)anthracene-7,12-dionene
- 1,4-chrysenequinone
- Benzo(e)pyrene
- Perylene
- Indeno[123-cd]pyrene
- Benzo(ghi)perylene
- Dibenzo(ah+ac)anthracene
- Coronene

Table ES-3b. Substances of Interest Not Detected in Stack Emissions from Site Delta (Oil).

Inorganic	VOC (>C2)	VOC (>C7)
Ag	2-methylindan	C-dimethylindane
Au	Methacrolein	2-decanone
Br	3-methyl-1-pentene	Dodecene
Cd	Butanal	Pentamethylbenzene
Cl	Butanone	Acenaphthylene
Hg	2,2-dimethylpentane	Acenaphthene
In		Fluorene
Na	VOC (>C7)	propylene glycol
Pd	Heptanal	hexyl acetate
Rb	alpha-Pinene	2-butoxyethyl acetate
U	beta-pinene	benzoic acid
Nitrate	2-pentylfuran	2-(2-butoxyethoxy) ethanol
	t-butylbenzene	hexadecanoic acid
Carbonyl	Isobutylbenzene	
Acrolein	Sec-butylbenzene	SVOC
Propionaldehyde	1,2,3-trimethylbenzene	B-methylfluorene
Crotonaldehyde	Indene	Perinaphthenone
Methacrolein	o-isopropyltoluene	2,3-Benzofluorene
Butyraldehyde	o-methylphenol	9-methylanthracene
	m-tolualdehyde	Retene
VOC (>C2)	Butylbenzene	1-MeFl+C-MePy/Fl
F 114	1,2-diethylbenzene	Benz(a)anthracene-7,12-dionene
1-butene&i-butene	4-tert-butyltoluene	1,4-chrysenequinone
1 & 2-butyne	1-undecene	Benzo(e)pyrene
Acetonitrile	2-methylbenzofuran	Perylene
tert-butanol	5-isopropyl-m-xylene	Indeno[123-cd]pyrene
2-methylpropanal	Isoamylbenzene	Benzo(ghi)perylene
Mechloroform	Pentylbenzene	Dibenzo(ah+ac)anthracene
2-methyloctane	1,2,3,4-tetrahydronaphthalene	Coronene
n-butylbenzene	1,2-dihydronaphthalene	
1,3-dimethyl-4-ethylbenzene	1,4-diisopropylbenzene	

The primary PM results presented in Tables ES-1a and ES-1b and particulate carbon results may be expressed as a PM2.5 speciation profile, which is the mass fraction of each species contributing to the total PM2.5 mass. The speciation profile is presented in Figure ES-1. The profile includes all species that were detected and includes, in addition to those in Tables ES-1 species with uncertainties greater than 100 percent or high blanks. A scaling factor was applied to organic carbon (for H and O in SVOCs) and common oxide states were assumed for other elements to determine mass emission rates.

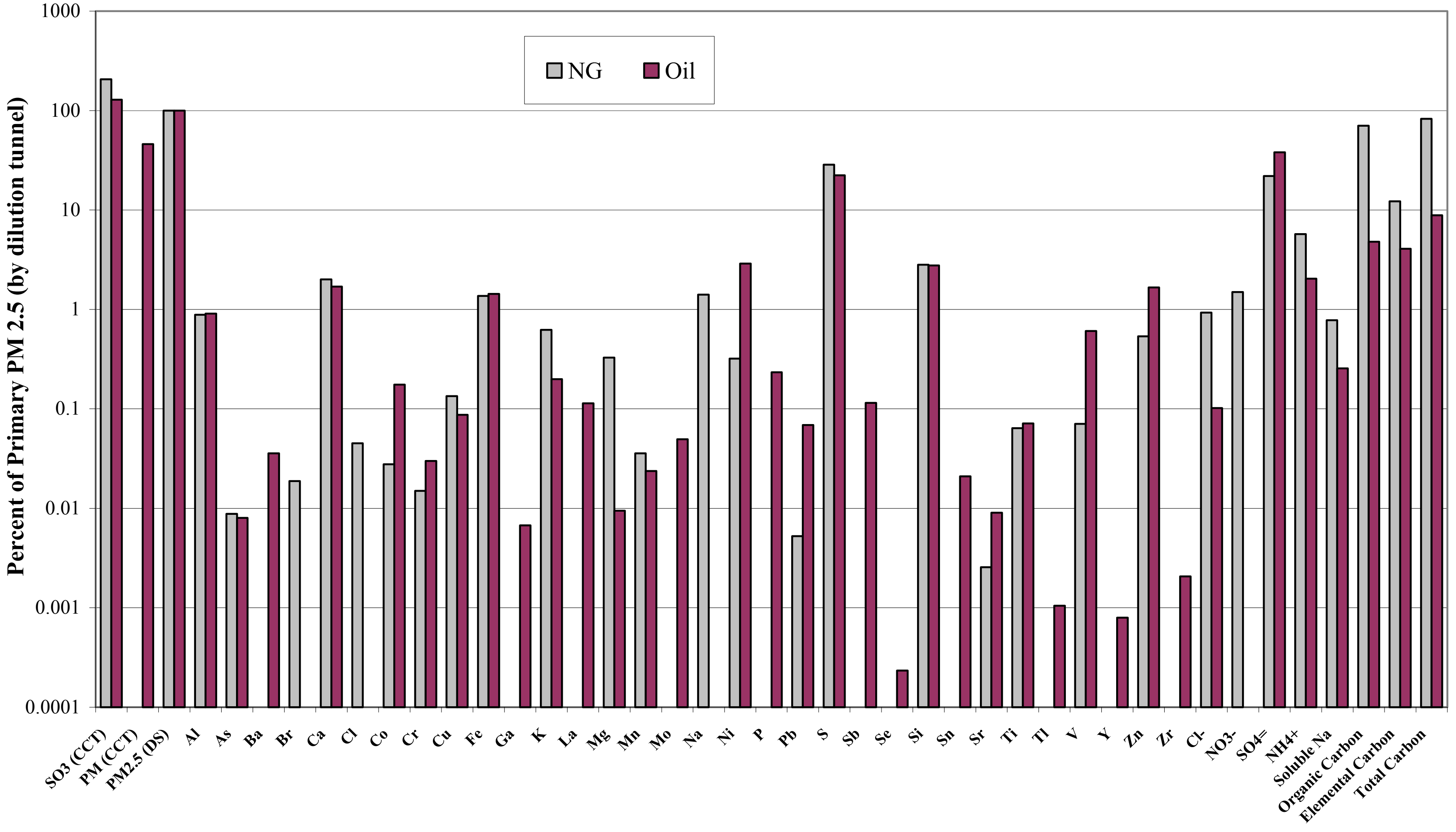

Figure ES-1. Speciation Profile for Primary PM Emissions from Site Delta.

The main findings of these tests are:

- PM mass emissions from the boiler during gas firing were low, consistent with levels expected for gaseous fuel combustion, but still higher than any previously tested gas-fired sources in the current program. The elevated PM mass emissions during gas combustion may be due to shedding of oil ash deposited on the boiler gas-side surfaces during oil-fired operation, because gas-fired testing was performed only a few days after the seasonal switch from oil firing to gas firing. This residue also may have biased other natural gas-fired emissions data. The dilution sampler apparatus was cleaned in the field between tests, but the field conditions were not ideal, creating the possibility for residual contamination in the sampler from the previous oil-fired tests.

- PM2.5 emissions from the boiler when firing No. 6 oil were more than an order of magnitude higher when firing natural gas. This is attributed to the elevated sulfur and ash content of the oil compared to natural gas.

- Two methods for determining the average emission factor for primary PM mass from oil firing gave results that corresponded relatively well: 0.016 lb/MMBtu using the dilution sampler; and 0.033 lb/MMBtu using a controlled condensation train. Both results include filterable and condensable PM. The dilution sampler result is believed to be the best representation of primary PM2.5 emissions to the atmosphere. The difference is attributed mainly to reduced condensation of sulfuric acid in the dilution sampler, which simulates the stack plume conditions driving condensation more accurately than the controlled condensation train.

- Quantified chemical species accounted for 128 percent of the measured PM2.5 mass from gas firing and 64 percent from oil firing (applying an organic carbon scaling factor and assuming common oxide states for other elements).

- Organic and elemental carbon comprise approximately 67 percent of the sum of species (measured by the dilution sampler) from gas firing, but only 15 percent of the sum of species from oil firing. Organic carbon results are probably biased high due to a significant measurement artifact; this artifact is more pronounced for the natural gas-fired tests.

- For oil firing, the predominant component of the PM2.5 (measured by the dilution sampler) is sulfur (60 percent of the sum of species as sulfate), reflecting the higher sulfur content of No. 6 oil compared to natural gas. Calcium, iron, nickel, silica, zinc and vanadium also are elevated in the oil combustion emissions, reflecting the ash content of the fuel.

- Most organic species were not detected at levels significantly above background levels in the ambient air or blanks.

- Particle size distribution measurements using a modified micro-orifice uniform deposit impactor determined that most of the particles were in the condensation mode during natural gas combustion, with an average of 77 percent of the mass in the fraction less than 0.32 micrometers. During oil combustion, an average of 76 percent of PM2.5 was in the size range less than 0.32 micrometers in aerodynamic diameter, very similar to the natural gas results.

Section 1
PROJECT DESCRIPTION

PROJECT OVERVIEW

In 1997, the United States Environmental Protection Agency (EPA) promulgated new National Ambient Air Quality Standards (NAAQS) for particulate matter, including for the first time particles with aerodynamic diameter smaller than 2.5 micrometers (PM2.5). PM2.5 in the atmosphere also contributes to reduced atmospheric visibility, which is the subject of existing rules for siting emission sources near Class 1 areas and new Regional Haze rules. There are few existing data regarding emissions and characteristics of fine aerosols from oil, gas and power industry combustion sources, and the information that is available is generally outdated and/or incomplete. Traditional stationary source air emission sampling methods tend to underestimate or overestimate the contribution of the source to ambient aerosols because they do not properly account for primary aerosol formation, which occurs after the gases leave the stack. Primary aerosol includes both filterable particles that are solid or liquid aerosols at stack temperature plus those that form as the stack gases cool through mixing and dilution processes in the plume downwind of the source. These deficiencies in the current methods can have significant impacts on regulatory decision-making. PM2.5 measurement issues were extensively reviewed by the American Petroleum Institute (API) (England et al., 1997), which concluded that dilution sampling techniques are more appropriate for obtaining a representative sample from combustion systems. These techniques have been widely used in research studies (e.g., Hildemann et al., 1994; McDonald et al., 1998), using clean ambient air to dilute the stack gas sample and providing 80-90 seconds residence time for aerosol formation prior to sample collection and analysis. More accurate and complete emissions data generated using the methods developed in this program will enable more accurate source-receptor and source apportionment analysis for PM2.5 NAAQS implementation and streamline the environmental assessment of oil, gas and power production facilities.

Dilution sampling was used to PM data from a dual fuel-fired (natural gas and No. 6 fuel oil) industrial package boiler that generates hot water at Site Delta on March 22 – 28, 2002 (No. 6 fuel oil operation) and April 2 – 8, 2002 (natural gas operation), along with emissions data obtained simultaneously using traditional hot filter/iced impinger methods. The U.S. Department of Energy (DOE), California Energy Commission (CEC), Gas Research Institute (GRI), New York State Energy Research and Development Authority (NYSERDA) and the American Petroleum Institute (API) jointly funded the tests. This test program is designed to provide reliable source emissions data for use in assessing the contribution of oil, gas and power generation industry combustion sources to ambient PM2.5 concentrations.

The goals of this program were to:

- Develop emission factors and speciation profiles for emissions of fine particulate matter, especially organic aerosols, for use in source receptor and source apportionment analysis;
- Identify and characterize PM2.5 precursor compound emissions that can be used in source receptor and source apportionment analysis; and
- Develop improved dilution sampling technology and test methods for PM2.5 mass emissions and speciation measurements, and compare results obtained with dilution and traditional stationary source sampling methods.

It should be noted that the project team chose to complete the industrial boiler tests in advance of a pilot scale study of the dilution sampler test method to address a compelling need for detailed data on fine and ultrafine particulate emissions. The pilot-scale study is evaluating dilution ratio and residence time design criteria established by Hildemann et al. (1989) as part of the development of a more compact and field portable sampler that gives comparable results. A dilution sampler based on the original Hildemann design was used for this test.

PROJECT OBJECTIVES

The specific objectives of this test were to:

Primary Objectives

- Develop emission factors and chemical speciation profiles for organic aerosols and PM2.5 mass;
- Characterize sulfate ($SO_4^=$), nitrate (NO_3^-), ammonium (NH_4^+), inorganic elements, elemental carbon (EC) and organic carbon (OC) in PM collected on filter media in the dilution sampler;

- Determine sulfur trioxide (SO_3) emissions using the controlled condensation method and compare to sulfate emissions measured using the dilution sampler;
- Characterize key secondary particle precursors in stack gas samples: volatile and semivolatile organic compounds (VOC and SVOC, respectively) with carbon number of 2 and above; sulfur dioxide (SO_2); ammonia (NH_3) and oxides of nitrogen (NO_x);
- Determine the fraction and size distribution of PM2.5 mass comprised by ultrafine (smaller than 0.3 micrometers (μm)) particles;
- Document the relevant process design characteristics and operating conditions during the test;
- Identify issues associated with PM measurement from sources with relatively dilute exhaust streams; and
- Compare emission factors with similar emission factors currently available.

Secondary Objectives

- Qualitatively determine total FPM emissions.

TEST OVERVIEW

The scope of testing is summarized in Table 1-1. The emissions testing included simultaneous collection and analysis of both undiluted exhaust gas and diluted exhaust gas samples. All emission samples were collected from an exhaust duct common to three boilers at the facility (only one boiler was in operation during these tests). The samples were analyzed for the compounds listed in Table 1-2. Process data and fuel gas samples were collected during the tests to document operating conditions.

Table 1-1. Overview of Sampling and Monitoring Scope.

	Sampling Location Number of Samples		
Sampling Procedure (Analytes)	Fuel Header	Exhaust Duct	Ambient Air (Combustion Inlet)
CCT (SO_3, SO_2)	--	8	--
Dilution sampler:			
Teflon® filter (mass, elements)	--	8	1
Quartz filter (ions, OC/EC)	--	8	1
K_2CO_3-impregnated cellulose fiber filter (SO_2)	--	8	1
Citric acid-impregnated cellulose fiber filter (NH_3)	--	8	1
TIGF/PUF/XAD-4 (SVOCs)	--	8	1
Tenax (VOCs: C_7+)	--	8	1
Stainless steel canisters (VOCs: C2-C10)	--	8	1
DNPH-coated silica gel cartridges (carbonyls)	--	8	1
MOUDI (ultrafine PM mass size distribution, elements)	--	8	(b)
Portable Analyzers (SO_2, NO_x, CO, CO_2, O_2)	--	8 (a)	--
Grab Sample - Fuel Oil	4	--	--
Grab Sample - Natural Gas	4	--	--

TIGF - Teflon®-impregnated glass fiber filter
PUF - polyurethane foam
XAD-4 - Amberlite® sorbent resin
DNPH – dinitrophenylhydrazine
MOUDI – micro-orifice uniform deposit impactor

a. Concentrations monitored for duration of all 8 test runs
b. MOUDI sample not collected during ambient air sampling.

Table 1-2. Summary of Exhaust Gas Analytical Targets.

Analytes	Undiluted Exhaust Gas Samples				Dilution Sampler								
	Coil	Quartz filter	Imp.	Gases	Quartz filter	TIGF/PUF/ XAD	TMF	Tenax	SS cans	DNPH cartridges	K_2CO_3 filter	Citric acid filter	MOUDI
PM2.5 mass		X (a)					X						
Ultrafine PM PSD													X
SO3/Sulfate		X (b)			X								
Chloride					X								
Ammonium					X								
Nitrate					X								
Elements							X						X
Organic carbon					X								
Elemental carbon					X								
Semivolatile organic compounds						X							
Volatile organic compounds*								X					
Volatile organic compounds**									X				
Aldehydes										X			
Ammonia (gaseous)												X	
NO_x				X									
SO_2			X	X							X		
CO				X									
O_2				X									
CO_2				X									
Moisture or relative humidity			X										
Velocity				X									
Temperature				X									

TMF - Teflon® membrane filter
TIGF - Teflon®-impregnated glass fiber filter
DNPH – dinitrophenylhydrazine
SS cans – stainless steel canisters
Imp. – iced impinger train
*Carbon number of 7 or greater
**Carbon number of 2 to 10
a. oil fired tests only; total PM measured.
b. Goksoyr-Ross condenser/frit assembly.

Source Level (Undiluted Exhaust Gas) Samples

A controlled condensation train (CCT) was used to collect samples for SO_3 and SO_2 analyses. PM collected on the CCT filter was measured for the oil-fired tests, but not for the natural gas fired tests. Portable electrochemical gas analyzers were used to measure oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), NO_x, and SO_2.

Diluted Exhaust Gas Samples

Dilution sampling was used to characterize PM2.5 including aerosols formed in the near-field plume. The dilution sampler extracted a sample stream from the stack into a mixing chamber, where it was diluted with purified ambient air approximately 31:1 during natural gas operation and 44:1 during No. 6 oil firing. Because PM2.5 behaves aerodynamically approximately like a gas at typical stack conditions, the samples were extracted nonisokinetically. A slipstream of the mixed and diluted sample was extracted into a residence time chamber where it was aged for approximately 70 seconds to allow time for low-concentration aerosols, especially organics, to condense and grow. The diluted and aged sample then passed through cyclone separators sized to remove particles larger than 2.5 µm, after which samples were collected on various media: high-purity quartz filter for ions and carbon speciation, Teflon® membrane filters (TMF) for PM2.5 mass and elements, potassium carbonate (K_2CO_3)-impregnated cellulose fiber filters for SO_2, citric acid-impregnated cellulose fiber filters for ammonia, Teflon®-impregnated glass fiber (TIGF) filters for particle phase SVOCs, a polyurethane foam (PUF)/Amberlite® sorbent resin (XAD-4)/PUF cartridge for gas phase SVOCs, Tenax tubes for VOCs with a carbon number greater than seven, stainless steel canisters for VOCs with a carbon number greater than two, dinitrophenylhydrazine (DNPH)-coated silica gel cartridges for carbonyls (aldehydes), and micro-orifice uniform deposit impactors (MOUDI) for ultrafine PM mass, size distribution, and elements. Four samples were collected on four separate test days while the boiler was firing No. 6 fuel oil and four samples were collected on four separate test days while the boiler was firing natural gas.

An ambient air sample was collected to establish background concentrations of measured substances. The same sampling and analysis procedures used for the dilution sampler were applied for collecting ambient air samples with the exception that the MOUDI sampling and analysis were not performed.

Process Monitoring

Process parameters periodically recorded (every 20 – 30 minutes) during the sample collection were heat rate; fuel oil pressure; feed water inlet temperature, pressure, and flow rate; hot water outlet temperature; windbox pressure; fan and feed water pump electrical current; and flue gas outlet temperature and oxygen.

Process Samples

A sample of the fuel oil burned in the boiler was collected on each day of source testing and analyzed for sulfur content, ash, moisture, heating value, viscosity, API gravity, asphaltenes, ash elemental composition, mercury, and carbon, hydrogen, oxygen, and nitrogen. A sample of the natural gas burned in the boiler was collected on each day of source testing and analyzed for sulfur content, heating value, and carbon, hydrogen, oxygen, and nitrogen.

KEY PERSONNEL

GE Energy and Environmental Research Corporation (GE EER) had overall responsibility for the test program. Key personnel and managers involved in the tests were:

- Glenn England (GE EER) – Program Manager (949) 859-8851 ext. 136
- Stephanie Wien (GE EER) – Project Engineer (949) 859-8851 ext. 155
- Oliver Chang (GE EER) – QA Coordinator (949) 859-8851 ext. 132
- Dave Ladd and Neal Conroy (GE Mostardi Platt (GE MP) – Field Team Leaders (949) 552-1803
- Judith Chow, John Watson, and Barbara Zielinska (Desert Research Institute (DRI)) – Consulting and Laboratory Analysis (775) 674-7050
- Karl Loos (Shell Global Solutions U.S.) – API Work Group Chairman (281) 544-7268
- Karin Ritter (API) – API Project Officer (202) 682-8472
- Paul Drayton (GRI) – GRI Project Manager (847) 768-0694)
- Marla Mueller (CEC) – CEC Project Manager (916) 654-4894)
- Kathy Stirling (DOE) – DOE Contracting Officer Representative (918) 699-2008)
- Barry Liebowitz (NYSERDA) – NYSERDA Project Manager (518) 862-1090 ext. 3248

Section 2

PROCESS DESCRIPTION

Site Delta's utilities plant includes four boilers and four diesel engines that vent to a common vertical stack for the building. Each of the boilers is a duel fuel-fired unit that can fire either No. 6 fuel oil or natural gas (Figure 2-1). Only Boiler #2 was in operation during these tests. Unit 2 is an industrial watertube package boiler with a single burner and a fuel heat input capacity is 65 million British thermal units per hour (MMBtu/hr). Fuel oil is injected through a single steam-atomized spray nozzle. A gas ring injector is used during natural gas firing. Tests were performed on the unit firing fuel oil first, followed after a few days by the natural gas tests. Hot exhaust gases from three of the boilers vent to the vertical stack via a common horizontal rectangular duct with a cross-section of approximately 6 feet by 9 feet. The exhaust gas measurements were made in this horizontal duct a short distance upstream of the vertical stack.

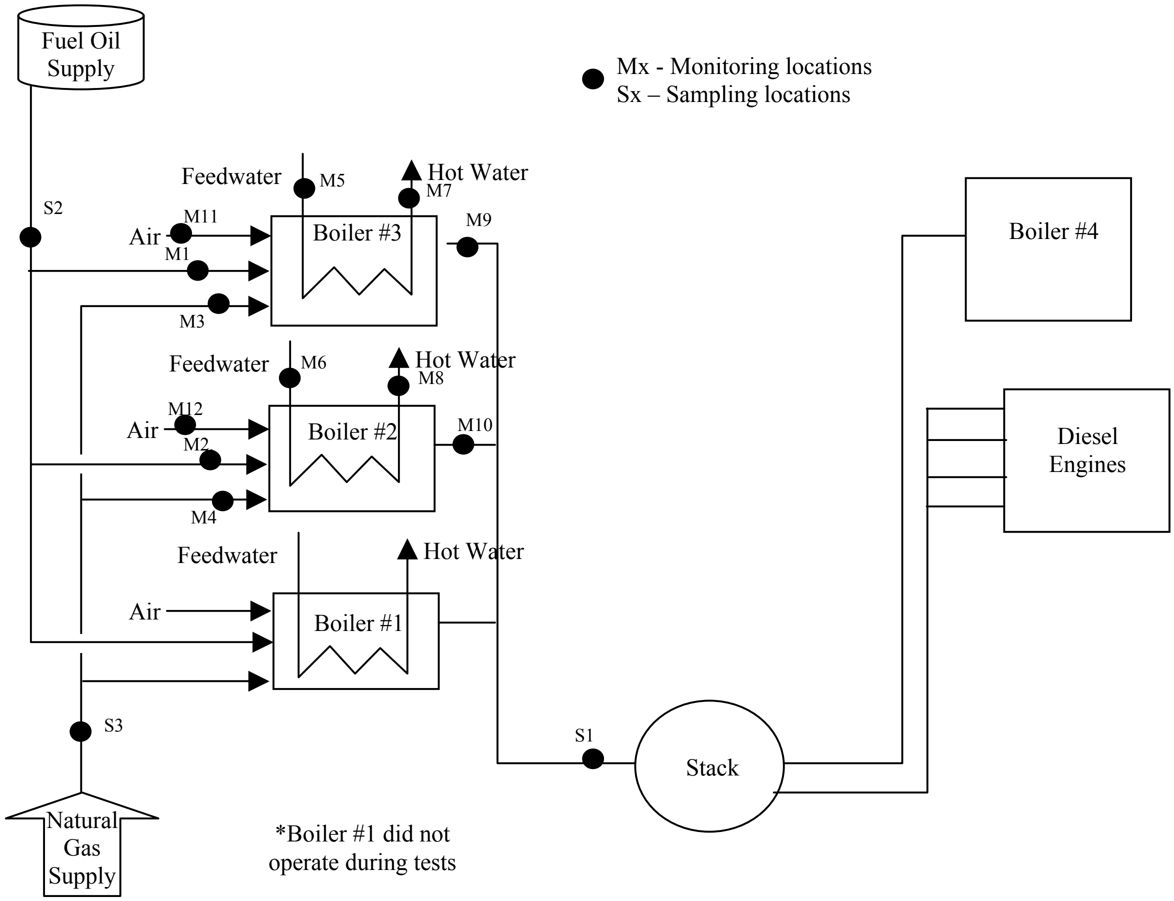

Figure 2-1. Site Delta Process Overview.

POLLUTION CONTROL EQUIPMENT DESCRIPTION

The boilers are not equipped with any combustion or post-combustion air pollution control equipment.

SAMPLING LOCATIONS

Flue Gas Sampling Locations

Emissions samples were collected from the boilers' common horizontal, rectangular exhaust duct. The duct has inside dimensions of 103 inches by 67 inches for an inside equivalent diameter of 80.2 inches at the sampling location. There are three 2.5-inch diameter capped ports positioned in a vertical alignment approximately 33.5, 57.25 and 81.5 inches above the sampling platform. The ports are 144 inches downstream (1.80 diameters) from a 90-degree bend in the duct and 114 inches upstream from a convergence of the duct. The sampling locations did not meet the minimum EPA Method 1 requirements for upstream (2 diameters) disturbances, but the criterion for downstream disturbances (0.5 diameters) was met. All ports were accessed from a single platform that is approximately 54 inches wide. The platform is approximately 14 feet above the ground and was accessed by a set of stairs. A preliminary velocity check was performed to determine the point of average flow and sampling was performed at points with velocities close to average flow. A test for cyclonic flow determined cyclonic flow was not present.

A single ambient air sample intended to be collected at the air inlet for the boilers was not possible due to the external location of the air intake on a public street. Instead, the ambient sample was taken inside the boiler room, which has exposure to outside air through vents used to cool the interior.

Section 3

TEST PROCEDURES

An overview of the sampling and analysis procedures is given in Table 3-1. Figures 3-1a and 3-1b show the testing chronology for the dilution sampler and undiluted exhaust gas methods for natural gas- and oil-operation, respectively. The time of day for the start and finish of each measurement run is shown on the figure. Dilution sampler testing and in-stack testing were performed concurrently. All samples were collected at points of average velocity through their respective ports.

STACK GAS FLOW RATE, MOISTURE CONTENT AND MOLECULAR WEIGHT

An S-type Pitot tube (EPA Method 2) was used to determine the average stack gas velocity and volumetric flow rate. Stack gas molecular weight was calculated in accordance with EPA Method 3. Moisture content of the sample was determined based on weight gain of the impingers used in the CCT according to EPA Method 4. A full velocity traverse of the stack was performed before and after each test to determine total stack gas flow rate.

UNDILUTED EXHAUST GAS TEST METHODS

Samples were collected to determine total PM, SO_3 and SO_2 in undiluted exhaust gas samples. PM measurements were only performed during the No. 6 oil operation tests because loadings were expected to be too low to quantify during the natural gas fired operation. O_2, CO_2, CO, SO_2, and NO_x concentrations in undiluted exhaust gas samples were measured on-site.

O_2, CO_2, CO, SO_2, and NO_x

Portable electrochemical analyzers were used to make periodic measurements of undiluted exhaust gas concentrations. A portable electrochemical analyzer (NOVA Instrument Company Model 375WP) was used as the primary measurement for O_2, CO_2 and CO. The electrochemical analyzer was calibrated with EPA Protocol gases before and after the test to verify accuracy. A portable analyzer (Cosa Instruments Model 6000CD) supplied by the plant was used for NO_x and SO_2 measurements. The Cosa analyzer also measured O_2, CO_2 and CO concentrations, which

Table 3-1. Summary of Test Procedures.

Sampling Location	Sample Type/Measurements	Sampling Approach	Analytical Principle	Reference
Exhaust Duct	Undiluted exhaust gas/sulfur trioxide	Controlled condensation train coil	IC ($SO_4^=$)	Maddalone et al, 1979.
	Undiluted exhaust gas/sulfur dioxide	Controlled condensation train impingers	IC ($SO_4^=$)	Maddalone et al, 1979.
	Undiluted exhaust gas/PM	Controlled condensation train filter	Gravimetric	Maddalone et al, 1979.
	Undiluted exhaust gas/velocity and temperature	S-type pitot and thermocouple	S-type pitot and thermocouple	U. S. EPA Method 2
	Undiluted exhaust gas/O_2, CO_2, CO, NO_X, SO_2	Portable continous emissions monitor	Electrochemical cell	
	Diluted Exhaust Gas/PM2.5 mass, elements	Dilution sampler and Teflon® filter	Gravimetry and XRF	U.S. EPA, 1999a; Hildemann et al., 1989
	Diluted Exhaust Gas/PM2.5 OC/EC	Dilution sampler and Quartz filter	TOR	U.S. EPA, 1999a; Hildemann et al., 1989
	Diluted Exhaust Gas/PM2.5 ions: sulfate, nitrate, chloride, ammonium, soluble Na	Dilution sampler and Quartz filter	IC	U.S. EPA, 1999a; Hildemann et al., 1989
	Diluted Exhaust Gas/Gaseous PM2.5 precursors - Ammonia	Dilution sampler and K2CO3- impregnated cellulose-fiber filter	IC	Chow and Watson, 1998
	Diluted Exhaust Gas/Gaseous PM2.5 precursors - Sulfur Dioxide	Dilution sampler and citric acid-impregnated cellosure-fiber filter	IC	Chow and Watson, 1998
	Diluted Exhaust Gas/Gaseous PM2.5 precursors - Speciated VOC (C7 and greater)	Dilution sampler and Tenax	GCMS/FID/FTIR	Zielinska et al., 1996; Hildemann et al., 1989
	Diluted Exhaust Gas/Gaseous PM2.5 precursors - Speciated VOC (C2 and greater)	Dilution sampler and stainless steel canisters	GCFID/ECD	U.S. EPA Method TO-15
	Diluted Exhaust Gas/gaseous PM2.5 precursors - Carbonyls (aldehydes)	Dilution sampler and DNPH-coated silica gel cartridges	HPLC	U.S. EPA Method TO-11A
	Diluted Exhaust Gas/SVOC	Dilution sampler and filter/PUF/XAD-4/PUF	GC/IRD/MS	U.S. EPA Method TO-13; Hildemann et al., 1989
	Diluted Exhaust Gas/Ultrafine PM size distribution: mass and elements	Dilution sampler and MOUDI	Gravimetry and XRF	

Table 3-1. Summary of Test Procedures (Continued).

Sampling Location	Sample Type/Measurements	Sampling Approach	Analytical Principle	Reference
Boilers air inlet-ambient air	Ambient/PM2.5 mass, elements	Teflon filter	Gravimetry and XRF	U.S. EPA, 1999a; Hildemann et al., 1989
	Ambient/PM2.5 OC/EC	Quartz filter	TOR	U.S. EPA, 1999a; Hildemann et al., 1989
	Ambient/PM2.5 ions: sulfate, nitrate, chloride, ammonium, soluble Na	Quartz filter	IC	U.S. EPA, 1999a; Hildemann et al., 1989
	Ambient/Gaseous PM2.5 precursors - Ammonia	K_2CO_3- impregnated cellulose-fiber filter	IC	Chow and Watson, 1998
	Ambient/Gaseous PM2.5 precursors - Sulfur dioxide	Citric acid-impregnated cellulose-fiber filter	IC	Chow and Watson, 1998
	Ambient/Gaseous PM2.5 precursors - Speciated VOC (C7 and greater)	Tenax	GCMS/FID/FTIR	Zielinska et al., 1996; Hildemann et al., 1989
	Ambient/Gaseous PM2.5 precursors - Speciated VOC (C2 and greater)	Stainless steel canisters	GCFID/ECD	U.S. EPA Method TO-15
	Ambient/Gaseous PM2.5 precursors - Carbonyls (aldehydes)	DNPH-coated silica gel cartridges	HPLC	U.S. EPA Method TO-11A
	Ambient/SVOC	TGIF filter/PUF/ XAD-4/PUF	GC/IRD/MS	U.S. EPA Method TO-13; Hildemann et al., 1989

DHPH: dinitrophenylhydrazine
ECD: electro-chemical detector
GC/IRD/MS: gas chromatography/Fourier transform infrared/ mass spectrometry
GCFID: gas chromatography/flame ionization detection
HPLC: high performance liquid chromatography
IC: ion chromatography
MOUDI: micro-orifice uniform deposit impactor
OC/EC: organic carbon/elemental carbon
PM: particulate matter
PM2.5: PM with aerodynamic diameter < 2.5 microns
PUF: polyurethane foam
SVOC: semi-volatile organic compounds
TIGF: Teflon® impregnated glass fiber filter
TOR: thermal/optical reflectance
VOC: volatile organic compounds
XAD-4 - Amberlite® sorbent resin
XRF: x-ray fluorescence

provided qualitative validation of measurements made with the NOVA analyzer. Measurements were typically recorded every 15 minutes.

Sulfur Trioxide and Sulfur Dioxide

Concentrations of SO_3 were measured using the controlled condensation method (Maddalone et al., 1979). Sample runs were two hours (No. 6 fuel oil) and four hours (natural gas) at a sampling rate of 0.3 standard cubic feet per minute (scfm). Flue gas was extracted from the source through a quartz probe heated to 500 degrees Fahrenheit (°F) to prevent sulfuric acid

		Boilers Exhaust Duct				Dilution Sampler Blank	Boilers Inlet Ambient Air Sample
	Time	Velocity	Portable Gas Analyzer	Dilution Sampler	CCT	Dilution Sampler	Dilution Sampler
02-Apr-02	9:00	9:20 - 9:55	Run 1 - NG	Run 1 - NG	Run 1 - NG		
Tues.	10:00		10:30	10:30	10:50		
	11:00		▨	▨	▨		
	12:00		▨	▨	▨		
	13:00		▨	▨	▨		
	14:00		▨	▨	14:50		
	15:00		▨	▨			
	16:00	▨	16:30	16:30			
03-Apr-02	8:00		Run 2 - NG	Run 2 - NG	Run 2 - NG		
Wed.	9:00	▨	9:30	9:30	9:00		
	10:00		▨	▨	▨		
	11:00		▨	▨	▨		
	12:00		▨	▨	13:00		
	13:00		▨	▨			
	14:00		▨	▨			
	15:00	▨	15:30	15:30			
04-Apr-02	8:00	▨	Run 3 - NG	Run 3 - NG	Run 3 - NG		
Thurs.	9:00		9:15	9:15	9:25		
	10:00		▨	▨	▨		
	11:00		▨	▨	▨		
	12:00		▨	▨	▨		
	13:00		▨	▨	13:25		
	14:00		▨	▨			
	15:00	▨	15:15	15:15			
05-Apr-02	8:00	▨	Run 4 - NG	Run 4 - NG	Run 4 - NG		
Fri.	9:00		9:15	9:15	9:45		
	10:00		▨	▨	▨		
	11:00		▨	▨	▨		
	12:00		▨	▨	▨		
	13:00		▨	▨	13:45		
	14:00		▨	▨			
	15:00	▨	15:15	15:15			
06-Apr-02	8:00					Sampler Blank- NG	
Sat.	9:00					9:30	
	10:00					▨	
	11:00					▨	
	12:00					▨	
	13:00					▨	
	14:00					▨	
	15:00					15:30	
4/8/2002	7:00						Ambient Air
Mon.	8:00						8:00
	9:00						▨
	10:00						▨
	11:00						▨
	12:00						▨
	13:00						▨
	14:00						14:00

Figure 3-1a. Chronology for Natural Gas-Fired Boiler Tests (Site Delta).

		Boilers Exhaust Duct				Dilution Sampler Blank	Boilers Air Inlet Ambient Sample
	Time	Velocity	Portable Gas Analyzer	Dilution Sampler	CCT	Dilution Sampler	Dilution Sampler
22-Mar-02	7:00	7:30 - 8:00					
Fri.	8:00		Run 1 - Oil	Run 1 - Oil			
	9:00		9:30	9:30	Run 1 - Oil		
	10:00				10:15		
	11:00						
	12:00				12:15		
	13:00		13:30	13:30			
	14:00	14:00 - 14:30					
	15:00						
23-Mar-02	7:00		Run 2 - Oil	Run 2 - Oil			
Sat.	8:00	8:00 - 8:30	8:30	8:30	Run 2 - Oil		
	9:00				9:00		
	10:00				11:00		
	11:00						
	12:00		12:30	12:30			
	13:00	13:26					
	14:00						
25-Mar-02	8:00						
Mon.	9:00						
	10:00	10:30 - 11:00	Run 3 - Oil	Run 3 - Oil	Run 3 - Oil		
	11:00		11:00	11:00	11:46		
	12:00						
	13:00				13:46		
	14:00		14:45 (a)				
	15:00	15:45		15:15 (a)			
	16:00						
26-Mar-02	7:00						
Tues.	8:00		Run 4 - Oil	Run 4 - Oil			
	9:00	9:00 - 9:25	9:45	9:45	Run 4 - Oil		
	10:00				10:35		
	11:00						
	12:00				12:35		
	13:00		13:45	13:45			
	14:00	14:18 - 14:33					
	15:00						
27-Mar-02	8:00					Sampler Blank - Oil	
Wed.	9:00					9:15	
	10:00						
	11:00						
	12:00						
	13:00					13:15	
	14:00						
28-Mar-02 Thurs.						Field Blank	

a. Sampling interrupted from 14:05 to 14:20 for Boiler opacity test.

Figure 3-1b. Chronology for Oil-Fired Boiler Tests (Site Delta).

condensation. The flue gas then passed through a quartz-fiber filter maintained at a temperature of 650 °F. The SO_3 was collected downstream of the filter in a quartz condenser coil maintained at a temperature above the dew point of water (generally 60 to 71 °F) and below the acid dew point (estimated to be 196 °F). Temperatures for the condenser coil circulating water ranged from 139 to 142 °F during the sampling. SO_2 in the sample gas was collected in the impinger train downstream of the condenser coil. The impinger train consisted of four impingers connected in series and immersed in an ice water bath. The first and second impingers contained 3 percent hydrogen peroxide (H_2O_2). The third impinger was empty and the last impinger contained silica gel. The impinger catch and rinse is analyzed for sulfate by ion chromatography (IC) and for moisture gain gravimetrically. Philip Analytical Services analyzed the quartz condenser coil catch for SO_3. A field blank and reagent blank were collected.

Controlled condensation sampling was performed according to the method as published except for the following modifications and clarifications:

- The sample was collected from a single traverse point near a point of average velocity to preserve the integrity of the dilution sampler method comparison. It is assumed that any PM present is small enough to mix aerodynamically in the same manner as a gas.
- Total PM in the undiluted stack gases was measured by pre- and post-test weighings of the quartz-fiber filter.

DILUTION SAMPLER TESTS

PM2.5 mass and chemical speciation in the stack gas was determined using a dilution sampler (Figure 3-2). A stainless steel probe with a buttonhook nozzle was used to withdraw the stack gas sample at a rate of approximately 25 liters per minute (Lpm). The sample was transported from the probe through a heated copper line into the dilution sampler. The sample was mixed in the sampler with purified ambient air under turbulent flow conditions to cool and dilute the sample to near-ambient conditions. The ambient air used for dilution was purified using a high efficiency particulate air (HEPA) filter to remove PM and an activated carbon bed to remove gaseous organic compounds. After passing through a length equal to 10 diameters, approximately 50 percent of the diluted sample was withdrawn into a large chamber, where the sample aged for approximately 70 seconds to allow low-concentration aerosols (especially

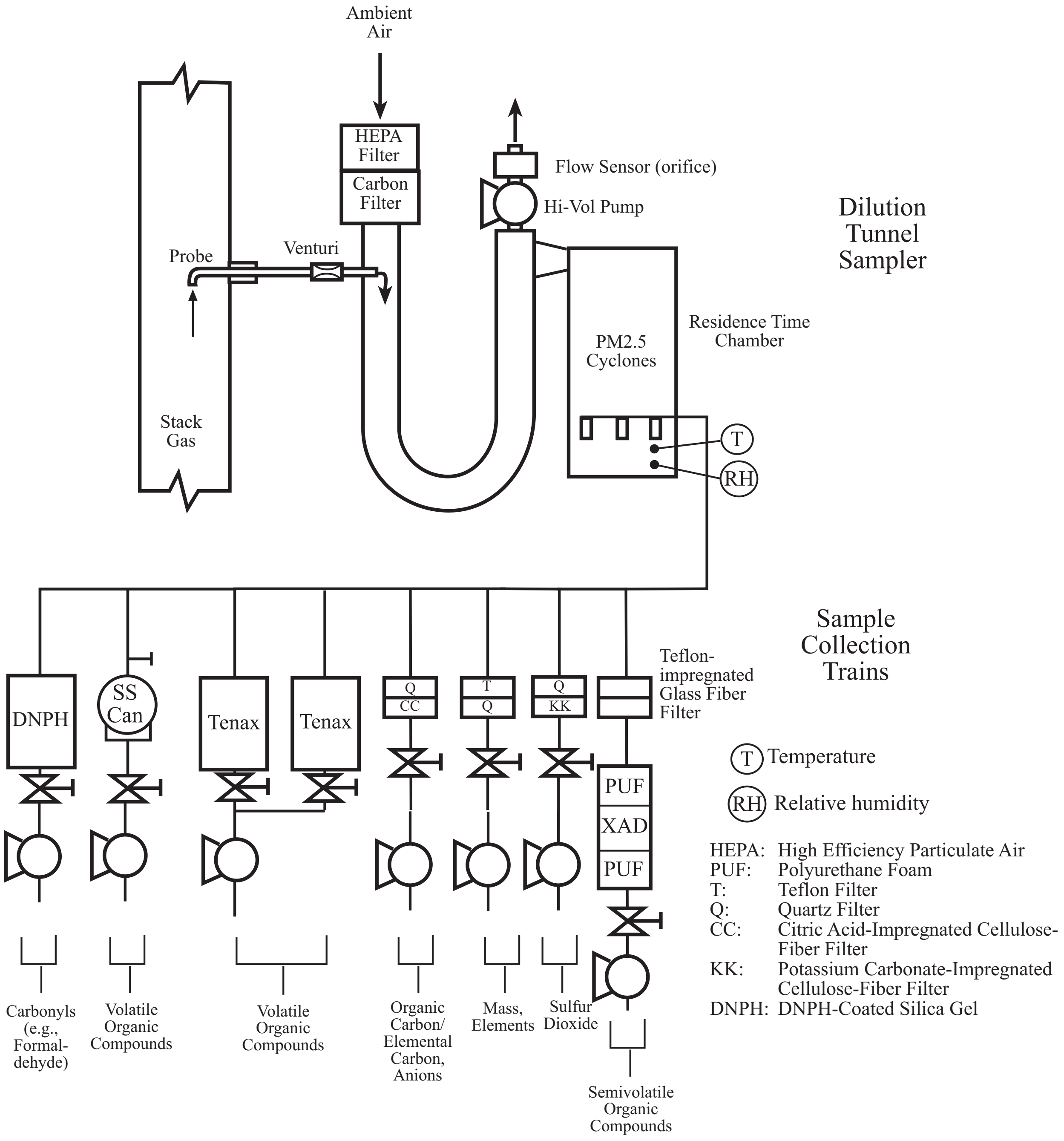

Figure 3-2. Dilution Sampler System.

organic aerosols) to fully form. The aged sample was withdrawn through a sampling manifold of three cyclone separators to remove particles larger than 2.5 microns (µm) into a sampling module to provide a uniform gas stream for the sample collection media (TMF, quartz filter, K_2CO_3-impregnated cellulose-fiber filter, citric acid-impregnated cellulose-fiber filter, Tenax tubes, DNPH-coated silica gel cartridges, stainless steel canisters, TIGF/PUF/XAD-4/PUF cartridge, and MOUDI). The sample flow rate through the probe was monitored using a venturi flow meter and thermocouple. The venturi velocity head was measured continuously during the test using a pressure transducer and a Magnehelic® gauge. An S-type Pitot tube with electronic pressure transducer and thermocouple were used to monitor the velocity in the stack. The thermocouples and pressure transducers were connected to a laptop computer data acquisition system. The dilution airflow and backpressure were adjusted to maintain the target dilution ratio and sample flow rates. Total sampling time for each No. 6 fuel oil test run was four hours and the total sampling time for each natural gas test run was six hours.

For these tests, flow rates were set in the field to achieve target dilution ratios of approximately 44:1 for each No. 6 fuel oil test run and 31:1 for each natural gas test run. These dilution ratios were selected to achieve low detection limits while allowing for collection of sufficient material for analysis. The ratio for the oil tests was set higher than the gas in order to avoid overloading the MOUDI sampler. The prior work of Hildemann et al. (1989) suggests that mixing between the sample and the dilution air begins to degrade below a dilution ratio of approximately 20:1. Dilution ratios ranged from 28 to 33 during the natural gas runs, which resulted in average diluted sample temperatures of 40 to 46 °C (Table 3-2a); the dilution ratios ranged from 39 to 48 during the No. 6 oil runs, which resulted in average diluted sample temperatures of 35 to 42 °C (Table 3-2b). Diluted sample temperatures are within 5°C of the ambient air temperature. Aerosol growth due to moisture condensation is expected to be negligible below a relative humidity (RH) of approximately 70 percent. RHs of the diluted samples during natural gas operation ranged from 10 to 20 percent. A RH sensor in the residence time chamber malfunctioned during some of the oil tests. Measured and calculated (based on measured ambient air RH, dilution ratio, measured stack gas moisture content and sample temperature) RHs of the diluted samples during oil operation ranged from 11 to 15 percent. Dilution sampler design

Table 3-2a. Dilution Sampler Operating Conditions (Site Delta – NG).

Parameter	Units	NG-Run 1 02-Apr-02	NG-Run 2 03-Apr-02	NG-Run 3 04-Apr-02	NG-Run 4 05-Apr-02	Ambient 08-Apr-02	NG-DSB 06-Apr-02
Ambient Air Temp.	^oC	44	47	42	40	40	38
Ambient RH	%	10	15	9	9	12	10
Dilution Chamber Temp.	^oC	43	46	42	40	n/a	40
Dilution Chamber RH	%	13	20	10	12	n/a	9
Stack Sample Flow Rate	dry slpm	14.6	14.8	14.1	15.1	n/a	n/a
Dilution Ratio (wet)	--	31.5	30.5	33.1	28.3	n/a	30.9
Dilution Ratio (dry)	--	33.8	32.4	35.1	30.1	n/a	32.9
Teflon Filter Flow Rate (mass, elements)	dry slpm	64.4	64.5	63.8	64.4	75.2	64.9
Quartz Filter Flow Rate (ions, OC/EC)	dry slpm	64.7	64.2	64.2	64.6	74.6	64.5
Citric Acid Filter Flow Rate (NH_3)	dry slpm	64.7	64.2	64.2	64.6	74.6	64.5
K_2CO_3 Filter Flow Rate (SO_2)	dry slpm	64.0	64.8	64.0	64.7	74.9	64.5
PUF/XAD (SVOC)	dry slpm	113	113	113	113	113	113
Tenax (VOC)	dry slpm	0.16	0.12	0.11	0.11	0.11	0.11
HPLC Cartridges (Carbonyls)	dry slpm	0.37	0.37	0.38	0.38	0.38	0.38
MOUDI	dry slpm	28.6	27.9	28.2	28.4	n/a	n/a
DusTrak	dry slpm	1.7	1.7	1.7	1.7	1.7	1.7

n/a - not applicable

Table 3-2b. Dilution Sampler Operating Conditions (Site Delta – Oil).

Parameter	Units	Oil-Run 1 22-Mar-02	Oil-Run 2 23-Mar-03	Oil-Run 3 25-Mar-03	Oil-Run 4 26-Mar-03	Oil-DSB 06-Apr-02
Ambient Air Temp.	^oC	40	41	44	43	43
Ambient RH	%	8	9	8	12	10
Dilution Chamber Temp.	^oC	35	39	42	41	40
Dilution Chamber RH	%	13	11	11	15	9
Stack Sample Flow Rate	dry slpm	17.0	15.6	17.5	16.3	n/a
Dilution Ratio (wet)	--	47.6	46.1	39.1	41.5	43.6
Dilution Ratio (dry)	--	50.5	47.4	40.9	43.7	45.6
Teflon Filter Flow Rate (mass, elements)	dry slpm	47.4	48.1	48.1	48.1	54.5
Teflon Filter No. 2 Flow Rate (mass)	dry slpm	47.0	47.6	48.2	49.5	55.7
Quartz Filter Flow Rate (ions, OC/EC)	dry slpm	46.7	47.1	49.1	49.6	55.4
Citric Acid Filter Flow Rate (NH_3)	dry slpm	46.7	47.1	49.1	49.6	55.4
K_2CO_3 Filter Flow Rate (SO_2)	dry slpm	47.5	48.2	47.9	47.9	55.3
PUF/XAD (SVOC)	dry slpm	112	113	113	113	113
Tenax (VOC)	dry slpm	0.16	0.16	0.16	0.16	0.13
HPLC Cartridges (Carbonyls)	dry slpm	0.38	0.38	0.37	0.37	0.37
MOUDI	dry slpm	28.1	28.0	28.1	28.5	n/a
DusTrak	dry slpm	1.7	1.7	1.7	1.7	1.7

n/a - not applicable

and operating parameters, including dilution ratio, are being evaluated in a separate pilot scale evaluation that will be discussed in a separate report.

A single ambient air sample was collected. A three-cyclone manifold (similar to the one inside the residence time chamber) was directly attached to the sampling module without the use of the dilution sampler. The ambient air sample was drawn into the module without dilution for a sampling period of six hours. Two blank samples were also collected using the dilution sampler. Filtered dilution air was drawn into the module without sample gas flow for a sampling period of six hours. For both the ambient air sample and the dilution sampler blank samples, the same sampling media were used as described below and in Figure 3-2.

PM2.5 Mass

Samples for PM2.5 mass measurements were collected on a 47-millimeter (mm) diameter polymethylpentane ringed, 2.0-µm pore size, TMF (Gelman No. RPJ047) placed in a two-stage Savillex filter holder. The filter packs were plugged directly into the bottom of the sampling module to ensure that no handling of the filters was required in the field. The flow rate through the filter was set prior to sample collection at a target rate of 75 standard liters per minute (sLpm) with a needle valve and monitored during sampling using a Thermo Scientific Incorporated (TSI) mass flow meter (Model 4043). Weighing was performed on a Cahn 31 electro-microbalance with a 1 microgram sensitivity.

Particle Size Distribution

A modified MOUDI (MSP Corp. Minneapolis, MN) operating at 30 Lpm was used to measure particle size distribution. The modified MOUDI classified particle mass into 5 size cuts: less than 0.1, 0.1 to 0.18, 0.18 to 0.32, 0.32 to 1.0 and 1.0 to 2.5 µm in aerodynamic diameter during the oil-fired tests and 4 size cuts: less than 0.1, 0.1 to 0.32, 0.32 to 1.0 and 1.0 to 2.5 µm in aerodynamic diameter during the natural gas-fired tests. A 37 mm polytetrafluoroethylene (PTFE) filter (2 µm, Gelman, Ann Arbor, MI) was placed as the backup filter to collect particles less than 0.1 µm; 47 mm PTFE filters were used at all other stages. The quartz-filter substrates were not coated. The collected samples were first weighed, and then analyzed by energy dispersive x-ray fluorescence (ED-XRF) to obtain the elemental composition in the specific particle size ranges.

Elements

ED-XRF analysis was performed on the TMFs for the following 40 elements: aluminum (Al), silver (Ag), arsenic (As), gold (Au), barium (Ba), bromine (Br), calcium (Ca), cadmium (Cd), chlorine (Cl), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), gallium (Ga), mercury (Hg), indium (In), potassium (K), lanthanum (La), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), palladium (Pd), rubidium (Rb), sulfur (S), antimony (Sb), selenium (Se), silicon (Si), tin (Sn), strontium (Sr), titanium (Ti), thallium (Tl), uranium (U), vanadium (V), yttrium (Y), zinc (Zn), and zirconium (Zr). Mg and Na results are considered semiquantitative because of analytical technique limitations.

A Kevex Corporation Model 700/8000 ED-XRF analyzer with a side-window, liquid-cooled, 60 kilo electron volts (keV), 3.3 milliamp rhodium anode x-ray tube and secondary fluorescers was used. The silicon detector had an active area of 30 square millimeters, with a system resolution better than 165 electron volts (eV). The analysis was controlled, spectra were acquired, and elemental concentrations were calculated by software on a microcomputer, which was interfaced to the analyzer. Five separate XRF analyses were conducted on each sample to optimize the detection limits for the specified elements. The filters were removed from their petri slides and placed with their deposit sides downward into polycarbonate filter cassettes. A polycarbonate retainer ring kept the filter flat against the bottom of the cassette. The cassettes were loaded into a carousel in the x-ray chamber. The sample chamber was evacuated to 10^{-3} Torr. A computer program controlled the positioning of the samples and the excitation conditions. Complete analysis of 16 samples under five excitation conditions required approximately 6 hours.

Sulfate, Nitrate, Chloride, Ammonium, Potassium, and Sodium

Samples for determining water-soluble NH_4^+, chloride (Cl^-), NO_3^-, $SO_4^=$, potassium (K^+), and sodium (Na^+) were collected on quartz fiber filters (Pallflex Tissuequartz 2500QAT-UP-47mm). The flow rate through the filter was set prior to sample collection at a target rate of 75 sLpm with a needle valve and monitored during sampling using a TSI mass flow meter (Model 4043).

For analysis, each quartz-fiber filter was cut in half. One half was placed in a polystyrene extraction vial with 15 milliliter (mL) of distilled deionized (DI) water while the other half was used for determination of OC and EC as described below. The extraction vials were capped and sonicated for 60 minutes, shaken for 60 minutes, then aged overnight to assure complete extraction of the deposited material. After extraction, these solutions were stored under refrigeration prior to analysis. Cl^-, NO_3^-, $SO_4^=$, NH_4^+, K^+, and Na^+ were measured with a Dionex 2020i ion chromatograph. Approximately 2 mL of the filter extract was injected into the ion chromatograph.

Organic and Elemental Carbon

Quartz fiber filters (Pallflex Tissuequartz 2500QAT-UP-47mm) were used to collect samples for determination of OC and EC mass (see above). The filters were heated in air for at least three hours at approximately 900 degrees Centigrade (°C) prior to use. Pre-acceptance testing was performed on each lot of filters. Filters with levels exceeding 1.5 micrograms per square centimeter ($\mu g/cm^2$) of OC or 0.5 $\mu g/cm^2$ of EC were refired or rejected. Pre-fired filters were sealed and stored in a freezer prior to preparation for field sampling.

The thermal/optical reflectance (TOR) method was used to determine OC and EC on the quartz filters. The TOR method is based on the principle that different types of carbon-containing particles are converted to gases under different temperature and oxidation conditions. The TOR carbon analyzer consists of a thermal system and an optical system. Reflected light is continuously monitored throughout the analysis cycle. The negative change in reflectance is proportional to the degree of pyrolytic conversion of carbon that takes place during OC analysis. After oxygen is introduced, the reflectance increases rapidly as the light-absorbing carbon burns off the filter. The carbon measured after the reflectance attains the value it had at the beginning of the analysis cycle is defined as EC.

VOCs

Tenax. Glass tubes filled with Tenax-TA (a polymer of 2,6-diphenyl-p-phenylene oxide) solid adsorbent were used to collect VOC samples. Two Tenax cartridges in parallel were used simultaneously for each test run due to the low concentrations expected in the sample. Each cartridge contained approximately 0.2 grams of Tenax resin. A sample rate of approximately 0.1 Lpm through each Tenax tube was used. The flow rate through the Tenax cartridges was controlled and monitored with a mass flow controller during sampling.

The Tenax samples were analyzed by the thermal desorption-cryogenic preconcentration method, followed by high resolution gas chromatographic separation and flame ionization detection (FID) of individual hydrocarbons for peak quantification, and/or combined mass selective detection/Fourier transform infrared detection (MSD/FTIR), for peak identification. The resultant peaks were quantified and recorded by the chromatographic data systems.

Canisters. In order to more fully speciate the VOCs, canister samples were taken to capture VOCs with a carbon number between two and ten. An integrated sample was collected in a canister downstream of the dilution sampler using a pump and flow control device to maintain a constant sample flow rate into the canister over the entire sampling period. The flow rate used is a function of the final desired sample pressure and the specified sampling period, for our purposes, 17 mL per minute.

For analysis, a known volume of gaseous sample is passed through a cryogenically cooled trap, cooled with liquid argon, cryogenically trapping out C_2 and heavier VOCs without trapping methane. The trap containing the condensed VOC is warmed with hot water and its contents injected into a gas chromatograph capillary column where separation of the VOC takes place. Detection of the hydrocarbons and oxygenated hydrocarbons is by FID, while detection of the halogenated compounds is by electron capture detection (ECD), and the resultant peaks are quantified and recorded by an electronic integrator and by the chromatographic data system.

SVOCs

Samples were collected using a filter followed by an adsorbent cartridge. The media used for collecting SVOCs were as follows:

- Pallflex (Putnam, CT) T60A20 102-mm TIGF filters;

- PUF sheets, purchased from E.R. Carpenter Company, Inc. (Richmond, VA) and cut into 2-inch diameter plugs;
- XAD-4 resin (20-60 mesh) purchased from Aldrich Chemical Company, Inc.

The sample was transferred from the sampling manifold through a 3/8-inch copper manifold leading to a momentum diffuser chamber followed by the filter and cartridge holder. The flow through the sampler was monitored continuously by a mass flow meter and kept at a target flow rate of 113 Lpm.

The samples were isotopically spiked, extracted in dichloromethane, and concentrated prior to analysis. Sample extracts were analyzed by the electron impact gas chromatography/mass spectrometric (GC/MS) technique, using a Hewlett-Packard 5890 gas chromatography (GC) equipped with a model 7673A Automatic Sampler and interfaced to a model 5970B mass selective detector (MSD). To assist in the unique identification of individual compounds, selected samples were analyzed by combined gas chromatography/Fourier transform infrared/mass spectrometry (GC/IRD/MSD) technique, i.e., using the Fourier transform infrared detector to aid mass spectrometric identification. Polycyclic aromatic hydrocarbons (PAH), and other compounds of interest, were quantified by multiple ion detection.

Carbonyls (Aldehydes and Ketones)

Carbonyls in the sample gas were collected by drawing sample through a cartridge containing DNPH-coated silica gel. The resulting products (hydrazones) in the cartridge are measured in the laboratory using high performance liquid chromatography (HPLC) to determine the levels of the carbonyl compounds originally present in the sample, as described in EPA Method TO-11A. Typically C_1-C_6 carbonyl compounds, including benzaldehyde, are measured effectively by this technique. The target flow rate used for this sample was approximately 0.4 Lpm.

Sulfur Dioxide

Filter packs containing a quartz filter followed by a K_2CO_3-impregnated cellulose-fiber filters were used to collect SO_2 gas downstream of the dilution sampler. The flow rate through the filter was set prior to sample collection at a target rate of 75 sLpm with a needle valve and monitored during sampling using a TSI mass flow meter (Model 4043). These filters were extracted with hydrogen peroxide and then analyzed using IC.

Ammonia

Filter packs containing a quartz filter followed by a citric acid impregnated cellulose-fiber filter were used to collect NH_3 gas downstream of the dilution sampler. The flow rate through the filter was set prior to sample collection at a target rate of 75 slpm with a needle valve and monitored during sampling using a TSI mass flow meter (Model 4043). These filters were extracted with DI water and then analyzed using automated colorimetry.

Section 4

TEST RESULTS

Stack emission results are presented in units of milligrams per dry standard cubic meter (mg/dscm) and pounds per hour (lb/hr). Concentrations are corrected to a standard temperature of 68 °F (20 °C) and a standard pressure of 29.92 inches (760 mm) of mercury unless otherwise indicated. Substances that were not detected in any of the four test runs generally are not listed on the tables. Where shown, undetected data are flagged "ND", treated as zeroes in sums, and excluded from average calculations. Data with one or more, but not all, runs less than the detection limit are flagged with a "<" symbol to indicate an upper limit of the true estimation. Ambient air samples were collected by drawing air directly into the sampling media. The dilution sampler is bypassed. The ambient air sample provides an indication of the potential significance of stack samples relative to the ambient air. Section 6 and Section 7 provide additional analyses of these results. The approximate minimum in-stack detection limits achieved for all measured substances are given in Table 4-1. These detection limits were calculated using the analytical laboratory detection limits and the average sample volume and dilution ratio for the natural gas tests. Detection limits for the No. 6 oil fired tests were about three times greater than for the natural gas fired tests due to different sample volumes and dilution ratios.

PROCESS OPERATING CONDITIONS

The boiler operating conditions during testing are summarized in Table 4-2. The boiler operated at approximately 75 percent of full capacity over the four No. 6 oil-fired runs and at about 35 percent of full capacity during the natural gas-fired test runs. The average measured fuel flow rate and fuel heating value were used to calculate heat input to the boiler during the tests; these data were used to convert in-stack emission rates (lb/hr) to emission factors (pounds of pollution per million British thermal units of gas fired (lb/MMBtu)), which are presented in Section 5.

PRELIMINARY TEST RESULTS

Preliminary tests were conducted to establish single points of near-average velocity in the stack for collection of samples. A velocity profile was developed by traversing the stack with the pitot

Table 4-1. Approximate In-Stack Detection Limits for Natural Gas- and No. 6 Oil-Fired Boiler Testing (Delta).

Substance	Dilution Tunnel (mg/dscm)*	In-Stack Methods (mg/dscm)	Substance	Dilution Tunnel (mg/dscm)	Substance	Dilution Tunnel (mg/dscm)	Substance	Dilution Tunnel (mg/dscm)
SO3	2.3E-03	5.0E-03	Ti	5.5E-05	1,4,5-trimethylnaphthalene	1.7E-04	C-MePy/MeFl	n/a
SO2	1.5E-03	3.3E-03	Tl	4.7E-05	Acenaphthylene	1.8E-04	D-MePy/MeFl	1.8E-06
PM2.5 mass	1.5E-03		U	4.3E-05	Acenaphthene	4.7E-05	4-methylpyrene	3.6E-06
Ag	2.3E-04	-	V	4.7E-05	Fluorene	2.2E-04	1-methylpyrene	1.4E-05
Al	1.9E-04	-	Y	2.5E-05	Phenanthrene	1.4E-05	Benzo(c)phenanthrene	2.0E-05
As	3.0E-05	-	Zn	2.1E-05	A-methylfluorene	1.9E-04	Benz(a)anthracene	1.1E-05
Au	5.9E-05	-	Zr	3.2E-05	1-methylfluorene	1.2E-04	7-methylbenz(a)anthracene	1.1E-05
Ba	9.8E-04	-	Cl-	2.2E-03	B-methylfluorene	1.2E-04	Chrysene	3.6E-06
Br	1.9E-05	-	SO4=, NO3-	2.2E-03	9-fluorenone	2.4E-04	Benzanthrone	1.6E-05
Ca	8.5E-05	-	NH4+	2.2E-03	Xanthone	7.2E-06	Benz(a)anthracene-7,12-dionene	6.6E-05
Cd	2.3E-04	-	Soluble Na	2.2E-04	Acenaphthenequinone	1.1E-05	5+6-methylchrysene	n/a
Cl	1.9E-04	-	SO2	1.5E-03	Perinaphthenone	1.8E-03	1,4-chrysenequinone	9.0E-06
Co	1.7E-05	-	NH3	5.8E-04	A-methylphenanthrene	8.6E-05	Benzo(b+j+k)fluoranthene	n/a
Cr	3.6E-05	-	OC	1.7E-02	2-methylphenanthrene	3.6E-06	7-methylbenzo(a)pyrene	1.3E-05
Cu	2.1E-05	-	EC	3.8E-03	B-methylphenanthrene	2.0E-05	Benzo(e)pyrene	1.1E-05
Fe	2.8E-05	-	Naphthalene	1.7E-03	C-methylphenanthrene	5.0E-05	Perylene	3.6E-06
Ga	3.6E-05	-	2-methylnaphthalene	1.1E-04	1-methylphenanthrene	3.9E-05	Benzo(a)pyrene	1.1E-05
Hg	4.9E-05	-	1-methylnaphthalene	6.8E-05	Anthrone	1.8E-06	Indeno[123-cd]pyrene	1.1E-05
In	2.5E-04	-	Biphenyl	1.2E-04	Anthraquinone	9.7E-05	Benzo(ghi)perylene	1.1E-05
K	1.2E-04	-	1+2-ethylnaphthalene	2.3E-04	2,3-Benzofluorene	n/a	Dibenzo(ah+ac)anthracene	1.1E-05
La	1.2E-03	-	2,6+2,7-dimethylnaphthalene	1.9E-04	3,6-dimethylphenanthrene	n/a	Coronene	1.1E-05
Mg	n/a	-	1,3+1,6+1,7-dimethylnaphthalene	4.1E-04	A-dimethylphenanthrene	8.5E-05	Volatile Organic Compounds	1.1E-03
Mn	3.0E-05	-	1,4+1,5+2,3-dimethylnaphthalene	1.8E-04	B-dimethylphenanthrene	5.9E-05	Formaldehyde	2.5E-3
Mo	5.1E-05	-	1,2-dimethylnaphthalene	1.2E-04	C-dimethylphenanthrene	5.9E-05	Acetaldehyde	6.9E-3
Na	n/a	-	2-Methylbiphenyl	2.9E-04	1,7-dimethylphenanthrene	5.9E-05	Acetone	3.1E-2
Ni	1.7E-05	-	3-Methylbiphenyl	4.1E-04	D-dimethylphenanthrene	5.4E-05	Acrolein	2.0E-3
P	1.1E-04	-	4-Methylbiphenyl	3.4E-05	E-dimethylphenanthrene	2.7E-05	Propionaldehyde	1.5E-3
Pb	5.7E-05	-	Dibenzofuran	1.1E-04	Anthracene	n/a	Crotonaldehyde	1.8E-3
Pd	2.1E-04	-	A-trimethylnaphthalene	3.4E-06	9-methylanthracene	8.3E-05	MEK	3.7E-3
Rb	1.9E-05	-	B-trimethylnaphthalene	1.8E-06	Fluoranthene	3.6E-06	Methacrolein	1.8E-3
S	9.4E-05	-	C-trimethylnaphthalene	1.4E-05	Pyrene	7.2E-06	Butyraldehyde	3.0E-3
Sb	3.4E-04	-	E-trimethylnaphthalene	1.8E-06	9-Anthraldehyde	4.8E-05	Benzaldehyde	1.6E-3
Se	2.3E-05	-	F-trimethylnaphthalene	1.7E-06	Retene	1.1E-04	Glyoxal	1.1E-3
Si	1.2E-04	-	2,3,5+I-trimethylnaphthalene	5.4E-06	Benzonaphthothiophene	3.6E-06	Valeraldehyde	1.7E-3
Sn	3.2E-04	-	2,4,5-trimethylnaphthalene	1.4E-05	1-MeFl+C-MePy/Fl	2.9E-05	M-Tolualdehyde	1.5E-3
Sr	2.1E-05	-	J-trimethylnaphthalene	1.4E-05	B-MePy/MeFl	1.8E-06	Hexanaldehyde	1.6E-3

* Detection limits listed are for natural gas operation; detection limits for No. 6 oil operation are about three times greater.

n/a - not applicable

Table 4-2. Process Operating Conditions (Delta).

Parameter	Units	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4
Date	dd-mmm-yr	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02	2-Apr-02	3-Apr-02	4-Apr-02	5-Apr-02
Start Time	hh:mm	9:30	8:30	11:00	9:45	10:30	9:30	9:15	9:15
End Time	hh:mm	13:30	12:30	15:15 (a)	13:45	16:30	15:30	15:15	15:15
Boiler #2 Firing Rate	MMBtu/hr	48.9	53.3	52.1	49.1	24.3	18.0	22.6	25.6
Boiler #2 Fuel Flow Rate	lb/hr	2,505	2,659	2,621	2,532	1,095	810	1,017	1,153
Boiler #2 Fuel Oil Pressure	psi	120	123	120	113	NA	NA	NA	NA
Boiler #2 Feedwater Flow Rate	gal/min	1,260	1,259	1,255	1,254	1,251	1,248	1,250	1,259
Boiler #2 Feedwater Inlet Temperature	F	324	325	320	326	352	359	353	352
Boiler #2 Hot Water Outlet Temperature	F	385	390	384	387	384	384	383	385
Boiler #2 Feedwater Pressure	psi	211	215	221	223	222	228	231	230
Boiler #2 Feedwater Pump Electical Current	amp	77	77	78	77	77	76	76	76
Boiler #2 Wind Box Pressure	inches H_2O	1.05	0.95	1.07	1.06	0.90	0.83	0.85	0.86
Boiler #2 Fan Electrical Current	amp	43	42	43	43	37	37	38	38

probe before and after each test run. However, due to very low velocity head pressures, the accuracy of the velocity measurements was considered unacceptable for stack flow determination. Therefore, stack gas flow rates were calculated based on fuel flow rate, fuel ultimate analyses, and measured excess oxygen concentrations.

STACK GAS CONDITIONS AND FLOW RATE

A summary of the stack conditions measured during testing is presented in Table 4-3. Stack gas temperatures averaged 379 to 435 °F during the oil-fired test runs and 300 to 325 °F during natural gas operation. Gas concentrations, which were determined using a portable analyzer provided by the plant, are presented on an "as measured" dry basis. Excess O_2 at the sampling location ranged from 10.0 to 11.2 percent during oil-fired operation and from 13.2 to 14.9 percent during gas-fired operation. The very high excess O_2 levels indicate a high level of air inleakage, most likely through the air registers and passages of Boilers Nos. 1 and 3 which were out of service during the tests, diluting the combustion products from Boiler No. 2.

PROCESS SAMPLE RESULTS

Tables 4-4a and 4-4b show the gas and oil samples analyses results, respectively. The oil samples contained an unusually high amount of free water, which is likely a sampling artifact from condensation in the fuel tap or water in the fuel tank. The free water was physically separated from the sample prior to all of the laboratory analyses except gross heat of combustion. As indicated in Table 4-4b, the gross heat of combustion results have been adjusted to a "water-free" basis.

The natural gas samples, which were collected in Tedlar bags, showed atypically high and variable nitrogen contents in the analyses. The bags were purged with nitrogen (N_2) prior to collecting the sample. It is believed that the sample collection procedure did not remove all of the N_2 used for purging. Because the other gas properties were consistent with N_2 dilution, the gas analyses results were corrected to a constant N_2 content of 2.7 percent by volume, which is the lowest level measured in the samples.

Table 4-3. Average Stack Gas Conditions (Delta).

Parameter	Units	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Avg - Oil	RSD - Oil	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Avg - NG	RSD - NG
Date	dd-mmm-yr	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	2-Apr-02	3-Apr-02	4-Apr-02	5-Apr-02		(%)
Start Time	hh:mm	9:30	8:30	11:00	9:45			10:30	9:30	9:15	9:15		
End Time	hh:mm	13:30	12:30	15:15 (a)	13:45			16:30	15:30	15:15	15:15		
Temperature	F	435	413	379	431	415	6	325	317	314	300	314	3
Moisture	% v	6.2	3.2	5.3	5.9	5.2	26	7.7	7.3	6.5	6.7	7.1	8
Velocity	ft/s	8.6	8.1	8.6	9.1	8.6	5	4.9	3.9	5.7	6.2	5.2	19
	m/s	2.6	2.5	2.6	2.8	2.6	5	1.5	1.2	1.7	1.9	1.6	19
Flowrate	acfm	27,000	25,400	26,800	28,400	26,900	5	15,300	12,300	17,800	19,200	16,100	19
	dscfm	14,900	14,900	16,000	15,800	15,400	4	9,510	7,760	11,300	12,500	10,200	20
	dscmm	423	421	452	449	436	4	269	220	321	352	291	20
NOx Concentration	ppmv (dry)	166	159	183	173	170	6	64	58	49	53	56	12
CO Concentaration	ppmv (dry)	1.8	2.5	3.2	2.7	2.6	23	1.3	2.7	1.7	1.5	1.8	35
SO_2 Concentration	ppmv (dry)	89.1	89.6	93.8	86.5	89.8	3	0	0	0	0	0	n/a
CO_2 Concentration	% v (dry)	8.7	8.9	8.2	8.0	8.5	5	5.2	4.0	4.1	4.3	4.4	12
O_2 Concentration	% v (dry)	10.6	10.0	10.6	11.2	10.6	5	13.2	13.9	14.9	14.7	14.2	6

RSD- Relative Standard Deviation

Table 4-4a. Natural Gas Samples Analysis (Delta).

	Units	NG-Run1	NG-Run2	NG-Run3	NG-Run4	Average	RSD (%)
Non-Hydrocarbon Gases*							
Nitrogen	% v/v	2.70	2.70	2.70	2.70	2.70	0
Oxygen	% v/v	ND	ND	ND	ND	ND	n/a
Carbon Dioxide	% v/v	0.80	0.77	0.77	0.76	0.78	3
Carbon Monoxide	% v/v	ND	ND	ND	ND	ND	n/a
Hydrogen	% v/v	ND	ND	ND	ND	ND	n/a
Helium	% v/v	ND	ND	ND	ND	ND	n/a
Water Vapor	% v/v	ND	ND	ND	ND	ND	n/a
Hydrocarbons*							
Methane	% v/v	93.48	93.90	93.98	93.95	93.83	0
Ethylene	% v/v	ND	ND	ND	ND	ND	n/a
Ethane	% v/v	2.33	2.18	2.14	2.18	2.21	4
Propylene	% v/v	ND	ND	ND	ND	ND	n/a
Propane	% v/v	0.412	0.281	0.249	0.254	0.299	26
Isobutane	% v/v	0.088	0.055	0.046	0.050	0.060	33
n-Butane	% v/v	0.088	0.058	0.058	0.053	0.064	25
Butenes	% v/v	ND	ND	ND	ND	ND	n/a
Isopentane	% v/v	0.034	0.024	0.019	0.021	0.025	27
n-Pentane	% v/v	0.023	0.016	0.013	0.014	0.017	26
Pentenes	% v/v	ND	ND	ND	ND	ND	n/a
Hexanes +	% v/v	0.034	0.025	0.020	0.025	0.026	22
Elemental Composition*							
Carbon	% w/w	71.05	71.03	71.00	71.03	71.03	0
Hydrogen	% w/w	23.0	23.1	23.1	23.1	23.1	0
Oxygen	% w/w	1.50	1.45	1.46	1.42	1.46	2
Nitrogen	% w/w	4.45	4.45	4.45	4.45	4.45	0
Total Sulfur (as H2S)	ppm w/w	7.0	6.2	9.5	10.6	8.3	24
Heat of Combustion % Physical Properties*							
Lower Heating Value	Btu/scf	907	901	900	900	902	0
Higher Heating Value	Btu/scf	1,005	1,000	999	998	1,001	0
Higher Heating Value	Btu/lb	22,214	22,233	22,238	22,216	22,225	0
Specfic Gravity	vs dry/normal air	0.592	0.589	0.588	0.588	0.589	0
Fd	dscf/MMBtu	8,659	8,668	8,672	8,672	8,668	0

n/a - not applicable

ND - Not Detected.

* Analyses corrected for residual nitrogen in sampling equipment.

Table 4-4b. No. 6 Fuel Oil Sample Analyses (Delta).

	Units	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD (%)
Asphaltenes	wt. %**	1.2	1.0	1.2	1.1	1.1	9
API Gravity	---**	19.5	19.4	18.6	18.4	19.0	3
Ash	mass %**	0.062	0.061	0.041	0.038	0.051	25
Kinematic Viscosity at 122 F	cSt**	82	119	109.5	85.3	99.0	18
Water by Distillation	wt. %	10.6	25.1	19.7	8.4	16	49
Gross Heat of Combustion	Btu/lb*	19,506	20,048	19,895	19,395	19,711	2
Mercury	ppm-wt.**	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0
Total Sulfur Content	wt. %**	0.250	0.250	0.266	0.268	0.259	4
Carbon	mass %**	87.6	86.5	87.3	87.1	87.1	1
Hydrogen	mass %**	11.6	11.9	11.6	11.4	11.6	2
Nitrogen	wt. %**	0.260	0.228	0.241	0.283	0.253	9
Oxygen	mass %**	0.25	1.11	0.61	0.88	0.71	52

* Sample analyzed as emulsion, analysis corrected for water.

** Water physically separated before analysis.

IN-STACK AND IMPINGER METHOD RESULTS

Sulfur Oxides

SO_3 and SO_2 emissions measured by the CCT method are presented in Table 4-5. Oil Run 2 was invalidated due to much lower moisture results (approximately half that of the other runs), an indicator of a sample train leak during that run. Based on the sulfur content of the fuel oil, the expected SO_2 concentration is 88 ppmv. This is very close to the SO_2 concentration measured using the portable gas analyzer (90 ppmv, presented earlier in Table 4-3). The SO_2 concentrations measured by the CCT ranged from 140 to 190 mg/dscm (52 to 71 ppmv) during oil firing, somewhat lower than expected based on the oil sulfur content indicating a possible low bias in the CCT SO_2 measurement for these runs.

The SO_2 concentration measured by the CCT during natural gas firing was 0.53 to 1.8 mg/dscm (0.20 to 0.69 ppmv). Based on the natural gas sulfur content, the expected SO_2 concentration is 0.16 ppmv.

SO_3 concentration measured by the CCT ranged from 16 to 21 mg/dscm (4.7 to 6.2 ppmv) during oil firing. For No. 6 oil applications, the SO_3 concentration is typically 1 to 3 percent of the SO_2 concentration. Based on the measured SO_2 concentration (from Table 4-3), the expected SO_3

Table 4-5. Sulfur Oxide Emissions Measured by Controlled Condensation Train (Delta).

Parameter	Units	Oil-Run 1	Oil-Run 2*	Oil-Run 3	Oil-Run 4	Avg - Oil	RSD - Oil	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Avg - NG	RSD - NG
Date	dd-mmm-yr	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	2-Apr-02	3-Apr-02	4-Apr-02	5-Apr-02		(%)
Sulfur Trioxide Concentration (CSO3)	ppmv (dry)	6.2E+0	-	4.7E+0	5.1E+0	5.3E+0	15	3.7E-1	1.5E-1	1.2E-1	1.6E-1	2.0E-1	58
Sulfur Dioxide Concentration (CSO2)	ppmv (dry)	7.1E+1	-	5.2E+1	5.4E+1	5.9E+1	17	6.9E-1	2.0E-1	2.2E-1	3.7E-1	3.7E-1	61
Sulfur Trioxide Concentration (CSO3)	mg/dscm	2.1E+1	-	1.6E+1	1.7E+1	1.8E+1	15	1.2E+0	4.8E-1	4.0E-1	5.4E-1	6.7E-1	58
Sulfur Dioxide Concentration (CSO2)	mg/dscm	1.9E+2	-	1.4E+2	1.4E+2	1.6E+2	17	1.8E+0	5.3E-1	6.0E-1	9.8E-1	9.9E-1	61
Sulfur Trioxide Emission Rate	lb/hr	1.2E+0	-	9.1E-1	1.0E+0	1.0E+0	12	4.4E-2	1.4E-2	1.7E-2	2.5E-2	2.5E-2	54
Sulfur Dioxide Emission Rate	lb/hr	1.0E+1	-	8.1E+0	8.5E+0	9.0E+0	14	6.6E-2	1.5E-2	2.5E-2	4.6E-2	3.8E-2	59
Sulfur Trioxide Emission Factor (ESO3)	lb/MMBtu	2.4E-2	-	1.7E-2	2.1E-2	2.1E-2	15	1.8E-3	7.8E-4	7.5E-4	9.9E-4	1.1E-3	46
Sulfur Dioxide Emission Factor (ESO2)	lb/MMBtu	2.1E-1	-	1.6E-1	1.7E-1	1.8E-1	17	2.7E-3	8.5E-4	1.1E-3	1.8E-3	1.6E-3	51

RSD- Relative Standard Deviation

* Run 2 invalidated

concentration therefore would be approximately 1 to 3 ppmv. The measured values are considerably higher than the expected value. SO_3 formation in combustion systems is very sensitive to temperature (equilibrium favors SO_3 over SO_2 at lower post-combustion zone temperatures) and oxygen availability; also, ash deposits on the boiler gas-side surfaces can catalyze formation. The elevated SO_3 concentration may be due to the high excess O_2 concentration (10.6 percent by volume) at the sampling location.

The SO_3 concentration measured by the CCT was 0.4 to 1.2 mg/dscm (0.12 to 0.37 ppmv) during natural gas firing. No other data for SO_3 from natural gas combustion was found for comparison, but using the same rule of thumb as for oil the expected SO_3 concentration would be 0.02 to 0.06 ppmv. This is well below the normal range of the method but above minimum analytical detection limits. The total level of SO_2 plus SO_3 from the natural gas results is much higher than expected based on the sulfur content of the natural gas. Because the natural gas tests were conducted only a few days after the seasonal switch from No. 6 oil to natural gas firing and since the firing rate during the gas tests was very low (approximately one-third of full capacity), it is suspected that sulfur-containing boiler ash deposits were slowly shedding and sulfur compounds were evolved when these deposits were captured on the high-temperature CCT filter. Although this potential artifact could not be determined conclusively, the SO_3 results for natural gas firing should be considered potentially unrepresentative and used with extreme caution.

PM Mass

PM was measured using the CCT's quartz-fiber filter as a semi-quantitative measure of total PM concentration (Table 4-6). This method was not designed for determination of PM emissions and because of differences in methodology between this method and the others used in these tests the results should be used with considerable caution. The filter holder design and use of very brittle quartz fiber filters tend to promote filter fragmentation that leads to loss of filter fibers and, therefore, relatively high imprecision in the results. In Runs 1 and 2, the net filter weights were negative; therefore, Runs 1 and 2 results are not reported. The high filter temperature (650 °F) used in the CCT precluded condensation of any sulfuric acid mist present in the sample, a portion of which condenses in the dilution sampler and is captured on the various dilution sampler filters. In addition, the dilution sampler filters captured only PM smaller than 2.5 µm in diameter, while

Table 4-6. PM Measured by CCT Filter (Delta – Oil).

	Units	Results					
Run Number Date	- -	Oil-Run1 22-Mar-02	Oil-Run2 23-Mar-02	Oil-Run3 25-Mar-02	Oil-Run4 26-Mar-02	Average	RSD
Total PM	mg/dscm	-	-	5.8E+0	7.0E+0	6.4E+0	13
	lb/hr	-	-	3.4E-1	4.2E-1	3.8E-1	14

n/a - not applicable
RSD - Relative Standard Deviation
Run 1 and Run 2 invalidated.

the CCT filter captures total PM. Thus, the CCT PM measurements and the dilution sampler PM measurements are not directly comparable.

DILUTION SAMPLER RESULTS

Data flags for the dilution sampler blank (DSB), field blank (FB), and ambient sample have been carried forward from Section 6 in the following tables. The blanks and ambient sample concentrations are flagged if they exceed the 95 percent confidence lower bound of the average of the test series. Flags suggest the field data may not be significantly different than the blank or ambient data and are discussed further in Section 6.

PM Mass

PM2.5 mass measurements using the dilution sampler include both solid aerosols that are directly emitted and those that condense under simulated stack plume conditions in the dilution sampler. The dilution sampler determines only the PM2.5 fraction of PM emissions; particles with aerodynamic diameter larger than 2.5 micrometers in the stack and those that grow larger than 2.5 micrometers are removed by cyclones upstream of the sample filter.

Natural Gas Combustion. PM2.5 concentration and emission rate for natural gas combustion average 0.32 mg/dscm and 0.012 lb/hr with relative standard deviations of 20 and 30 percent, respectively (Table 4-7a). PM2.5 concentrations measured in the boiler stack gas during natural gas firing were approximately an order of magnitude higher than the concentration measured in the ambient air. Dilution sampler blank (DSB) concentrations of PM2.5 mass were slightly higher than the measured emissions during natural gas operation. The high DSB for the natural gas test series indicates residual contamination from the oil-fired tests. The natural-fired tests

Table 4-7a. Dilution Sampler PM2.5 Results (Delta – NG).

	Units	Results							
Run Number	-	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	NG-Ambient	MDL
Date	-	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02		(%)	08-Apr-02	(1)
PM2.5	mg/dscm	3.8E-1	2.3E-1	3.3E-1	3.1E-1	3.2E-1 a	20	3.7E-2	1.5E-3
	lb/hr	1.4E-2	6.8E-3	1.4E-2	1.4E-2	1.2E-2	30	n/a	n/a

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

were performed a few days following the oil-fired tests. This contamination also may have biased other natural gas-fired emissions data. The dilution sampler apparatus was cleaned in the field between tests, but the field conditions were not ideal; therefore, the likelihood of residual contamination from the oil tests is considered significant and the mass results are probably biased high. This issue is discussed further in Section 6 and Section 7.

Oil Combustion. With oil firing (Table 4-7b), the average PM2.5 concentration (14 mg/dscm) and emission rate (0.82 lb/hr) are much higher than the natural gas results. This is consistent with the elevated ash and sulfur content of the oil compared to natural gas. The average PM2.5 concentration is over an order of magnitude greater than the concentrations in the DSB, field blank (FB), and ambient sample (please refer to Section 6 for additional discussion of blank results).

Particle Size Distribution

PM2.5 particle size distribution results from the MOUDI are presented in Tables 4-8 and 4-9 and Figures 4-1 and 4-2; the figures show the relative distribution of the total elemental mass collected among the various size ranges below 2.5 µm.

Table 4-7b. Dilution Sampler PM2.5 Results (Delta – Oil).

	Units	Results							
Run Number	-	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Oil-Ambient	MDL
Date	-	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	08-Apr-06	(1)
PM2.5	mg/dscm	1.5E+1	9.7E+0	1.7E+1	1.5E+1	1.4E+1	23	3.7E-2	4.1E-3
	lb/hr	8.6E-1	5.4E-1	1.0E+0	8.8E-1	8.2E-1	24	n/a	n/a

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-8. MOUDI Particle Size Distribution Results (Delta – NG).

Size Fraction (μm)	mg/dscm NG Run 1	NG Run 2	NG Run 3	NG Run 4	Average	Mass Distribution
1.0-2.5	1.6E-2	2.5E-2	4.3E-2	5.8E-3	2.3E-2	7%
0.32-1	5.8E-2	5.9E-2	6.0E-2	2.9E-2	5.1E-2	16%
0.1-0.32	1.1E-1	1.1E-1	8.3E-2	9.2E-2	9.7E-2	30%
<0.1	1.6E-1	9.6E-2	1.9E-1	1.7E-1	1.5E-1	47%

Table 4-9. MOUDI Particle Size Distribution Results (Delta – Oil).

Size Fraction (μm)	mg/dscm Oil Run 1	Oil Run 2	Oil Run 3	Oil Run 4	Average	Mass Distribution
1.0-2.5	1.1E+0	1.1E+0	5.3E-1	1.2E-1	7.0E-1	9%
0.32-1	3.5E+0	7.6E-1	3.4E-1	1.2E-1	1.2E+0	15%
0.18-0.32	8.0E-1	1.5E+0	1.2E+0	3.4E-1	9.7E-1	12%
0.1-0.18	4.2E+0	2.6E+0	1.5E+0	9.8E-1	2.3E+0	28%
<0.1	2.4E+0	2.5E+0	4.5E+0	2.7E+0	3.0E+0	37%

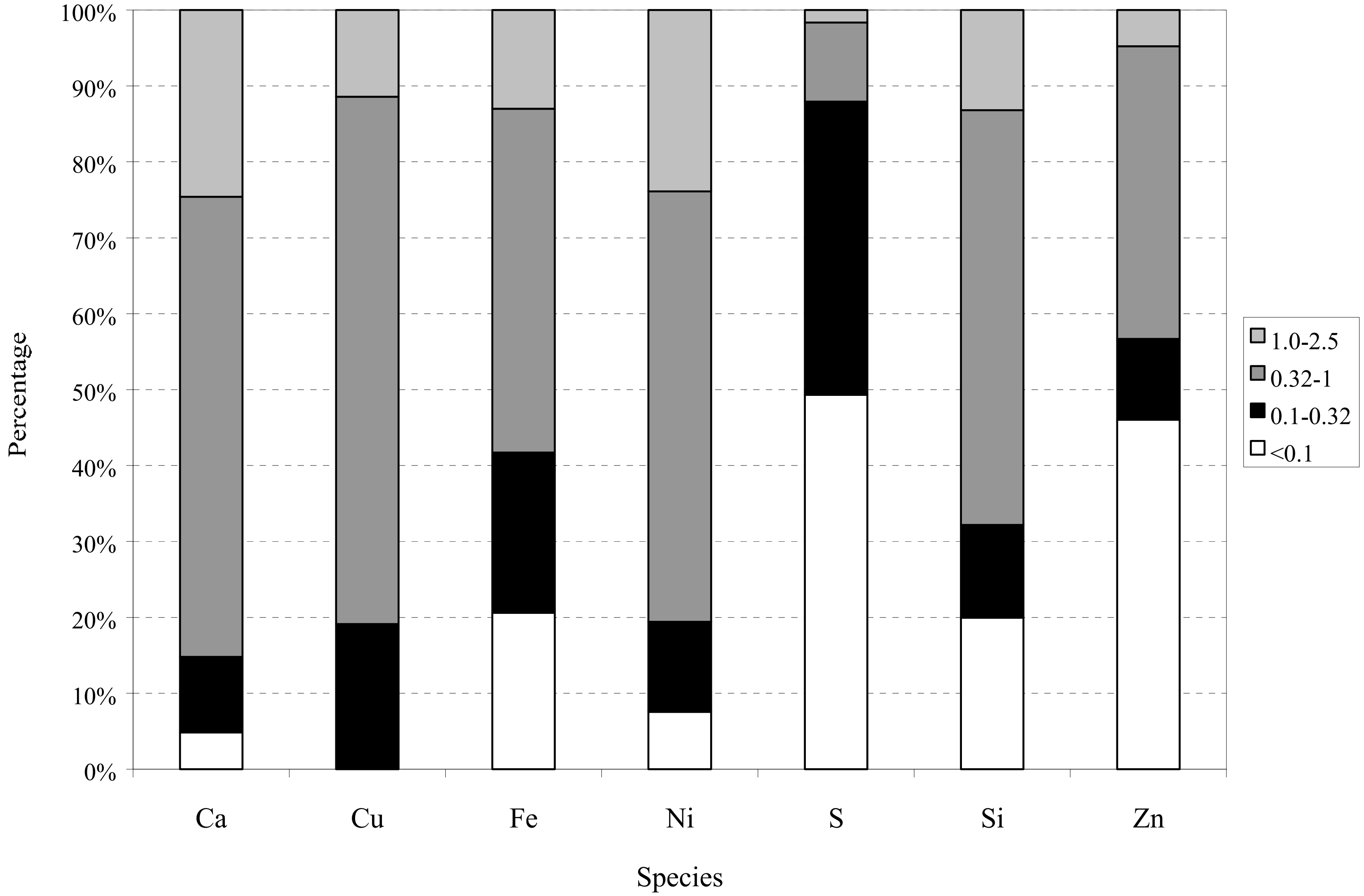

Figure 4-1. Relative Distribution of Elements in Different Size Ranges (Delta – NG).

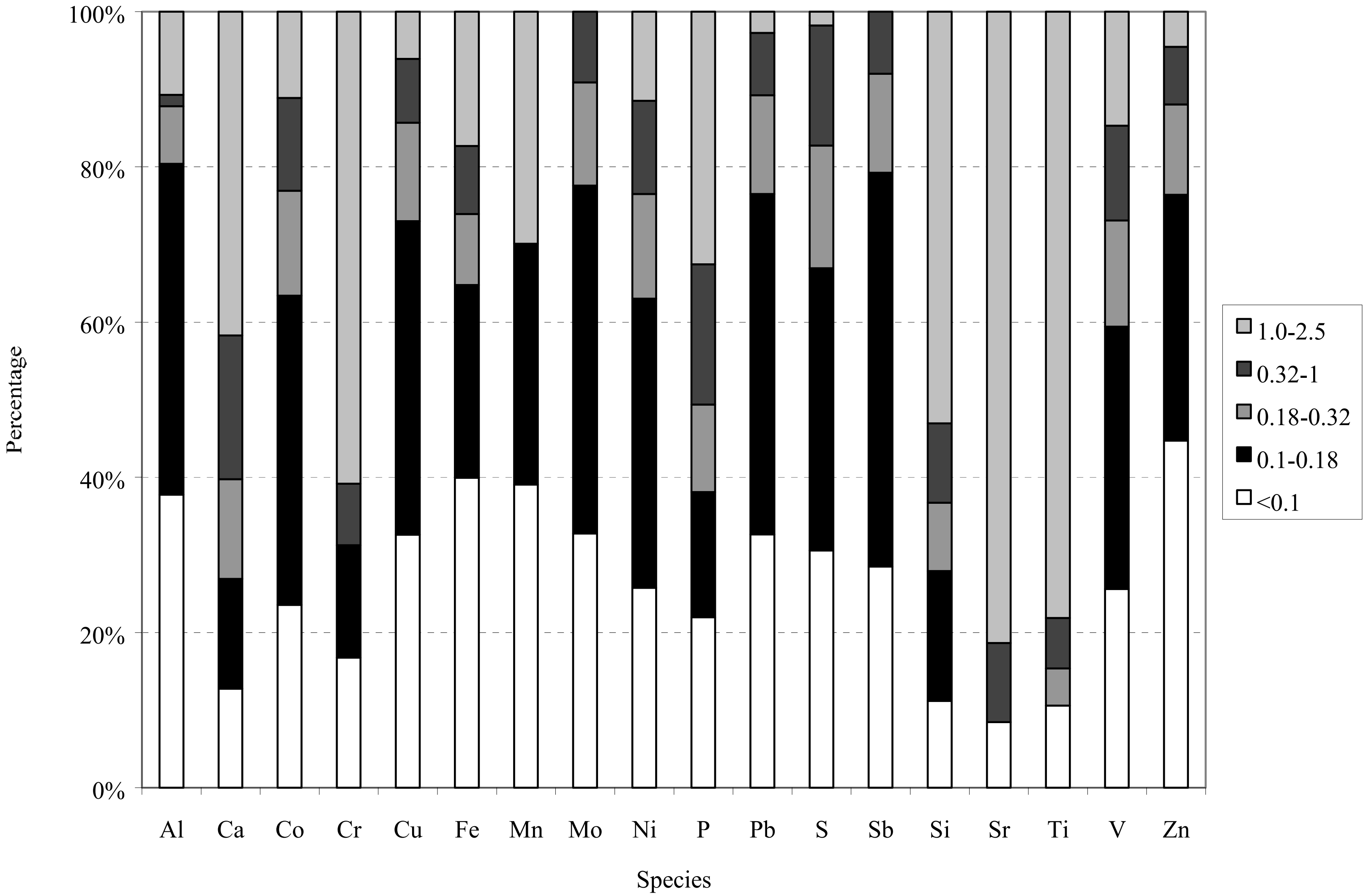

Figure 4-2. Relative Distribution of Elements in Different Size Ranges (Delta - Oil).

Natural Gas Combustion. The total PM2.5 mass collected on the different stages of the MOUDI (0.33 mg/dscm) agrees well with the results from the dilution sampler TMF (0.32 mg/dscm). Most of the individual elements are below detection limits for natural gas combustion due to the combination of low element concentrations in the fuel and combustion air plus the separation of already low PM concentrations into different size fractions. Although an average of 77 percent of the mass was in the fraction less than 0.32 µm, and 90 percent below 1 µm (Table 4-8), greater than 60 percent of the Ca, Cu, Fe, Ni and Si, was found in the accumulation mode, i.e., 0.32-2.5 µm (Figure 4-1). The size distribution of Zn was bimodal. S was present mainly in the condensation mode (i.e., particles with diameter less than 0.32 µm), which is consistent with the nucleation and condensational growth of aerosols originating from species in the vapor state. More significant levels of S were observed in the natural gas results than expected, which indicates the possibility of either entrained boiler ash deposits in the flue gas and/or contamination from S deposited in the sampler during the preceding oil tests.

Oil Combustion. During oil combustion, an average of 77 percent of PM2.5 was in the size range less than 0.32 µm in aerodynamic diameter (Table 4-9), very similar to the natural gas results. The size distribution is bimodal in the condensation and accumulation modes, probably due to the combination of sulfur (with potential to form sulfuric acid in the combustion products) and very fine refractory ash constituents in the fuel oil. The total average PM2.5 concentration measured by the MOUDI (8.2 mg/dscm) and the average concentration from the dilution sampler TMF (14 mg/dscm) are similar. The lower PM2.5 mass concentration observed in the MOUDI may be explained by PM losses associated with the high ash loading and sticky nature of the oil PM.

Al, Ca, Cr, Fe, Si, and Ti are considered refractory metals that do not vaporize during combustion (Meij, 1994), and thus would be expected to be dominant in the larger size fractions. It should be noted that only one sample of Al in the size less than 0.1 µm, and 2 samples in the range of 0.1-0.18 µm were above detection limits, which may distort the actual distribution. For S, a very volatile element, more than 95 percent of the mass was in samples below 1 µm.

Those elements that vaporize during combustion and subsequently condense within the combustion system as the flue gas cools have the potential to become enriched in the fine particle fractions. The relative enrichment factor (RE) is an expression of the fate of trace elements in the ash and emissions from a combustion unit (Meij, 1994).

$$RE = \frac{element\ concentration\ in\ ash}{element\ concentration\ in\ fuel} \times \frac{\%\ ash\ content\ of\ fuel}{100}$$

RE is, therefore, an indicator of the element's degree of volatility (greater RE indicates greater volatility) for those elements that subsequently condense within the combustion system. A bimodal distribution can be observed for Mn and Sr, which have an RE between 1.3 and 2. Pb, Sb, Zn, Co, Cu, Mo, Ni, P, and V have RE greater than 2, and, with the exception of P, more than 85 percent of each element's mass was found in the less than 1.0 μm fraction.

The results indicate that while non-volatile (refractory) elements exist as solids in the flue gas stream, volatile elements that condense are adsorbed or diffused to the surface of pre-existing particles (ash) and condensational growth dominates the particle transformation. Further evidence of this can be seen by comparing the S size distributions for oil and gas combustion. The fraction of S in the range of 0.1-0.32 μm is greater for oil combustion (Figure 4-2) than for natural gas combustion (Figure 4-1), which is mostly less than 0.1 μm. S is the dominant elemental (excluding carbon) PM2.5 constituent in No. 6 oil exhaust, followed by Ni, Si, Fe, Zn and Ca (see Table 4-15b, discussed later).

$SO_4^=$, Cl^-, NO_3^-, NH_4^+ and Na^+ ions

Quartz filters were analyzed for $SO_4^=$, Cl^-, NO_3^-, NH_4^+ and Na^+ ions.

Natural Gas Combustion. Results from the natural gas-fired boilers are shown in Table 4-10a. The analytical lab invalidated the results from Run 4 due to incorrect loading of the filter media by the lab. This error was discovered after the testing was complete. $SO_4^=$ had the highest average concentration at 0.071 mg/dscm, followed by NH_4^+ at 0.019 mg/dscm. All of the stack sample concentrations were at least five times greater than the ambient concentrations. Similar to the PM2.5 results, the natural gas DSB concentrations (Table 6-2a) were equal to or slightly lower than the stack sample averages, indicating there is likely bias in the stack samples from residue (please refer to Section 6 for additional discussion of blank results).

Table 4-10a. Dilution Sampler Sulfate, Nitrate, Chloride, Ammonium, and Soluble Sodium Results (Delta – NG).

Parameter	Units	Value							
Run Number	-	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	NG-Ambient	MDL
Date	-	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02		(%)	08-Apr-02	(1)
Sulfate	mg/dscm	9.2E-2	4.8E-2	7.4E-2	-	7.1E-2 a	31	5.0E-03	2.2E-3
	lb/hr	3.3E-3	1.4E-3	3.1E-3	-	2.6E-3	40	n/a	
Nitrate	mg/dscm	7.9E-3	4.9E-3	2.4E-3	-	5.1E-3 a d	54	7.3E-04	2.2E-3
	lb/hr	2.8E-4	1.4E-4	1.0E-4	-	1.8E-4	54	n/a	
Chloride	mg/dscm	3.3E-3	2.8E-3	3.0E-3	-	3.0E-3 a	8	2.4E-04	2.2E-3
	lb/hr	1.2E-4	8.1E-5	1.3E-4	-	1.1E-4	22	n/a	
Ammonium	mg/dscm	2.6E-2	1.5E-2	1.6E-2	-	1.9E-2 a	31	8.3E-04	2.2E-3
	lb/hr	9.1E-4	4.4E-4	6.8E-4	-	6.8E-4	35	n/a	
Soluble Na	mg/dscm	1.1E-3	9.9E-4	1.0E-3	-	1.1E-3	6	1.8E-04	2.2E-4
	lb/hr	4.0E-5	2.9E-5	4.5E-5	-	3.8E-5	21	n/a	

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
Run 4 invalidated by lab.
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Oil Combustion. The results from the oil-fired boiler are shown in Table 4-10b. $SO_4^{=}$ had the highest average concentration at 5.4 mg/dscm, followed by NH_4^+ at 0.29 mg/dscm. NO_3^- was not detected in any of the oil-operated tests. All detected concentrations from the oil-fired tests were more than an order of magnitude above ambient levels. The average stack concentrations of Cl^-, NH_4^+, and soluble Na were less than five times the concentrations in the DSB; however, the 95% confidence lower bounds for the average concentrations for all compounds were greater than the concentrations in the DSB, suggesting the stack results are significantly different than background levels. All substances were non-detect in the FB (please refer to Section 6 for additional discussion of blank results).

Table 4-10b. Dilution Sampler Sulfate, Nitrate, Chloride, Ammonium, and Soluble Sodium Results (Delta – Oil).

Parameter	Units	Value							
Run Number	-	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Oil-Ambient	MDL
Date	-	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	08-Apr-06	(1)
Sulfate	mg/dscm	5.6E+0	3.3E+0	6.7E+0	6.2E+0	5.4E+0	28	5.0E-3	6.1E-3
	lb/hr	3.1E-1	1.8E-1	3.9E-1	3.7E-1	3.1E-1	30	n/a	
Nitrate	mg/dscm	ND	ND	ND	ND	ND e	n/a	7.3E-4	6.1E-3
	lb/hr	ND	ND	ND	ND	ND	n/a	n/a	
Chloride	mg/dscm	1.7E-2	1.1E-2	1.6E-2	1.4E-2	1.5E-2	18	2.4E-4	6.1E-3
	lb/hr	9.5E-4	6.2E-4	9.4E-4	8.5E-4	8.4E-4	18	n/a	
Ammonium	mg/dscm	3.4E-1	2.0E-1	3.2E-1	3.0E-1	2.9E-1	22	8.3E-4	6.1E-3
	lb/hr	1.9E-2	1.1E-2	1.9E-2	1.8E-2	1.7E-2	23	n/a	
Soluble Na	mg/dscm	1.2E-2	1.3E-2	2.1E-2	1.6E-2	1.5E-2	26	1.8E-4	6.1E-4
	lb/hr	6.6E-4	7.3E-4	1.2E-3	9.3E-4	8.9E-4	29	n/a	

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Particulate Carbon

OC and EC were measured on quartz filters from the dilution sampler as a measurement of particulate carbon emissions including the organic compounds that condense under ambient conditions.

Natural Gas Combustion. The emissions from the natural gas-fired boilers are shown in Table 4-11a. The analytical lab invalidated the results from Run 4 as discussed above. An average OC concentration of 0.21 mg/dscm was measured. EC concentrations ranged from 0.025 to 0.060 mg/dscm with an average of 0.038 mg/dscm; the high variability among the runs causes the EC emission factor to be excluded as non-representative in Section 5. OC accounts for approximately 83 percent of the total carbon mass. Average carbon concentrations measured in the stack gas are about a factor of seven greater than the ambient sample concentration. The natural gas OC DSB concentrations (Table 6-3a) are slightly higher than the natural gas stack sample averages and the total carbon levels in the DSB and the stack samples average are about

Table 4-11a. Dilution Sampler Organic and Elemental Carbon Results (Delta – NG).

Parameter	Units	Value							
Run Number	-	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	NG-Ambient	MDL
Date	-	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02		(%)	08-Apr-02	(1)
Organic Carbon (OC) **	mg/dscm	2.2E-1	2.0E-1	2.1E-1	-	2.1E-1 a	4	2.3E-2	1.7E-2
	lb/hr	7.7E-3	5.8E-3	9.1E-3	-	7.6E-3	22	n/a	
Elemental Carbon (EC)	mg/dscm	2.5E-2	2.9E-2	6.0E-2	-	3.8E-2 a	50	2.5E-3	3.8E-3
	lb/hr	9.0E-4	8.4E-4	2.5E-3	-	1.4E-3	68	n/a	
Total Carbon (TC)*	mg/dscm	2.4E-1	2.3E-1	2.7E-1	-	2.5E-1	9	2.6E-2	3.8E-3
	lb/hr	8.6E-3	6.7E-3	1.2E-2	-	9.0E-3	28	n/a	
Backup Filter OC ***	mg/dscm	2.2E-1	2.0E-1	2.2E-1	-	2.1E-1 a	5	5.1E-3	1.7E-2
	lb/hr	7.8E-3	5.8E-3	9.2E-3	-	7.6E-3	22	n/a	

* TC = OC + EC; TC Average calculated as average of TC runs, not OC Average + EC Average; TC MDL is lesser of OC MDL and EC MDL.

** OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote *** and Sections 6 & 7 for further discussion.

*** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion.

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
Run 4 results invalidated by analytical lab.
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

equal, indicating there is likely bias in the stack samples from oil-fired operation residue (please refer to Section 6 for additional discussion of blank results).

The quartz fiber filters used for OC/EC analysis have the potential for positive OC bias due to adsorption of VOCs on the media and the collected sample. A backup quartz fiber filter placed directly behind the TMF was used to evaluate the potential magnitude of the absorptive bias on the clean media. The OC concentrations on the backup filter and on the primary filter are equal at two significant figures (Table 4-11a); the average results are not significantly different at the 95 percent confidence level. Some individual VOCs were present in the sample at concentrations similar to OC and the sum of measured VOCs is several times higher than OC. Therefore the magnitude of any bias in the OC result is potentially significant, and may be the same magnitude as the measured value. This issue is discussed further in Section 7.

Contradicting this observation is the fact that the total PM2.5 mass is reasonably well accounted for by the reconstructed mass from the individual species measurements (within 28 percent), and on average OC comprises 58 percent of the reconstructed mass, albeit with high uncertainty associated with most of the measurements. The reconstructed mass analysis is discussed in Section 5. The OC artifact is the subject of ongoing studies, and because the artifact is not well understood it is the current convention not to subtract the backup OC from the primary result. However, the similarity of the primary and backup OC results indicates the need for caution when using these results.

Oil Combustion. The emissions from the oil-fired boilers are shown in Table 4-11b. Total carbon emissions were about five times greater during oil-operation than during natural gas operation. OC concentrations ranged from 0.45 to 0.77 mg/dscm. EC concentrations ranged from 0.42 to 0.92 mg/dscm. OC accounts for approximately 52 percent of the total carbon mass. Average carbon concentrations measured in the stack gas are over an order of magnitude greater than the ambient sample concentration. The average stack concentrations of OC and EC were less than five times the concentrations in the DSB; however, the 95% confidence lower bounds for the OC and EC average concentrations were greater than the concentrations in the DSB, suggesting the stack results are significantly different than background levels.

Table 4-11b. Dilution Sampler Organic and Elemental Carbon Results (Delta – Oil).

Parameter	Units	Value							
Run Number	-	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Oil-Ambient	MDL
Date	-	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	08-Apr-06	(1)
Organic Carbon (OC) **	mg/dscm	7.7E-1	6.0E-1	4.5E-1	7.3E-1	6.4E-1	23	2.3E-2	4.6E-2
	lb/hr	4.3E-2	3.4E-2	2.6E-2	4.3E-2	3.6E-2	23	n/a	
Elemental Carbon (EC)	mg/dscm	4.2E-1	9.2E-1	5.8E-1	4.7E-1	6.0E-1	37	2.5E-3	1.1E-2
	lb/hr	2.3E-2	5.1E-2	3.4E-2	2.8E-2	3.4E-2	36	n/a	
Total Carbon (TC)*	mg/dscm	1.2E+0	1.5E+0	1.0E+0	1.2E+0	1.2E+0	17	2.6E-2	1.1E-2
	lb/hr	6.6E-2	8.5E-2	6.0E-2	7.1E-2	7.1E-2	15	n/a	
Backup Filter OC ***	mg/dscm	1.5E-1	1.1E-1	1.1E-1	6.5E-2	1.1E-1 a b	31	5.1E-3	4.6E-2
	lb/hr	8.3E-3	6.4E-3	6.5E-3	3.9E-3	6.3E-3	29	n/a	

* TC = OC + EC; TC Average calculated as average of TC runs, not OC Average + EC Average; TC MDL is lesser of OC MDL and EC MDL.

** OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote *** and Sections 6 & 7 for further discussion.

*** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion.

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

EC was non-detect in the FB and the OC FB level was less than that in the DSB (please refer to Section 6 for additional discussion of blank results). It should be noted that the natural gas results likely have greater potential for positive bias from filter absorption of volatile organic species than the oil results because the natural gas carbon emission levels are much lower. This is supported by the much lower Backup Filter OC/OC ratios for oil-fired operation than for natural gas-fired operation.

Particulate Carbon Speciation

SVOCs were measured to determine the extent to which OC measured on the quartz filters could be speciated. SVOCs were determined on the combined TIGF/PUF/XAD-4/PUF cartridge used with the dilution sampler. This method determines both particulate and vapor phase SVOCs together, but it is assumed that all SVOCs eventually will condense to particulate phase in the atmosphere. The high variability among runs for many of the SVOC compounds results in high uncertainties for their respective emission factors, resulting in their exclusion from presentation in Section 5.

Natural Gas Combustion. Results of the stack emissions and ambient air sample for the natural gas operation are presented in Table 4-12a. 1,3+1,6+1,7-dimethylnaphthalene is the most abundant SVOC in the diluted samples with an average concentration of 0.015 mg/dscm. All but two of the SVOC compounds at detectable levels in the stack gas were over an order of magnitude greater than their concentrations in the ambient air. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 75 percent of the detected SVOCs; DSB levels were greater than the stack sample averages for about 36 percent of the detected compounds. In general, FB concentrations were much lower than DSB levels (please refer to Section 6 for additional discussion of blank results).

Oil Combustion. Results of the stack emissions and ambient air sample for the oil operation are presented in Table 4-12b. 1,3+1,6+1,7-dimethylnaphthalene is the most abundant SVOC in the diluted samples with an average concentration of 0.022 mg/dscm. All the SVOC compounds at detectable levels in the stack gas were over an order of

Table 4-12a. Dilution Sampler Particulate Carbon Speciation Results (Delta – NG).

Parameter	Value							
Units	mg/dscm					%	mg/dscm	
Run Number	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	Ambient	MDL
Date	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02			08-Apr-02	
1,3+1,6+1,7-dimethylnaphthalene	2.0E-2	2.0E-2	1.2E-2	8.6E-3	1.5E-2	38	1.1E-3	4.1E-4
Naphthalene	1.1E-2	2.1E-2	2.7E-3	2.1E-3	9.2E-3 b d	97	1.2E-4	1.7E-3
2-methylnaphthalene	5.5E-3	6.3E-3	3.6E-3	3.1E-3	4.6E-3	33	4.3E-4	1.1E-4
1-methylnaphthalene	3.3E-3	3.5E-3	2.0E-3	1.7E-3	2.6E-3	33	2.2E-4	6.8E-5
2,6+2,7-dimethylnaphthalene	3.3E-3	3.5E-3	2.0E-3	1.5E-3	2.6E-3	38	2.0E-4	1.9E-4
2-Methylbiphenyl	3.7E-3	2.4E-3	5.4E-4	ND	< 2.2E-3 b	72	ND	2.8E-4
1+2-ethylnaphthalene	2.9E-3	2.7E-3	1.2E-3	9.0E-4	1.9E-3 b	53	1.2E-4	2.3E-4
3-Methylbiphenyl	3.0E-3	2.1E-3	5.8E-4	ND	< 1.9E-3 b	64	ND	4.0E-4
A-trimethylnaphthalene	1.5E-3	1.9E-3	9.3E-4	6.0E-4	1.2E-3 a	47	6.3E-5	3.4E-6
9-fluorenone	1.9E-3	2.1E-3	6.6E-4	2.8E-4	1.2E-3 a	72	2.7E-5	2.4E-4
1,4+1,5+2,3-dimethylnaphthalene	1.7E-3	1.6E-3	8.2E-4	7.4E-4	1.2E-3	42	8.0E-5	1.8E-4
C-trimethylnaphthalene	1.4E-3	1.9E-3	7.2E-4	5.2E-4	1.1E-3 a	55	4.4E-5	1.4E-5
B-trimethylnaphthalene	1.2E-3	1.6E-3	7.3E-4	4.7E-4	1.0E-3 a	51	5.0E-5	1.8E-6
Phenanthrene	8.4E-4	1.1E-3	5.9E-4	4.2E-4	7.3E-4 a	39	4.4E-5	1.4E-5
1,2-dimethylnaphthalene	8.9E-4	8.6E-4	5.4E-4	3.7E-4	6.7E-4	38	4.3E-5	1.2E-4
2,3,5+I-trimethylnaphthalene	7.7E-4	9.4E-4	5.3E-4	2.8E-4	6.3E-4	46	3.6E-5	5.4E-6
E-trimethylnaphthalene	7.0E-4	1.0E-3	3.4E-4	2.6E-4	5.8E-4 a	60	2.6E-5	1.8E-6
Acenaphthene	9.1E-4	2.5E-4	ND	ND	< 5.8E-4 a d	81	1.6E-5	4.6E-5
F-trimethylnaphthalene	7.0E-4	8.2E-4	3.8E-4	2.3E-4	5.3E-4 a	52	2.5E-5	1.7E-6
Fluorene	2.6E-4	5.5E-4	2.5E-4	ND	< 3.6E-4 a	48	1.8E-5	2.2E-4
4-Methylbiphenyl	6.1E-4	ND	8.7E-5	ND	< 3.5E-4 b	106	ND	3.4E-5
Pyrene	5.2E-4	4.1E-4	1.9E-4	1.0E-4	3.1E-4 a	62	7.4E-6	7.2E-6
A-methylfluorene	4.0E-4	2.9E-4	3.1E-4	2.0E-4	3.0E-4 a	28	2.9E-5	1.9E-4
Chrysene	3.3E-4	5.6E-4	8.2E-5	4.1E-5	2.5E-4 a b d	96	2.5E-6	3.6E-6
C-methylphenanthrene	3.3E-4	2.2E-4	2.3E-4	2.1E-4	2.5E-4 a	21	2.8E-5	5.0E-5
Anthrone	4.7E-4	1.6E-4	2.7E-4	7.3E-5	2.4E-4 a	70	9.4E-6	1.8E-6
Biphenyl	2.4E-4	3.3E-4	2.1E-4	1.7E-4	2.4E-4 a	28	1.8E-5	1.2E-4
2-methylphenanthrene	3.1E-4	3.5E-4	1.8E-4	1.1E-4	2.4E-4 a	48	1.5E-5	3.6E-6
Dibenzofuran	2.2E-4	3.4E-4	2.3E-4	1.6E-4	2.4E-4 a	33	1.6E-5	1.1E-4
J-trimethylnaphthalene	3.1E-4	3.9E-4	1.1E-4	7.9E-5	2.2E-4 a	68	7.2E-6	1.4E-5
4-methylpyrene	4.0E-4	3.0E-4	1.2E-4	6.6E-5	2.2E-4 a	70	4.0E-6	3.6E-6
Acenaphthylene	2.0E-4	2.4E-4	ND	ND	< 2.2E-4	15	6.7E-6	1.8E-4
9-Anthraldehyde	2.1E-4	ND	ND	ND	< 2.1E-4 e	n/a	1.6E-6	4.8E-5
1-methylfluorene	1.4E-4	2.6E-4	ND	ND	< 2.0E-4 a	43	ND	1.2E-4
A-methylphenanthrene	2.5E-4	2.3E-4	ND	8.9E-5	< 1.9E-4 a	46	1.1E-5	8.6E-5
9-methylanthracene	ND	ND	1.9E-4	1.8E-4	< 1.8E-4 a	5	2.4E-5	8.2E-5
C-dimethylphenanthrene	3.0E-4	2.2E-4	1.0E-4	6.6E-5	1.7E-4 a	63	5.3E-6	5.9E-5
2,4,5-trimethylnaphthalene	2.0E-4	2.8E-4	1.2E-4	6.7E-5	1.7E-4 a	56	8.3E-6	1.4E-5
Benzanthrone	1.7E-4	4.0E-4	7.5E-5	3.5E-5	1.7E-4 a d	96	1.8E-6	1.6E-5
Fluoranthene	2.2E-4	2.3E-4	1.1E-4	6.9E-5	1.6E-4 a	50	5.9E-6	3.6E-6
B-MePy/MeFl	2.4E-4	1.8E-4	7.3E-5	3.7E-5	1.3E-4 a	71	1.1E-6	1.8E-6
Benz(a)anthracene	1.5E-4	3.1E-4	3.3E-5	2.2E-5	1.3E-4 a d	105	6.4E-7	1.1E-5
D-MePy/MeFl	2.1E-4	1.6E-4	7.5E-5	3.9E-5	1.2E-4 a	64	1.9E-6	1.8E-6
Anthraquinone	1.3E-4	1.1E-4	ND	ND	< 1.2E-4	12	ND	9.7E-5
D-dimethylphenanthrene	1.3E-4	9.4E-5	ND	ND	< 1.1E-4 d	23	2.7E-6	5.4E-5
1-methylpyrene	2.0E-4	1.5E-4	6.6E-5	4.0E-5	1.1E-4 a	64	1.8E-6	1.4E-5
3,6-dimethylphenanthrene	9.5E-5	ND	ND	ND	< 9.5E-5 e	n/a	ND	8.4E-5
A-dimethylphenanthrene	9.4E-5	ND	ND	ND	< 9.4E-5 e	n/a	3.1E-6	8.4E-5
5+6-methylchrysene	9.7E-5	1.7E-4	1.7E-5	1.6E-5	7.5E-5 a b d	99	2.4E-6	-
Anthracene	7.1E-5	1.5E-4	2.2E-5	3.5E-5	6.8E-5 a d	81	3.0E-6	-
1-methylphenanthrene	ND	ND	7.9E-5	5.1E-5	< 6.5E-5	31	ND	3.9E-5
E-dimethylphenanthrene	6.7E-5	6.9E-5	2.9E-5	ND	< 5.5E-5	41	1.7E-6	2.7E-5

Table 4-12a. Dilution Sampler Particulate Carbon Speciation Results (Delta – NG) (Continued).

Parameter	Value							
Units	mg/dscm					%	mg/dscm	
Run Number	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	Ambient	MDL
Date	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02			08-Apr-02	
Xanthone	4.4E-5	5.4E-5	3.3E-5	2.5E-5	3.9E-5 a b	33	2.7E-6	7.2E-6
C-MePy/MeFl	6.2E-5	4.5E-5	1.9E-5	7.7E-6	3.3E-5 a b	74	3.2E-7	1.8E-6
Benzo(a)pyrene	4.5E-5	1.9E-5	ND	ND	< 3.2E-5 a b d	57	1.1E-6	1.1E-5
7-methylbenzo(a)pyrene	2.1E-5	ND	ND	ND	< 2.1E-5 e	n/a	7.2E-7	1.3E-5
Benzo(b+j+k)fluoranthene	1.9E-5	1.3E-5	1.7E-5	7.7E-6	1.4E-5 a d	36	8.7E-7	1.8E-6
7-methylbenz(a)anthracene	1.3E-5	1.3E-5	ND	ND	< 1.3E-5 a	3	ND	1.1E-5
Benzonaphthothiophene	1.0E-5	1.1E-5	ND	ND	< 1.1E-5 a d	3	3.0E-7	3.6E-6
B-methylphenanthrene	ND	ND	ND	ND	ND e	n/a	6.2E-7	2.0E-5
Benzo(e)pyrene	ND	ND	ND	ND	ND e	n/a	8.2E-7	1.1E-5
Acenaphthenequinone	ND	ND	ND	ND	ND e	n/a	9.2E-7	1.1E-5

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-12b. Dilution Sampler Particulate Carbon Speciation Results (Delta – Oil).

Parameter	Value									
Units	mg/dscm							%	mg/dscm	
Run Number	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4		Average		RSD	Ambient	MDL
Date	22-Mar-02	23-Mar-02	24-Mar-02	25-Mar-02					08-Apr-02	
1,3+1,6+1,7-dimethylnaphthalene	1.5E-2	2.0E-2	3.2E-2	2.2E-2		2.2E-2	a	32	1.1E-3	8.4E-4
Naphthalene	ND	2.0E-2	8.6E-3	1.4E-2	<	1.4E-2	b	39	1.2E-4	3.6E-3
2-Methylbiphenyl	ND	8.5E-3	ND	ND	<	8.5E-3	e	n/a	ND	5.9E-4
2-methylnaphthalene	4.1E-3	7.7E-3	1.1E-2	1.0E-2		8.1E-3	a	36	4.3E-4	2.3E-4
1-methylnaphthalene	2.2E-3	4.3E-3	5.9E-3	5.6E-3		4.5E-3	a	38	2.2E-4	1.4E-4
2,6+2,7-dimethylnaphthalene	2.8E-3	3.5E-3	5.5E-3	4.1E-3		4.0E-3	a	30	2.0E-4	3.9E-4
3-Methylbiphenyl	ND	4.7E-3	1.6E-3	ND	<	3.1E-3	a b	70	ND	8.3E-4
4-Methylbiphenyl	ND	2.8E-3	ND	ND	<	2.8E-3	e	n/a	ND	7.0E-5
1+2-ethylnaphthalene	1.9E-3	2.7E-3	3.7E-3	2.1E-3		2.6E-3	a b	32	1.2E-4	4.7E-4
Pyrene	4.1E-3	2.2E-3	1.0E-3	7.9E-4		2.0E-3	a	75	7.4E-6	1.5E-5
A-trimethylnaphthalene	6.6E-4	3.1E-3	1.8E-3	2.5E-3		2.0E-3	a	52	6.3E-5	7.0E-6
1,4+1,5+2,3-dimethylnaphthalene	1.5E-3	1.3E-3	1.9E-3	2.1E-3		1.7E-3	a	22	8.0E-5	3.7E-4
Phenanthrene	2.5E-3	1.8E-3	1.2E-3	1.0E-3		1.6E-3		40	4.4E-5	2.9E-5
C-trimethylnaphthalene	4.7E-4	2.6E-3	1.2E-3	1.8E-3		1.5E-3	a	59	4.4E-5	2.9E-5
B-trimethylnaphthalene	3.6E-4	2.3E-3	1.3E-3	2.0E-3		1.5E-3	a	58	5.0E-5	3.7E-6
4-methylpyrene	2.0E-3	1.6E-3	5.1E-4	5.3E-4		1.2E-3		65	4.0E-6	7.4E-6
C-methylphenanthrene	2.6E-3	1.1E-3	5.5E-4	4.1E-4		1.2E-3	a d	88	2.8E-5	1.0E-4
C-dimethylphenanthrene	2.4E-3	1.0E-3	6.6E-4	4.4E-4		1.1E-3		78	5.3E-6	1.2E-4
1,2-dimethylnaphthalene	7.8E-4	9.1E-4	1.4E-3	1.0E-3		1.0E-3	a	26	4.3E-5	2.5E-4
2,3,5+I-trimethylnaphthalene	4.0E-4	1.4E-3	8.3E-4	1.4E-3		1.0E-3	a	48	3.6E-5	1.1E-5
2-methylphenanthrene	1.7E-3	9.6E-4	5.1E-4	4.6E-4		9.1E-4		63	1.5E-5	7.4E-6
Acenaphthene	3.0E-4	1.4E-3	7.8E-4	1.1E-3		9.0E-4	d	53	1.6E-5	9.6E-5
B-MePy/MeFl	1.1E-3	1.3E-3	5.8E-4	4.9E-4		8.7E-4		45	1.1E-6	3.7E-6
E-trimethylnaphthalene	2.2E-4	1.4E-3	7.1E-4	1.0E-3		8.2E-4	a	59	2.6E-5	3.7E-6
9-fluorenone	6.1E-4	1.0E-3	8.9E-4	7.0E-4		8.1E-4		23	2.7E-5	4.9E-4
F-trimethylnaphthalene	3.1E-4	1.1E-3	7.7E-4	9.9E-4		8.0E-4	a	44	2.5E-5	3.5E-6
D-MePy/MeFl	1.3E-3	1.0E-3	3.4E-4	3.2E-4		7.4E-4		66	1.9E-6	3.7E-6
A-methylphenanthrene	1.4E-3	7.0E-4	4.3E-4	3.3E-4		7.2E-4		69	1.1E-5	1.8E-4
1-methylphenanthrene	1.4E-3	ND	3.5E-4	2.7E-4	<	6.8E-4		95	ND	8.1E-5
Acenaphthylene	ND	6.5E-4	ND	ND	<	6.5E-4	e	n/a	ND	3.8E-4
Fluoranthene	1.0E-3	7.0E-4	4.1E-4	3.6E-4		6.3E-4		50	5.9E-6	7.4E-6
A-methylfluorene	ND	5.6E-4	ND	ND	<	5.6E-4	e	n/a	2.9E-5	3.9E-4
D-dimethylphenanthrene	1.2E-3	4.9E-4	2.7E-4	1.5E-4		5.3E-4	d	89	2.7E-6	1.1E-4
Fluorene	ND	5.2E-4	ND	5.1E-4	<	5.1E-4		2	1.8E-5	4.5E-4
Benz(a)anthracene	2.1E-4	2.5E-4	3.0E-4	1.2E-3		4.9E-4	a d	95	6.4E-7	2.2E-5
1-methylpyrene	9.2E-4	7.2E-4	1.2E-4	1.6E-4		4.8E-4	a	84	1.8E-6	2.9E-5
Biphenyl	ND	6.7E-4	2.9E-4	ND	<	4.8E-4	a d	57	1.8E-5	2.5E-4
Dibenzofuran	3.1E-4	6.0E-4	4.6E-4	3.6E-4		4.3E-4	a	30	1.6E-5	2.3E-4
3,6-dimethylphenanthrene	6.6E-4	3.7E-4	1.7E-4	ND	<	4.0E-4		62	ND	1.7E-4
Anthrone	3.9E-4	3.6E-4	6.7E-4	1.7E-4		4.0E-4		52	9.4E-6	3.7E-6
1-methylfluorene	4.0E-4	3.8E-4	ND	ND	<	3.9E-4		5	ND	2.4E-4
A-dimethylphenanthrene	6.6E-4	2.9E-4	1.7E-4	ND	<	3.7E-4		69	ND	1.7E-4
Anthraquinone	6.2E-4	3.8E-4	2.5E-4	2.1E-4		3.6E-4		51	ND	2.0E-4
C-MePy/MeFl	5.2E-4	3.9E-4	1.9E-4	1.6E-4		3.1E-4		54	3.2E-7	3.7E-6
Chrysene	4.7E-4	4.5E-4	1.7E-4	1.1E-4		3.0E-4	a	63	2.5E-6	7.4E-6
J-trimethylnaphthalene	3.8E-5	7.3E-4	2.5E-4	1.8E-4		3.0E-4	a d	101	7.2E-6	3.0E-5
2,4,5-trimethylnaphthalene	9.0E-5	4.5E-4	2.4E-4	3.5E-4		2.8E-4	a	54	8.3E-6	2.9E-5
1,7-dimethylphenanthrene	4.9E-4	1.6E-4	1.2E-4	ND	<	2.6E-4		79	ND	1.2E-4
B-dimethylphenanthrene	2.2E-4	ND	1.1E-4	ND	<	1.6E-4		47	ND	1.2E-4
B-methylphenanthrene	1.5E-4	ND	ND	ND	<	1.5E-4	e	n/a	ND	4.1E-5
E-dimethylphenanthrene	2.3E-4	1.0E-4	7.8E-5	ND	<	1.4E-4	d	61	1.7E-6	5.5E-5

Table 4-12b. Dilution Sampler Particulate Carbon Speciation Results (Delta – Oil) (Continued).

Parameter	Value							
Units	mg/dscm					%	mg/dscm	
Run Number	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Ambient	MDL
Date	22-Mar-02	23-Mar-02	24-Mar-02	25-Mar-02			08-Apr-02	
Anthracene	2.6E-4	1.7E-4	4.1E-5	4.0E-5	1.3E-4 a b d	85	3.0E-6	-
Benzonaphthothiophene	1.9E-5	3.1E-5	3.1E-4	ND	< 1.2E-4 d	137	3.0E-7	7.4E-6
9-Anthraldehyde	1.2E-4	ND	ND	ND	< 1.2E-4 e	n/a	ND	1.0E-4
Benzanthrone	2.2E-4	1.2E-4	7.3E-5	3.5E-5	1.1E-4 a	71	1.8E-6	3.3E-5
Benzo(a)pyrene	ND	9.2E-5	1.2E-4	9.7E-5	< 1.0E-4 a b	16	1.1E-6	2.2E-5
Xanthone	1.7E-4	7.7E-5	3.3E-5	7.2E-5	8.9E-5 b	67	2.7E-6	1.5E-5
7-methylbenzo(a)pyrene	ND	ND	9.5E-5	7.5E-5	< 8.5E-5 d	17	7.2E-7	2.6E-5
Benzo(c)phenanthrene	8.5E-5	ND	ND	ND	< 8.5E-5 e	n/a	ND	4.1E-5
Acenaphthenequinone	ND	ND	7.3E-5	3.2E-5	< 5.3E-5 d	56	9.2E-7	2.2E-5
Benzo(b+j+k)fluoranthene	4.6E-5	ND	ND	ND	< 4.6E-5 e	n/a	8.7E-7	3.7E-6
5+6-methylchrysene	4.4E-5	2.3E-5	2.3E-5	1.5E-5	2.7E-5 a b d	47	2.4E-6	-
9-methylanthracene	ND	ND	ND	ND	ND e	n/a	2.4E-5	1.7E-4
Benzo(e)pyrene	ND	ND	ND	ND	ND e	n/a	8.2E-7	2.3E-5

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

magnitude greater than their concentrations in the ambient air. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 58 percent of the detected SVOCs; DSB levels were greater than the stack sample averages for about 19 percent of the detected compounds. In general, FB concentrations were much lower than DSB levels (please refer to Section 6 for additional discussion of blank results).

Particulate Carbon Precursors and Other VOCs by Tenax

Tenax sorbent was used to collect VOCs with a boiling point of approximately 40 °C and greater. The Tenax sample media is susceptible to degradation from components in the sample stream, producing decomposition byproducts that obscure the actual concentrations in the exhaust gas. In particular, the Tenax results should be viewed as highly uncertain for benzaldehyde, benzoic acid, hexadecanoic acid, phenol and acetophenone, which are all believed to be Tenax decomposition byproducts. Only the reactions of VOCs with carbon numbers higher than seven are considered important in formation of secondary organic aerosols (Grosjean and Seinfeld, 1989), because the products from those having fewer than seven carbon atoms are too volatile to form aerosols under atmospheric conditions; thus, the VOC results are presented as two groups: Particulate Carbon Precursors (VOC with Carbon Number 8 or greater) and Other VOCs (VOC with Carbon Number 7 or less).

Natural Gas Combustion. Results of the stack emissions for the natural gas operation are presented in Table 4-13a. The most abundant VOC in the diluted samples with a carbon number of 8 or greater (particulate carbon precursors) was m & p xylene, with an average concentration of 0.058 mg/dscm. The most abundant VOC in the diluted samples with a carbon number of 7 or less (Other VOCs) was 1,3-dichlorobenzene with an average concentration of 0.036 mg/dscm. Ambient levels were greater than the stack sample averages 95% confidence lower bounds for about 16 percent of the detected VOCs. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 56 percent of the detected VOCs; DSB levels were greater than the stack sample averages for about 15 percent of the detected compounds. In general, FB concentrations were non-detect or lower than DSB levels (please refer to Section 6 for additional discussion of blank results).

Oil Combustion. Results of the stack emissions for the oil operation are presented in Table 4-13b. The most abundant VOC in the diluted samples with a carbon number of 8 or greater (particulate carbon precursors) was decene with an average concentration of 0.25 mg/dscm. The most abundant VOC in the diluted samples with a carbon number of 7 or less (Other VOCs) was 1,3 dichlorobenzene with an average concentration of 0.040 mg/dscm. Ambient levels were greater than the stack sample averages 95% confidence lower bounds for about 32 percent of the detected VOCs. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 68 percent of the detected VOCs; DSB levels were greater than the stack sample averages for about 19 percent of the detected compounds. In general, FB concentrations were non-detect or lower than DSB levels (please refer to Section 6 for additional discussion of blank results).

Table 4-13a. Volatile Organic Compounds from Tenax Sorbent (Delta – NG).

Parameter	Value							
Units	mg/dscm					%		
Run Number	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run4	Average	RSD	NG-Ambient	MDL
Date	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02			08-Apr-02	(1)
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)								
m & p-xylene	5.0E-2	5.1E-2	7.6E-2	5.4E-2	5.8E-2 a d	21	7.7E-2	1.1E-3
(+/-)-limonene	5.5E-2	8.7E-2	4.7E-2	2.4E-2	5.3E-2 a	50	1.8E-3	1.1E-3
Undecane	2.0E-2	1.3E-1	2.0E-2	8.9E-3	4.4E-2 a b d	126	1.4E-3	1.1E-3
Decane	4.0E-2	7.1E-2	3.7E-2	1.2E-2	4.0E-2 a	61	4.5E-3	1.1E-3
Nonane	4.6E-2	6.3E-2	2.8E-2	1.3E-2	3.7E-2 a	58	8.4E-3	1.1E-3
Octadecane	3.3E-2	4.5E-2	4.3E-2	1.8E-2	3.5E-2	36	ND	1.1E-3
Hexadecane	3.3E-2	4.1E-2	4.3E-2	1.8E-2	3.4E-2	34	ND	1.1E-3
Decanal	ND	ND	3.4E-2	ND	< 3.4E-2 e	n/a	ND	1.1E-3
Heptadecane	3.3E-2	4.1E-2	4.0E-2	1.8E-2	3.3E-2	32	ND	1.1E-3
m-ethyltoluene	1.6E-2	3.6E-2	2.3E-2	1.5E-2	2.2E-2 a	43	2.6E-3	1.1E-3
Pentadecane	1.8E-2	2.1E-2	3.7E-2	1.2E-2	2.2E-2 a	48	6.3E-4	1.1E-3
Eicosane	1.5E-2	2.1E-2	3.3E-2	8.9E-3	1.9E-2 a	52	ND	1.1E-3
1,2,4-trimethylbenzene	1.6E-2	3.1E-2	1.7E-2	1.1E-2	1.9E-2 a	46	2.2E-3	1.1E-3
Tetradecane	1.9E-2	2.1E-2	2.0E-2	9.1E-3	1.7E-2 a	31	9.4E-4	1.1E-3
Ethylbenzene	1.3E-2	1.3E-2	2.1E-2	2.1E-2	1.7E-2 a d	27	4.7E-2	1.1E-3
o-xylene	1.4E-2	1.8E-2	2.0E-2	1.6E-2	1.7E-2 a d	13	3.1E-2	1.1E-3
Dodecane	1.2E-2	2.8E-2	1.4E-2	7.1E-3	1.5E-2	59	7.2E-4	1.1E-3
Acetophenone	9.4E-3	1.5E-2	1.1E-2	4.0E-3	9.8E-3	46	2.2E-3	1.1E-3
Nonanal	5.1E-3	8.3E-3	1.5E-2	8.5E-3	9.2E-3 b	45	ND	1.1E-3
p-ethyltoluene	6.5E-3	1.2E-2	1.1E-2	6.9E-3	9.2E-3 a	32	7.8E-4	1.1E-3
3-methyloctane	9.1E-3	1.1E-2	9.1E-3	7.0E-3	9.1E-3 a	18	ND	1.1E-3
Nonadecane	4.1E-3	1.3E-2	ND	5.9E-3	< 7.7E-3 a	61	ND	1.1E-3
1,3,5-trimethylbenzene	5.9E-3	1.3E-2	6.9E-3	5.1E-3	7.7E-3 a	46	1.1E-3	1.1E-3
Tridecane	9.4E-3	9.6E-3	7.2E-3	4.2E-3	7.6E-3 a	33	5.7E-4	1.1E-3
1,6+1,3+1,7-dimethylnaphthalene	8.0E-3	1.2E-2	6.8E-3	3.5E-3	7.5E-3 a	45	5.6E-4	1.1E-3
p-isopropyltoluene	8.7E-3	1.0E-2	6.4E-3	3.8E-3	7.3E-3	39	2.9E-4	1.1E-3
Styrene	9.7E-3	7.2E-3	9.8E-3	1.5E-3	7.0E-3 a	55	2.0E-3	1.1E-3
Naphthalene	6.5E-3	9.1E-3	3.4E-3	ND	< 6.4E-3 a	45	8.2E-4	1.1E-3
Dimethyloctane	5.3E-3	8.3E-3	7.3E-3	2.8E-3	5.9E-3 a	40	5.9E-4	1.1E-3
1-methylindan	6.1E-3	9.1E-3	5.8E-3	2.1E-3	5.8E-3 a d	49	2.9E-3	1.1E-3
o-ethyltoluene	4.4E-3	9.5E-3	4.9E-3	3.3E-3	5.5E-3 a	50	7.4E-4	1.1E-3
2-methylnaphthalene	6.1E-3	8.7E-3	5.1E-3	2.1E-3	5.5E-3 a	49	4.5E-4	1.1E-3
2-methyloctane	4.7E-3	4.9E-3	4.6E-3	2.6E-3	4.2E-3 a	25	1.6E-3	1.1E-3
Propylbenzene	2.9E-3	6.3E-3	3.8E-3	3.4E-3	4.1E-3 a	37	4.9E-4	1.1E-3
1-decene	3.1E-3	4.9E-3	ND	ND	< 4.0E-3 a d	31	5.8E-4	1.1E-3
1-undecene	ND	3.7E-3	ND	ND	< 3.7E-3 e	n/a	ND	1.1E-3
Octanal	2.3E-3	3.7E-3	4.0E-3	3.6E-3	3.4E-3 a	22	ND	1.1E-3
B-dimethylindane	4.0E-3	4.6E-3	2.7E-3	1.8E-3	3.3E-3 a	38	ND	1.1E-3
Propylcyclohexane	3.2E-3	4.4E-3	3.7E-3	1.7E-3	3.3E-3 a	36	3.3E-4	1.1E-3
1-methylnaphthalene	3.1E-3	4.6E-3	2.2E-3	1.4E-3	2.8E-3 a	49	2.5E-4	1.1E-3
2,6+2,7-dimethylnaphthalene	2.1E-3	3.5E-3	2.1E-3	ND	< 2.6E-3	30	1.3E-4	1.1E-3
4-ethyl-o-xylene	2.1E-3	3.5E-3	1.7E-3	ND	< 2.4E-3 a	39	3.1E-4	1.1E-3
2-methylindan	1.8E-3	2.6E-3	ND	ND	< 2.2E-3 d	26	7.7E-4	1.1E-3
Indan	1.6E-3	3.8E-3	2.0E-3	9.9E-4	2.1E-3	57	1.0E-4	1.1E-3
Phenanthrene	1.8E-3	2.0E-3	2.4E-3	ND	< 2.1E-3	14	ND	1.1E-3
5-ethyl-m-xylene	1.6E-3	2.9E-3	1.5E-3	ND	< 2.0E-3 a	40	2.8E-4	1.1E-3
Isopropylbenzene	ND	1.9E-3	ND	ND	< 1.9E-3 e	n/a	1.4E-4	1.1E-3
Dodecene	1.2E-3	2.7E-3	ND	ND	< 1.9E-3	56	ND	1.1E-3
A-dimethylindane	1.8E-3	ND	ND	ND	< 1.8E-3 e	n/a	6.1E-4	1.1E-3
4-n-propyltoluene + 1,4-diethylbenzen	1.5E-3	2.2E-3	ND	ND	< 1.8E-3 d	27	1.9E-4	1.1E-3
1,2,3,5-tetramethylbenzene	1.4E-3	2.7E-3	1.2E-3	ND	< 1.7E-3	48	1.6E-4	1.1E-3
D-dimethylindan	1.9E-3	1.5E-3	ND	ND	< 1.7E-3	14	4.1E-4	1.1E-3
m-isopropyltoluene	ND	1.7E-3	ND	ND	< 1.7E-3 e	n/a	1.0E-4	1.1E-3
2-ethyl-p-xylene	1.3E-3	1.8E-3	ND	ND	< 1.5E-3 d	21	7.6E-5	1.1E-3

Table 4-13a. Volatile Organic Compounds from Tenax Sorbent (Delta – NG) (Continued).

Parameter	Value							
Units	mg/dscm					%		
Run Number Date	NG-Run 1 02-Apr-02	NG-Run 2 03-Apr-02	NG-Run 3 04-Apr-02	NG-Run4 05-Apr-02	Average	RSD	NG-Ambient 08-Apr-02	MDL (1)
1,3-diethylbenzene	1.1E-3	1.8E-3	ND	ND	< 1.4E-3 d	32	1.2E-4	1.1E-3
1,2,4,5-tetramethylbenzene	ND	1.4E-3	ND	ND	< 1.4E-3 e	n/a	1.0E-4	1.1E-3
2,3+1,5+1,4-dimethylnaphthalene	ND	1.3E-3	ND	ND	< 1.3E-3 e	n/a	7.0E-5	1.1E-3
1-nonene	ND	ND	1.3E-3	ND	< 1.3E-3 e	n/a	ND	1.1E-3
1,2,3,4-tetramethylbenzene	ND	1.3E-3	ND	ND	< 1.3E-3 e	n/a	1.4E-4	1.1E-3
2,3-benzofuran	1.2E-3	1.4E-3	ND	ND	< 1.3E-3 a	11	ND	1.1E-3
2-n-propyltoluene	ND	ND	ND	ND	ND e	n/a	5.5E-4	1.1E-3
alpha-Pinene	ND	ND	ND	ND	ND e	n/a	8.4E-5	1.1E-3
Butylbenzene	ND	ND	ND	ND	ND e	n/a	8.1E-5	1.1E-3
4-methylstyrene	ND	ND	ND	ND	ND e	n/a	6.5E-5	1.1E-3
1,2,3-trimethylbenzene	ND	ND	ND	ND	ND e	n/a	6.2E-5	1.1E-3
1+2-ethylnaphthalene	ND	ND	ND	ND	ND e	n/a	5.8E-5	1.1E-3
Pentylbenzene	ND	ND	ND	ND	ND e	n/a	5.1E-5	1.1E-3
Isobutylbenzene	ND	ND	ND	ND	ND e	n/a	4.1E-5	1.1E-3
1,2-diethylbenzene	ND	ND	ND	ND	ND e	n/a	3.7E-5	1.1E-3
Other VOCs (Carbon Number 7 or less)								
1,3-dichlorobenzene	6.4E-2	3.3E-2	3.3E-2	1.3E-2	3.6E-2 a	59	3.8E-3	1.1E-3
Cyclohexanone	1.9E-2	3.6E-2	3.4E-2	3.0E-2	3.0E-2 a	26	5.6E-3	1.1E-3
Benzaldehyde	1.7E-2	2.9E-2	4.1E-2	2.5E-2	2.8E-2 a	37	3.2E-3	1.1E-3
Phenol	1.6E-2	2.5E-2	* 1.8E-2	3.9E-3	1.6E-2	56	2.5E-3	1.1E-3
Heptanal	6.8E-3	ND	ND	ND	< 6.8E-3 e	n/a	7.7E-4	1.1E-3
Butyl acetate	4.3E-3	5.7E-3	ND	ND	< 5.0E-3 d	21	5.0E-4	1.1E-3
1,2-dichlorobenzene	3.0E-3	4.3E-3	3.3E-3	2.3E-3	3.2E-3 a	27	5.1E-4	1.1E-3
t-2-heptenal	ND	1.5E-3	ND	ND	< 1.5E-3 e	n/a	ND	1.1E-3
m & p-methylphenol	1.3E-3	ND	ND	ND	< 1.3E-3 e	n/a	6.4E-5	1.1E-3
2-heptanone	ND	ND	ND	ND	ND e	n/a	2.1E-4	1.1E-3

* More than 50% of the compound was collected in the backup sample tube, indicating possible breakthrough

** The compound was detected in the backup sample tube but not detected in the first sample tube, indicating possible breakthrough

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-13b. Volatile Organic Compounds from Tenax Sorbent (Delta – Oil)

Parameter	Value							
Units	mg/dscm					%		
Run Number Date	Oil-Run 1 22-Mar-02	Oil-Run 2 23-Mar-02	Oil-Run 3 25-Mar-02	Oil-Run4 26-Mar-02	Average	RSD	Ambient 08-Apr-02	MDL (1)
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)								
Decane	3.2E-2	2.5E-2	3.7E-2	9.2E-1	2.5E-1 a b d	175	4.5E-3	1.5E-3
Nonane	5.6E-2	3.6E-2	6.2E-2	5.8E-1	1.8E-1 a d	145	8.4E-3	1.5E-3
Undecane	2.3E-2	2.1E-2	1.9E-2	2.9E-1	8.8E-2 a b d	152	1.4E-3	1.5E-3
Pentadecane	1.0E-1	3.6E-2	9.0E-2	* 8.2E-2	7.7E-2	37	6.3E-4	1.5E-3
Hexadecane	7.3E-2	4.3E-2	5.8E-2	5.9E-2	5.9E-2 a	21	ND	1.5E-3
m & p-xylene	3.0E-2	2.9E-2	6.2E-2	1.1E-1	5.8E-2 a d	66	7.7E-2	1.5E-3
(+/-)-limonene	2.6E-2	3.4E-2	2.7E-2	9.4E-2	4.5E-2 a	72	1.8E-3	1.5E-3
Heptadecane	4.8E-2	4.0E-2	4.6E-2	4.5E-2	4.5E-2 a	7	ND	1.5E-3
Tetradecane	6.0E-2	2.3E-2	5.2E-2	4.3E-2	4.4E-2	36	9.4E-4	1.5E-3
Dodecane	1.6E-2	1.3E-2	1.6E-2	9.6E-2	3.5E-2 a b d	115	7.2E-4	1.5E-3
Decanal	4.5E-2	ND	** 2.1E-2	ND	< 3.3E-2 b	52	ND	1.5E-3
Octadecane	4.3E-2	2.8E-2	3.2E-2	2.9E-2	3.3E-2 a	21	ND	1.5E-3
Dimethyloctane	3.1E-3	ND	2.4E-3	8.0E-2	< 2.8E-2 a d	157	5.9E-4	1.5E-3
1,6+1,3+1,7-dimethylnaphthalene	1.7E-2	2.1E-2	2.3E-2	5.2E-2	2.8E-2 a	58	5.6E-4	1.5E-3
1,2,4-trimethylbenzene	1.3E-2	1.4E-2	1.8E-2	5.3E-2	2.4E-2 a d	78	2.2E-3	1.5E-3
2-methylnaphthalene	1.3E-2	1.5E-2	2.0E-2	3.9E-2	2.2E-2 a	55	4.5E-4	1.5E-3
p-isopropyltoluene	3.0E-2	2.1E-2	1.7E-2	1.7E-2	2.1E-2 a	29	2.9E-4	1.5E-3
m-ethyltoluene	1.2E-2	1.0E-2	2.4E-2	3.3E-2	2.0E-2 a	55	2.6E-3	1.5E-3
Naphthalene	7.9E-3	1.4E-2	1.7E-2	3.5E-2	1.8E-2 a	62	8.2E-4	1.5E-3
o-xylene	1.0E-2	8.8E-3	1.7E-2	3.5E-2	1.8E-2 a d	68	3.1E-2	1.5E-3
Ethylbenzene	9.5E-3	9.2E-3	1.9E-2	3.1E-2	1.7E-2 a d	59	4.7E-2	1.5E-3
Propylcyclohexane	2.2E-3	1.9E-3	1.7E-3	6.2E-2	1.7E-2 a d	177	3.3E-4	1.5E-3
Tridecane	2.3E-2	1.0E-2	2.1E-2	* 1.2E-2	1.7E-2	38	5.7E-4	1.5E-3
Octanal	1.5E-2	1.0E-2	1.8E-2	1.4E-2	1.4E-2	21	ND	1.5E-3
Eicosane	1.5E-2	8.7E-3	1.8E-2	8.9E-3	1.3E-2 a	37	ND	1.5E-3
3-methyloctane	4.3E-3	2.4E-3	6.3E-3	3.6E-2	1.2E-2 a	130	ND	1.5E-3
1-methylnaphthalene	7.3E-3	8.4E-3	1.1E-2	2.3E-2	1.2E-2 a	57	2.5E-4	1.5E-3
1-decene	7.0E-3	ND	7.1E-3	** 2.3E-2	< 1.2E-2 d	73	5.8E-4	1.5E-3
1-methylindan	5.4E-3	9.3E-3	7.3E-3	2.4E-2	1.2E-2 a d	74	2.9E-3	1.5E-3
Nonanal	2.4E-2	** 2.3E-3	** 4.8E-3	1.1E-2	1.1E-2 a b	93	ND	1.5E-3
p-ethyltoluene	5.5E-3	6.5E-3	4.5E-3	2.4E-2	1.0E-2 a d	92	7.8E-4	1.5E-3
1,3,5-trimethylbenzene	5.7E-3	5.1E-3	7.7E-3	2.0E-2	9.6E-3 a	73	1.1E-3	1.5E-3
Styrene	9.1E-3	ND	4.5E-3	1.4E-2	< 9.3E-3 a d	52	2.0E-3	1.5E-3
2,6+2,7-dimethylnaphthalene	6.1E-3	6.3E-3	7.7E-3	1.6E-2	9.0E-3 a	51	1.3E-4	1.5E-3
1,2,4,5-tetramethylbenzene	ND	ND	ND	7.6E-3	< 7.6E-3 e	n/a	1.0E-4	1.5E-3
Nonadecane	5.9E-3	8.5E-3	7.4E-3	7.6E-3	7.3E-3 a	15	ND	1.5E-3
2-ethyl-p-xylene	ND	ND	ND	7.1E-3	< 7.1E-3 e	n/a	7.6E-5	1.5E-3
Acetophenone	5.3E-3	3.0E-3	7.4E-3	1.2E-2	6.9E-3 a b	56	2.2E-3	1.5E-3
2-methyloctane	2.5E-3	ND	2.9E-3	1.5E-2	< 6.8E-3 a d	105	1.6E-3	1.5E-3
o-ethyltoluene	3.5E-3	3.7E-3	5.7E-3	1.4E-2	6.7E-3 a	73	7.4E-4	1.5E-3
B-dimethylindane	3.0E-3	2.1E-3	ND	1.1E-2	< 5.5E-3 a	93	ND	1.5E-3
Biphenyl	5.0E-3	ND	3.7E-3	7.3E-3	< 5.3E-3 a	35	ND	1.5E-3
2,3-benzofuran	1.6E-3	* 6.0E-3	3.7E-3	* 7.5E-3	4.7E-3 a	55	ND	1.5E-3
2-methylindan	2.6E-3	5.2E-3	2.1E-3	8.5E-3	4.6E-3 a	63	7.7E-4	1.5E-3
1,2,3,4-tetramethylbenzene	ND	ND	ND	4.3E-3	< 4.3E-3 e	n/a	1.4E-4	1.5E-3
1,2,3,5-tetramethylbenzene	2.2E-3	2.3E-3	2.3E-3	1.0E-2	4.2E-3 a d	93	1.6E-4	1.5E-3
Propylbenzene	2.6E-3	2.5E-3	3.6E-3	7.5E-3	4.0E-3 a	58	4.9E-4	1.5E-3
4-ethyl-o-xylene	ND	2.4E-3	1.6E-3	7.8E-3	< 3.9E-3 a d	87	3.1E-4	1.5E-3

Table 4-13b. Volatile Organic Compounds from Tenax Sorbent (Delta – Oil) (Continued).

Parameter	Value							
Units	mg/dscm					%		
Run Number	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run4	Average	RSD	Ambient	MDL
Date	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02			08-Apr-02	(1)
5-ethyl-m-xylene	2.0E-3	1.9E-3	2.2E-3	8.3E-3	3.6E-3 a d	87	2.8E-4	1.5E-3
Indan	ND	1.9E-3	2.6E-3	6.1E-3	< 3.6E-3 a d	63	1.0E-4	1.5E-3
A-dimethylindane	ND	3.5E-3	ND	ND	< 3.5E-3 e	n/a	6.1E-4	1.5E-3
m-isopropyltoluene	ND	ND	ND	3.4E-3	< 3.4E-3 e	n/a	1.0E-4	1.5E-3
2,3+1,5+1,4-dimethylnaphthalene	2.5E-3	2.2E-3	3.0E-3	5.9E-3	3.4E-3 a	50	7.0E-5	1.5E-3
2-n-propyltoluene	ND	ND	3.4E-3	ND	< 3.4E-3 e	n/a	5.5E-4	1.5E-3
Phenanthrene	4.8E-3	3.0E-3	3.0E-3	2.1E-3	3.2E-3 a	35	ND	1.5E-3
1+2-ethylnaphthalene	1.8E-3	1.8E-3	2.5E-3	5.4E-3	2.9E-3 a	60	5.8E-5	1.5E-3
1,3-diisopropylbenzene	ND	ND	2.7E-3	ND	< 2.7E-3 e	n/a	ND	1.5E-3
4-n-propyltoluene + 1,4-diethylbenzen	ND	1.7E-3	1.7E-3	4.3E-3	< 2.6E-3 d	59	1.9E-4	1.5E-3
D-dimethylindan	ND	2.3E-3	ND	2.6E-3	< 2.4E-3	10	4.1E-4	1.5E-3
4-methylstyrene	ND	2.3E-3	ND	1.4E-3	< 1.9E-3 d	34	6.5E-5	1.5E-3
1,3-diethylbenzene	ND	ND	1.3E-3	2.1E-3	< 1.7E-3 d	31	1.2E-4	1.5E-3
1-nonene	ND	1.7E-3	1.4E-3	ND	< 1.6E-3	14	ND	1.5E-3
1,2-dimethylnaphthalene	ND	ND	1.6E-3	1.5E-3	< 1.6E-3	4	ND	1.5E-3
Isopropylbenzene	ND	ND	ND	1.5E-3	< 1.5E-3 e	n/a	1.4E-4	1.5E-3
alpha-Pinene	ND	ND	ND	ND	ND e	n/a	8.4E-5	1.5E-3
Butylbenzene	ND	ND	ND	ND	ND e	n/a	8.1E-5	1.5E-3
1,2,3-trimethylbenzene	ND	ND	ND	ND	ND e	n/a	6.2E-5	1.5E-3
Pentylbenzene	ND	ND	ND	ND	ND e	n/a	5.1E-5	1.5E-3
Isobutylbenzene	ND	ND	ND	ND	ND e	n/a	4.1E-5	1.5E-3
1,2-diethylbenzene	ND	ND	ND	ND	ND e	n/a	3.7E-5	1.5E-3
Other VOCs (Carbon Number 7 or less)								
1,3-dichlorobenzene	1.7E-2	4.7E-2	3.0E-2	6.6E-2	4.0E-2 a	54	3.8E-3	1.5E-3
Benzaldehyde	ND	ND	1.7E-2	* 3.4E-2	< 2.6E-2 a b d	47	3.2E-3	1.5E-3
Cyclohexanone	ND	2.3E-2	1.4E-2	** 3.0E-2	< 2.3E-2	35	5.6E-3	1.5E-3
Butyl acetate	ND	ND	ND	1.6E-2	< 1.6E-2 e	n/a	5.0E-4	1.5E-3
Phenol	7.3E-3	9.7E-3	1.8E-2	2.7E-2	1.5E-2 a	57	2.5E-3	1.5E-3
t-2-heptenal	ND	ND	2.0E-3	1.7E-2	< 9.7E-3 a	113	ND	1.5E-3
1,2-dichlorobenzene	3.7E-3	3.7E-3	8.9E-3	1.7E-2	8.4E-3 a	76	5.1E-4	1.5E-3
2-heptanone	ND	ND	2.4E-3	2.4E-3	< 2.4E-3	2	2.1E-4	1.5E-3
m & p-methylphenol	ND	ND	1.7E-3	ND	< 1.7E-3 e	n/a	6.4E-5	1.5E-3
Heptanal	ND	ND	ND	ND	ND e	n/a	7.7E-4	1.5E-3

* More than 50% of the compound was collected in the backup sample tube, indicating possible breakthrough

** The compound was detected in the backup sample tube but not detected in the first sample tube, indicating possible breakthrough

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Particulate Carbon Precursors and Other VOCs by Canisters

Stainless steel canisters were used to measure VOCs for which Tenax may not work well and low molecular weight VOCs that could contribute to ozone formation and/or OC measurement artifacts. The analysis of the sample obtained from the canisters allows for detection of organic species with carbon numbers as low as two. The VOC results are presented as two groups: Particulate Carbon Precursors (VOC with Carbon Number 8 or greater) and Other VOCs (VOC with Carbon Number 7 or less).

Natural Gas Combustion. Results of the stack emissions for the natural gas operation are presented in Table 4-14a. The most abundant VOC in the diluted samples with a carbon number of 8 or greater (particulate carbon precursors) was 1-decene with an average concentration of 0.20 mg/dscm. The most abundant VOC in the diluted samples with a carbon number of 7 or less (Other VOCs) was n-butane with an average concentration of 0.35 mg/dscm. All stack sample averages were at least eight times greater than the concentrations measured in the ambient samples. Ambient levels were greater than the stack sample averages 95% confidence lower bounds for about 17 percent of the detected VOCs. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 87 percent of the detected VOCs; DSB levels were greater than the stack sample averages for about 15 percent of the detected compounds. Please refer to Section 6 for additional discussion of blank results.

Oil Combustion. Results of the stack emissions for the oil operation are presented in Table 4-14b. The most abundant VOC in the diluted samples with a carbon number of 8 or greater (particulate carbon precursors) was 1-decene with an average concentration of 0.15 mg/dscm. The most abundant VOC in the diluted samples with a carbon number of 7 or less (Other VOCs) was acetone with an average concentration of 0.59 mg/dscm. All stack sample averages were greater than the concentrations measured in the ambient sample and over 97% of the stack sample averages were over an order of magnitude greater than the concentrations measured in the ambient sample. Ambient levels were greater than the stack sample averages 95% confidence lower bounds for about 27 percent of the detected VOCs. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 88 percent of the detected VOCs; DSB levels were greater than the stack sample averages for about 45 percent of the detected compounds. Please refer to Section 6 for additional discussion of blank results.

Elements

Element concentrations were measured by XRF analysis of the TMFs used in the dilution sampler. Mg and Na results are considered semi-quantitative because of interferences in the XRF analysis.

Table 4-14a. Volatile Organic Compounds from Canisters (Delta – NG).

Parameter	Value										
Units	mg/dscm								(%)	mg/dscm	
Run Number Date	NG-Run 1 2-Apr-02	NG-Run 2 3-Apr-02	NG-Run 3 4-Apr-02	NG-Run 4 5-Apr-02		Stack Average			RSD	NG-Ambient 8-Apr-02	MDL (1)
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)											
1-decene	2.6E-1	2.7E-1	1.5E-1	1.1E-1		2.0E-1	a		40	4.5E-3	3.4E-4
2,3,5-trimethylhexane	6.8E-2	1.7E-1	7.0E-2	5.5E-2		9.1E-2	a		59	1.8E-3	3.4E-4
m- & p-xylene	9.6E-2	1.0E-1	6.3E-2	4.7E-2		7.7E-2	a		34	3.9E-3	3.4E-4
Limonene	7.6E-2	1.1E-1	4.1E-2	2.8E-2		6.4E-2	a		58	2.0E-3	3.4E-4
n-undecane	2.8E-2	1.9E-1	2.3E-2	1.3E-2		6.3E-2	a	d	133	1.1E-3	3.4E-4
n-decane	4.9E-2	6.4E-2	4.8E-2	1.8E-2		4.5E-2	a		44	1.5E-3	3.4E-4
Styrene + heptanal	3.7E-2	6.6E-2	1.1E-2	1.2E-2		3.2E-2	a	d	83	9.4E-4	3.4E-4
o-xylene	3.5E-2	4.6E-2	2.3E-2	1.9E-2		3.1E-2	a		40	1.5E-3	3.4E-4
m-ethyltoluene	3.0E-2	4.8E-2	2.1E-2	1.6E-2		2.9E-2	a		49	1.2E-3	3.4E-4
n-nonane	3.0E-2	4.0E-2	2.1E-2	1.2E-2		2.6E-2	a		47	1.1E-3	3.4E-4
Ethylbenzene	3.1E-2	3.1E-2	1.8E-2	1.3E-2		2.3E-2	a		39	1.1E-3	3.4E-4
Isobutylbenzene	4.1E-2	2.6E-2	1.7E-2	9.6E-3		2.3E-2	a		57	1.1E-3	3.4E-4
1,2,3-trimethylbenzene	2.1E-2	3.3E-2	1.4E-2	9.9E-3		2.0E-2	a		51	7.0E-4	3.4E-4
1,3,5-trimethylbenzene	2.0E-2	2.9E-2	1.5E-2	9.6E-3		1.8E-2	a		45	7.6E-4	3.4E-4
2,2,5-trimethylhexane	6.2E-2	4.8E-3	2.6E-3	9.6E-4		1.8E-2	a	d	169	9.2E-5	3.4E-4
2-methyloctane	3.5E-2	1.1E-2	ND	9.6E-4	<	1.6E-2	a	d	111	1.6E-4	3.4E-4
n-octane	2.1E-2	2.0E-2	1.1E-2	9.2E-3		1.5E-2	a		40	9.9E-4	3.4E-4
n-dodecane	1.4E-2	2.8E-2	7.8E-3	6.4E-3		1.4E-2	a		71	4.5E-4	3.4E-4
Isopropylcyclohexane	1.7E-2	2.2E-2	1.2E-2	6.7E-3		1.4E-2	a		45	6.9E-4	3.4E-4
Nonanal	6.8E-3	4.1E-2	2.2E-3	8.0E-3		1.4E-2	a	d	123	3.7E-4	3.4E-4
alpha-pinene	1.1E-2	1.4E-2	4.4E-3	2.3E-2		1.3E-2	a		58	7.2E-5	3.4E-4
2,2,4-trimethylpentane	1.7E-2	2.0E-2	8.1E-3	7.7E-3		1.3E-2	a		47	9.4E-4	3.4E-4
2,3,-trimethylpentane	3.2E-2	8.3E-3	4.1E-3	3.8E-3		1.2E-2	a	d	111	4.0E-4	3.4E-4
Octanal	6.4E-3	3.2E-2	4.4E-3	3.5E-3		1.2E-2	a	d	119	4.9E-4	3.4E-4
p-ethyltoluene	1.1E-2	2.0E-2	7.8E-3	6.7E-3		1.1E-2	a		52	4.4E-4	3.4E-4
3-methyloctane	1.3E-2	1.1E-2	8.1E-3	6.4E-3		9.8E-3	a		32	4.9E-4	3.4E-4
o-ethyltoluene	1.0E-2	1.6E-2	6.3E-3	6.1E-3		9.5E-3	a		47	3.8E-4	3.4E-4
n-propylbenzene	9.7E-3	1.6E-2	7.0E-3	5.1E-3		9.3E-3	a		49	3.5E-4	3.4E-4
Indan	8.6E-3	1.7E-2	6.7E-3	2.9E-3		8.7E-3	a		67	3.4E-4	3.4E-4
2-methylheptane	1.1E-2	1.1E-2	5.9E-3	6.1E-3		8.4E-3	a		33	5.8E-4	3.4E-4
3-methylheptane	1.0E-2	1.1E-2	5.6E-3	5.4E-3		8.1E-3	a		37	4.9E-4	3.4E-4
1,4-diethylbenzene	4.3E-3	1.7E-2	5.6E-3	4.8E-3		8.0E-3	a		78	3.4E-4	3.4E-4
C11 paraffin A	1.8E-3	2.1E-2	1.9E-3	1.3E-3		6.6E-3	a	d	150	9.2E-5	3.4E-4
Naphthalene	5.4E-3	1.2E-2	3.3E-3	3.8E-3		6.1E-3	a		64	3.2E-4	3.4E-4
1,2,4,5-tetramethylbenzene	4.3E-3	1.5E-2	3.3E-3	1.9E-3		6.0E-3	a	d	96	2.1E-4	3.4E-4
3-ethylpentane	6.4E-3	7.3E-3	4.4E-3	4.1E-3		5.6E-3	a		27	5.2E-4	3.4E-4
3,6-dimethyloctane	6.1E-3	7.6E-3	5.9E-3	2.6E-3		5.5E-3	a		38	2.3E-4	3.4E-4
2,6-dimethyloctane	ND	5.5E-3	ND	ND	<	5.5E-3	e		n/a	1.1E-4	3.4E-4
C9 olefin 3	7.9E-3	7.6E-3	3.7E-3	2.6E-3		5.4E-3	a		50	3.5E-4	3.4E-4
Isopropylbenzene	5.7E-3	9.0E-3	4.1E-3	2.6E-3		5.3E-3	a		52	2.2E-4	3.4E-4
C10 aromatic 2	3.2E-3	1.1E-2	3.3E-3	2.9E-3		5.2E-3	a		79	1.9E-4	3.4E-4
Isopropyltoluene	5.4E-3	1.0E-2	2.2E-3	2.6E-3		5.1E-3	a		73	2.5E-4	3.4E-4
1,3-diethylbenzene	6.4E-3	8.6E-3	1.9E-3	2.2E-3		4.8E-3	a		69	1.2E-4	3.4E-4
1-methylindan	1.4E-3	1.6E-2	1.1E-3	9.6E-4		4.8E-3	a	d	151	7.2E-5	3.4E-4
C10 aromatic 6	1.1E-3	1.3E-2	1.1E-3	6.4E-4		4.1E-3	a	d	154	1.0E-4	3.4E-4
1,2,3,4-trimethylbenzene	1.8E-3	1.1E-2	1.1E-3	1.6E-3		3.9E-3	a	d	123	1.2E-4	3.4E-4
C10 aromatic 4	1.8E-3	1.2E-2	3.7E-4	1.3E-3		3.9E-3	a	d	142	1.2E-4	3.4E-4
1,2,3,5-tetramethylbenzene	4.3E-3	5.2E-3	3.0E-3	2.2E-3		3.7E-3	a		36	1.9E-4	3.4E-4
C10 olefin 2	3.6E-3	5.2E-3	3.3E-3	2.2E-3		3.6E-3	a		34	2.3E-4	3.4E-4
C8 paraffin 3	5.4E-3	8.0E-3	3.7E-4	6.4E-4		3.6E-3	a	d	104	6.2E-5	3.4E-4
4-methylheptane	4.3E-3	4.1E-3	2.6E-3	2.9E-3		3.5E-3	a		25	2.1E-4	3.4E-4
C8 paraffin 2	5.7E-3	3.1E-3	1.9E-3	2.6E-3		3.3E-3	a		51	1.8E-4	3.4E-4
C10 paraffin C	3.9E-3	5.5E-3	2.2E-3	9.6E-4		3.2E-3	a		63	1.2E-4	3.4E-4

Table 4-14a. Volatile Organic Compounds from Canisters (Delta – NG) (Continued).

Parameter	Value										
Units	mg/dscm								(%)	mg/dscm	
Run Number Date	NG-Run 1 2-Apr-02	NG-Run 2 3-Apr-02	NG-Run 3 4-Apr-02	NG-Run 4 5-Apr-02	Stack Average				RSD	NG-Ambient 8-Apr-02	MDL (1)
2-propyltoluene	2.1E-3	8.0E-3	1.5E-3	9.6E-4		3.1E-3	a	d	104	7.2E-5	3.4E-4
2,4,4-trimethyl-1-pentene	3.9E-3	1.7E-3	2.6E-3	3.2E-3		2.9E-3	a		33	1.2E-4	3.4E-4
beta-pinene	2.9E-3	4.8E-3	1.1E-3	1.6E-3		2.6E-3	a		64	1.7E-4	3.4E-4
C11 paraffin B	1.1E-3	7.3E-3	7.4E-4	6.4E-4		2.4E-3	a	d	133	5.1E-5	3.4E-4
Nonene-1	2.5E-3	3.5E-3	1.9E-3	1.6E-3		2.4E-3	a		35	1.5E-4	3.4E-4
1,2-diethylbenzene	7.2E-4	5.2E-3	7.4E-4	2.6E-3		2.3E-3	a	d	92	3.1E-5	3.4E-4
2,5-diemthylhexane	3.2E-3	2.8E-3	1.5E-3	1.6E-3		2.3E-3	a		38	1.9E-4	3.4E-4
C9 paraffin 2	2.1E-3	4.1E-3	1.1E-3	9.6E-4		2.1E-3	a		70	1.3E-4	3.4E-4
C11 aromatic 3	3.6E-4	3.1E-3	ND	ND	<	1.7E-3			112	ND	3.4E-4
Octene-1	2.5E-3	2.1E-3	1.5E-3	6.4E-4		1.7E-3	a		48	1.0E-5	3.4E-4
1,1-dimethylcyclohexane	1.8E-3	3.8E-3	3.7E-4	6.4E-4		1.7E-3	a	d	95	6.2E-5	3.4E-4
C8 olefin 2	ND	3.5E-4	ND	2.9E-3	<	1.6E-3	a	d	111	2.1E-5	3.4E-4
Indene	7.2E-4	4.1E-3	7.4E-4	3.2E-4		1.5E-3	a	d	121	7.2E-5	3.4E-4
1,2,4-trimethylbenzene	1.1E-3	1.7E-3	1.5E-3	1.6E-3		1.5E-3	a		19	8.2E-5	3.4E-4
C10 paraffin A	2.1E-3	1.7E-3	1.1E-3	6.4E-4		1.4E-3	a		47	2.1E-5	3.4E-4
Dodecene-1	ND	1.4E-3	ND	ND	<	1.4E-3	e		n/a	ND	3.4E-4
C11 aromatic 1	1.1E-3	2.4E-3	7.4E-4	3.2E-4		1.1E-3	a		80	3.1E-5	3.4E-4
C10 aromatic 5	1.1E-3	1.7E-3	3.7E-4	9.6E-4		1.0E-3	a		54	8.2E-5	3.4E-4
C9 olefin 4	1.1E-3	1.4E-3	7.4E-4	6.4E-4		9.6E-4	a		35	3.1E-5	3.4E-4
sec-butylbenzene	7.2E-4	1.0E-3	7.4E-4	6.4E-4		7.8E-4	a		22	3.1E-5	3.4E-4
C8 olefin 1	7.2E-4	1.0E-3	7.4E-4	6.4E-4		7.8E-4			22	5.1E-5	3.4E-4
C8 paraffin 1	7.2E-4	6.9E-4	ND	ND	<	7.0E-4			2	1.0E-5	3.4E-4
C10 aromatic 1	ND	6.9E-4	ND	ND	<	6.9E-4	e		n/a	ND	3.4E-4
C9 paraffin 1	1.1E-3	3.5E-4	7.4E-4	3.2E-4		6.2E-4	a		58	2.1E-5	3.4E-4
C9 olefin 1	7.2E-4	3.5E-4	7.4E-4	ND	<	6.0E-4	a		37	ND	3.4E-4
2,3-dimethylhexane	7.2E-4	6.9E-4	3.7E-4	3.2E-4		5.2E-4	a		40	2.1E-5	3.4E-4
C8 olefin 3	3.6E-4	6.9E-4	3.7E-4	6.4E-4		5.1E-4	a		34	4.1E-5	3.4E-4
C9 paraffin 3	3.6E-4	6.9E-4	3.7E-4	ND	<	4.7E-4			40	3.1E-5	3.4E-4
4,4-dimethylheptane	3.6E-4	6.9E-4	ND	3.2E-4	<	4.6E-4	a		45	1.0E-5	3.4E-4
2,6-dimethylheptane	7.2E-4	3.5E-4	3.7E-4	3.2E-4		4.4E-4	a		43	1.0E-5	3.4E-4
2,5-dimethylheptane	7.2E-4	3.5E-4	3.7E-4	3.2E-4		4.4E-4	a		43	3.1E-5	3.4E-4
2,4-diemthylhexane	7.2E-4	3.5E-4	3.7E-4	3.2E-4		4.4E-4	a		43	4.1E-5	3.4E-4
2,4-dimethylheptane	3.6E-4	ND	ND	ND	<	3.6E-4	e		n/a	2.1E-5	3.4E-4
Other VOCs (Carbon Number 7 or less)											
n-butane	7.7E-1	3.1E-1	1.8E-1	1.3E-1		3.5E-1	a	d	83	1.3E-2	3.4E-4
Acetone	4.3E-1	1.3E-1	5.0E-1	1.9E-1		3.2E-1	a		56	7.8E-3	3.4E-4
Toluene	5.2E-1	3.7E-1	2.0E-1	1.4E-1		3.1E-1	a		55	1.3E-2	3.4E-4
Ethane	3.9E-1	3.2E-1	2.7E-1	2.4E-1		3.0E-1	a		21	8.7E-3	3.4E-4
Propane	4.8E-1	3.1E-1	2.1E-1	1.7E-1		3.0E-1	a		47	5.9E-3	3.4E-4
F 12	2.1E-1	2.7E-1	1.3E-1	1.4E-1		1.9E-1			34	8.6E-4	3.4E-4
Chloromethane	2.5E-1	1.4E-1	1.6E-1	1.3E-1		1.7E-1	a		34	4.3E-3	3.4E-4
Ethene	1.9E-1	1.6E-1	1.4E-1	1.3E-1		1.5E-1	a		17	5.0E-3	3.4E-4
Acetaldehyde	1.4E-1	1.8E-1	1.4E-1	1.0E-1		1.4E-1	a		22	3.6E-3	3.4E-4
Isopentane	1.6E-1	2.2E-1	9.0E-2	9.4E-2		1.4E-1	a		44	7.6E-3	3.4E-4
Ethanol + ACN	1.4E-1	7.8E-2	1.8E-1	8.2E-2		1.2E-1	a		42	2.6E-3	3.4E-4
Isobutane	1.2E-1	1.7E-1	8.4E-2	7.5E-2		1.1E-1	a		40	4.6E-3	3.4E-4
n-hexane	1.7E-1	2.0E-1	2.7E-2	2.2E-2		1.0E-1	a	d	89	1.7E-3	3.4E-4
Methylene chloride	1.4E-1	1.2E-1	5.8E-2	5.2E-2		9.3E-2	a		48	2.6E-3	3.4E-4
Cyclohexane	7.1E-2	9.2E-2	1.1E-1	6.6E-2		8.6E-2			26	7.4E-4	3.4E-4
Acetylene	9.3E-2	1.1E-1	6.4E-2	6.8E-2		8.3E-2	a		24	2.6E-3	3.4E-4
Propene	8.4E-2	9.4E-2	5.3E-2	4.7E-2		6.9E-2			33	1.9E-3	3.4E-4
n-pentane	7.0E-2	7.8E-2	3.3E-2	3.0E-2		5.3E-2	a		47	3.1E-3	3.4E-4
Methanol	1.1E-1	4.1E-2	8.1E-3	2.9E-2		4.8E-2	a	d	95	3.0E-4	3.4E-4

Table 4-14a. Volatile Organic Compounds from Canisters (Delta – NG) (Continued).

Parameter	Value							
Units	mg/dscm					(%)	mg/dscm	
Run Number Date	NG-Run 1 2-Apr-02	NG-Run 2 3-Apr-02	NG-Run 3 4-Apr-02	NG-Run 4 5-Apr-02	Stack Average	RSD	NG-Ambient 8-Apr-02	MDL (1)
Iso-butene	6.1E-2	5.7E-2	3.7E-2	3.3E-2	4.7E-2	29	1.9E-3	3.4E-4
2-methylpentane	5.6E-2	7.9E-2	2.1E-2	2.1E-2	4.4E-2 a	64	3.8E-3	3.4E-4
F 113	2.3E-2	3.5E-2	6.8E-2	1.6E-2	3.5E-2 a	65	1.5E-3	3.4E-4
Benzene	4.2E-2	3.9E-2	2.9E-2	2.4E-2	3.4E-2 a	25	1.8E-3	3.4E-4
Methylcyclopentane	4.3E-2	4.9E-2	2.0E-2	1.6E-2	3.2E-2 a	51	1.3E-3	3.4E-4
3-methylhexane + pentanal	2.8E-2	3.5E-2	2.0E-2	2.1E-2	2.6E-2 a	26	2.4E-3	3.4E-4
3-methylpentane	3.5E-2	3.8E-2	1.3E-2	1.3E-2	2.5E-2 a	55	2.0E-3	3.4E-4
Methylcyclohexane	3.3E-2	3.8E-2	1.4E-2	1.1E-2	2.4E-2 a	55	1.4E-3	3.4E-4
1-pentene	4.7E-2	2.9E-2	9.3E-3	6.7E-3	2.3E-2 a d	81	4.1E-4	3.4E-4
2-propanol	ND	1.2E-2	2.8E-2	2.7E-2	< 2.2E-2 a	41	6.1E-4	3.4E-4
n-heptane	2.1E-2	2.5E-2	1.2E-2	1.2E-2	1.8E-2 a	38	1.5E-3	3.4E-4
Hexanal	1.5E-2	1.5E-2	9.3E-3	1.8E-2	1.4E-2 a	27	8.5E-4	3.4E-4
2-methylhexane	1.6E-2	1.9E-2	8.9E-3	1.1E-2	1.4E-2 a	33	1.5E-3	3.4E-4
1-butene	1.1E-2	2.0E-2	1.2E-2	9.9E-3	1.3E-2 a	36	6.4E-4	3.4E-4
t-2-butene	1.5E-2	1.8E-2	9.3E-3	8.3E-3	1.3E-2 a	37	6.3E-4	3.4E-4
C7 olefin 1	1.3E-2	6.6E-3	ND	1.3E-2	< 1.1E-2	34	3.4E-4	3.4E-4
Chlorobenzene	1.7E-2	1.3E-2	7.4E-3	5.4E-3	1.1E-2 a	50	6.0E-4	3.4E-4
c-2-butene	1.9E-2	1.2E-2	7.0E-3	4.5E-3	1.1E-2 a	60	5.1E-4	3.4E-4
2,3-dimethylbutane	1.2E-2	1.3E-2	6.7E-3	5.7E-3	9.4E-3 a	40	6.2E-4	3.4E-4
Isoprene	1.3E-2	2.0E-2	1.5E-3	3.2E-4	8.8E-3 a d	109	7.8E-4	3.4E-4
2-methyl-1-butene	1.1E-2	1.1E-2	5.6E-3	4.8E-3	8.1E-3 a	42	4.6E-4	3.4E-4
t-2-pentene	8.2E-3	1.1E-2	6.3E-3	5.4E-3	7.8E-3 a	32	5.0E-4	3.4E-4
2,2-dimethylbutane	8.6E-3	1.1E-2	3.7E-3	6.1E-3	7.4E-3	43	5.2E-4	3.4E-4
Cyclopentane	1.0E-2	1.0E-2	4.8E-3	4.5E-3	7.3E-3 a	42	3.4E-4	3.4E-4
2-methyl-2-butene	7.2E-3	1.0E-2	4.4E-3	5.4E-3	6.8E-3 a	38	6.2E-4	3.4E-4
2,2,3-trimethylbutane	1.8E-2	3.8E-3	2.2E-3	1.6E-3	6.4E-3 a d	121	1.6E-4	3.4E-4
2,3-dimethylpentane	6.8E-3	8.3E-3	4.1E-3	4.8E-3	6.0E-3 a	32	6.8E-4	3.4E-4
Benzaldehyde	5.4E-3	9.7E-3	4.1E-3	2.6E-3	5.4E-3 a	57	1.5E-4	3.4E-4
1-hexene	5.7E-3	9.3E-3	2.2E-3	1.9E-3	4.8E-3 a	73	1.1E-4	3.4E-4
1,3-dimethylcyclopentane	4.7E-3	4.8E-3	3.3E-3	5.1E-3	4.5E-3 a	18	3.4E-4	3.4E-4
MTBE	3.9E-3	7.6E-3	2.6E-3	3.5E-3	4.4E-3 a	50	3.3E-4	3.4E-4
c-2-pentene	4.7E-3	6.2E-3	3.3E-3	2.9E-3	4.3E-3 a	35	2.7E-4	3.4E-4
2-methyl-2-pentene	6.1E-3	5.9E-3	1.9E-3	2.9E-3	4.2E-3 a	51	3.1E-4	3.4E-4
2,4-dimethylpentane	4.3E-3	5.9E-3	2.2E-3	2.6E-3	3.7E-3 a	45	3.1E-4	3.4E-4
1,3-butadiene	5.4E-3	4.8E-3	2.6E-3	1.9E-3	3.7E-3 a	46	2.8E-4	3.4E-4
t-3-hexene + chloroform	2.1E-3	4.8E-3	1.9E-3	3.2E-4	2.3E-3 a d	82	1.1E-4	3.4E-4
3-methyl-1-butene	2.5E-3	3.5E-3	1.9E-3	1.3E-3	2.3E-3	41	1.3E-4	3.4E-4
t-2-hexene	2.1E-3	3.1E-3	1.9E-3	1.9E-3	2.3E-3 a	26	1.8E-4	3.4E-4
Cyclopentene	2.5E-3	2.8E-3	1.5E-3	1.3E-3	2.0E-3 a	37	1.0E-4	3.4E-4
2-methyl-1-pentene	3.2E-3	1.4E-3	1.5E-3	1.3E-3	1.8E-3 a	50	1.3E-4	3.4E-4
trans-3-methyl-2-pentene	3.2E-3	1.0E-3	1.9E-3	9.6E-4	1.8E-3 a	59	1.5E-4	3.4E-4
1-methylcyclopentene	1.4E-3	2.4E-3	1.5E-3	1.3E-3	1.7E-3 a	31	1.6E-4	3.4E-4
Cyclohexene	2.9E-3	1.4E-3	1.1E-3	6.4E-4	1.5E-3 a	64	1.3E-4	3.4E-4
3,3-dimethylpentane	1.4E-3	1.4E-3	7.4E-4	1.9E-3	1.4E-3	35	1.5E-4	3.4E-4
cis-3-methyl-2-pentene	1.1E-3	1.4E-3	1.1E-3	9.6E-4	1.1E-3 a	16	1.1E-4	3.4E-4
c-2-hexene	1.1E-3	1.4E-3	1.1E-3	9.6E-4	1.1E-3	16	9.2E-5	3.4E-4
C6 olefin	1.1E-3	1.4E-3	7.4E-4	6.4E-4	9.6E-4	35	3.1E-5	3.4E-4
4-methyl-1-pentene	7.2E-4	1.0E-3	3.7E-4	6.4E-4	6.9E-4 a	40	4.1E-5	3.4E-4

Table 4-14a. Volatile Organic Compounds from Canisters (Delta – NG) (Continued).

Parameter	Value								
Units	mg/dscm						(%)	mg/dscm	
Run Number Date	NG-Run 1 2-Apr-02	NG-Run 2 3-Apr-02	NG-Run 3 4-Apr-02	NG-Run 4 5-Apr-02	Stack Average		RSD	NG-Ambient 8-Apr-02	MDL (1)
t-3-heptene	3.6E-4	6.9E-4	3.7E-4	6.4E-4	5.1E-4	a	34	2.1E-5	3.4E-4
C7 olefin 2	3.6E-4	3.5E-4	3.7E-4	ND	< 3.6E-4	a	3	2.1E-5	3.4E-4
4-methylhexene	3.6E-4	3.5E-4	3.7E-4	3.2E-4	3.5E-4	a	6	4.1E-5	3.4E-4
c-3-hexene	3.6E-4	3.5E-4	3.7E-4	3.2E-4	3.5E-4		6	2.1E-5	3.4E-4

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-14b. Volatile Organic Compounds from Canisters (Delta – Oil).

Parameter	Value										
Units	mg/dscm								(%)	mg/dscm	
Run Number Date	Oil-Run 1 22-Mar-02	Oil-Run 2 23-Mar-02	Oil-Run 3 25-Mar-02	Oil-Run 4 26-Mar-02		Stack Average			RSD	Oil-Ambient 8-Apr-02	MDL (1)
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)											
1-decene	8.3E-2	7.9E-2	9.1E-2	3.6E-1		1.5E-1	a	d	89	4.5E-3	4.7E-4
n-decane	1.9E-2	3.9E-2	2.6E-3	4.1E-1		1.2E-1	a	d	166	1.5E-3	4.7E-4
2,3,5-trimethylhexane	9.8E-2	6.7E-2	7.8E-2	1.3E-1		9.4E-2	a		31	1.8E-3	4.7E-4
m- & p-xylene	7.5E-2	7.1E-2	1.1E-1	1.1E-1		9.2E-2	a		24	3.9E-3	4.7E-4
n-undecane	1.1E-2	3.5E-2	1.3E-2	1.7E-1		5.7E-2	a	d	133	1.1E-3	4.7E-4
n-nonane	1.4E-2	1.8E-2	8.6E-4	1.6E-1		4.7E-2	a	d	155	1.1E-3	4.7E-4
Isopropylcyclohexane	2.6E-3	1.1E-2	1.3E-2	1.5E-1		4.3E-2	a	d	159	6.9E-4	4.7E-4
1,3-diethylbenzene	2.0E-2	5.0E-2	6.3E-2	3.5E-2		4.2E-2			45	1.2E-4	4.7E-4
o-xylene	2.6E-2	3.0E-2	4.2E-2	6.1E-2		4.0E-2	a		39	1.5E-3	4.7E-4
m-ethyltoluene	1.7E-2	2.5E-2	2.8E-2	7.3E-2		3.6E-2	a		70	1.2E-3	4.7E-4
Isobutylbenzene	1.7E-2	3.3E-2	2.0E-2	6.0E-2		3.2E-2	a		61	1.1E-3	4.7E-4
1,2,3-trimethylbenzene	1.3E-2	2.6E-2	2.6E-2	5.7E-2		3.1E-2	a		61	7.0E-4	4.7E-4
1,3,5-trimethylbenzene	9.5E-3	1.7E-2	1.2E-2	8.2E-2		3.0E-2	a	d	115	7.6E-4	4.7E-4
Limonene	9.5E-3	2.7E-2	1.4E-2	6.2E-2		2.8E-2	a	d	84	2.0E-3	4.7E-4
Ethylbenzene	2.1E-2	2.1E-2	3.4E-2	3.7E-2		2.8E-2	a		31	1.1E-3	4.7E-4
Nonanal	5.3E-3	3.0E-3	6.0E-2	3.8E-2		2.7E-2	a	d	103	3.7E-4	4.7E-4
2-propyltoluene	7.4E-3	2.7E-2	5.2E-2	1.6E-2		2.6E-2	a		75	7.2E-5	4.7E-4
C10 paraffin C	1.1E-2	3.1E-2	4.1E-2	1.7E-2		2.5E-2			56	1.2E-4	4.7E-4
Styrene + heptanal	5.8E-3	1.4E-2	2.4E-2	5.1E-2		2.4E-2	a	d	83	9.4E-4	4.7E-4
n-dodecane	1.6E-3	2.2E-2	4.3E-4	5.6E-2		2.0E-2	a	d	130	4.5E-4	4.7E-4
Indan	4.2E-3	1.0E-2	7.7E-3	4.8E-2		1.8E-2	a	d	116	3.4E-4	4.7E-4
n-octane	1.6E-2	1.5E-2	1.0E-2	2.5E-2		1.7E-2	a		37	9.9E-4	4.7E-4
2,2,4-trimethylpentane	1.3E-2	9.4E-3	1.5E-2	2.5E-2		1.6E-2	a		42	9.4E-4	4.7E-4
Octanal	3.7E-3	6.9E-3	1.6E-2	3.0E-2		1.4E-2	a	d	84	4.9E-4	4.7E-4
1,2-diethylbenzene	5.3E-3	1.7E-2	2.1E-2	1.1E-2		1.3E-2	a		51	3.1E-5	4.7E-4
C10 aromatic 1	ND	ND	ND	1.3E-2	<	1.3E-2	e		n/a	ND	4.7E-4
3,6-dimethyloctane	5.3E-4	3.0E-3	4.7E-3	4.5E-2		1.3E-2	a	d	159	2.3E-4	4.7E-4
C10 olefin 2	9.0E-3	3.5E-3	2.2E-3	3.5E-2		1.2E-2	a	d	124	2.3E-4	4.7E-4
1,4-diethylbenzene	4.2E-3	1.0E-2	1.0E-2	2.1E-2		1.1E-2	a		60	3.4E-4	4.7E-4
o-ethyltoluene	5.3E-3	9.4E-3	9.9E-3	1.8E-2		1.1E-2	a		50	3.8E-4	4.7E-4
n-propylbenzene	5.3E-3	7.9E-3	8.6E-3	2.1E-2		1.1E-2	a		65	3.5E-4	4.7E-4
2-methylheptane	9.0E-3	7.9E-3	9.9E-3	1.4E-2		1.0E-2	a		25	5.8E-4	4.7E-4
3-methyloctane	5.3E-3	8.4E-3	3.9E-3	2.3E-2		1.0E-2	a	d	86	4.9E-4	4.7E-4
2,6-dimethyloctane	ND	1.5E-3	ND	1.8E-2	<	9.9E-3	a	d	120	1.1E-4	4.7E-4
p-ethyltoluene	5.3E-3	9.4E-3	1.1E-2	1.3E-2		9.7E-3	a		35	4.4E-4	4.7E-4
3-methylheptane	9.0E-3	7.4E-3	9.9E-3	1.2E-2		9.6E-3	a		20	4.9E-4	4.7E-4
alpha-pinene	3.7E-3	6.9E-3	4.7E-3	2.2E-2		9.5E-3	a	d	93	7.2E-5	4.7E-4
Isopropylbenzene	4.2E-3	5.0E-3	5.2E-3	2.3E-2		9.3E-3	a	d	98	2.2E-4	4.7E-4
1,2,4,5-tetramethylbenzene	2.6E-3	9.4E-3	5.6E-3	1.7E-2		8.5E-3	a		70	2.1E-4	4.7E-4
C9 olefin 3	4.7E-3	4.5E-3	5.6E-3	1.9E-2		8.5E-3	a	d	84	3.5E-4	4.7E-4
1,2,4-trimethylbenzene	2.6E-3	1.5E-3	3.4E-3	2.2E-2		7.4E-3	a	d	132	8.2E-5	4.7E-4
Naphthalene	5.3E-4	7.4E-3	9.0E-3	1.2E-2		7.3E-3	a		68	3.2E-4	4.7E-4
3-ethylpentane	5.8E-3	5.4E-3	8.6E-3	8.3E-3		7.0E-3	a		23	5.2E-4	4.7E-4
beta-pinene	2.1E-3	1.5E-3	2.2E-3	2.2E-2		6.8E-3	a	d	144	1.7E-4	4.7E-4
1,2,3,5-tetramethylbenzene	3.7E-3	9.4E-3	5.6E-3	8.3E-3		6.7E-3	a		38	1.9E-4	4.7E-4
C11 paraffin A	ND	3.5E-3	4.3E-3	1.2E-2	<	6.6E-3	a	d	71	9.2E-5	4.7E-4
Nonene-1	2.6E-3	1.5E-3	1.7E-3	1.9E-2		6.3E-3	a	d	138	1.5E-4	4.7E-4
C9 paraffin 2	1.6E-3	1.5E-3	1.3E-3	2.1E-2		6.3E-3	a	d	154	1.3E-4	4.7E-4
1-methylindan	1.1E-3	4.0E-3	ND	1.3E-2	<	6.1E-3	a	d	105	7.2E-5	4.7E-4
2,4,4-trimethyl-1-pentene	4.2E-3	6.9E-3	6.0E-3	5.5E-3		5.7E-3	a		20	1.2E-4	4.7E-4
2,3,-trimethylpentane	4.2E-3	4.0E-3	6.0E-3	7.8E-3		5.5E-3	a		33	4.0E-4	4.7E-4

Table 4-14b. Volatile Organic Compounds from Canisters (Delta – Oil) (Continued).

Parameter	Value										
Units	mg/dscm								(%)	mg/dscm	
Run Number	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4		Stack Average			RSD	Oil-Ambient	MDL
Date	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02						8-Apr-02	(1)
Isopropyltoluene	1.6E-3	7.9E-3	4.7E-3	7.3E-3		5.4E-3	a		54	2.5E-4	4.7E-4
4-methylheptane	3.7E-3	3.5E-3	6.0E-3	6.0E-3		4.8E-3	a		29	2.1E-4	4.7E-4
2,5-dimethylheptane	ND	9.9E-4	8.6E-4	1.2E-2	<	4.7E-3	a	d	139	3.1E-5	4.7E-4
C10 aromatic 6	1.1E-3	4.0E-3	5.2E-3	8.7E-3		4.7E-3	a		67	1.0E-4	4.7E-4
C11 aromatic 1	ND	1.5E-3	5.6E-3	6.0E-3	<	4.3E-3	a		57	3.1E-5	4.7E-4
C10 aromatic 4	5.3E-4	4.0E-3	3.0E-3	9.6E-3		4.3E-3	a	d	90	1.2E-4	4.7E-4
C10 paraffin A	ND	9.9E-4	ND	6.9E-3	<	3.9E-3		d	106	2.1E-5	4.7E-4
C10 aromatic 2	1.6E-3	5.0E-3	5.2E-3	3.7E-3		3.8E-3	a		43	1.9E-4	4.7E-4
1,2,3,4-trimethylbenzene	1.1E-3	6.4E-3	2.2E-3	5.5E-3		3.8E-3	a		68	1.2E-4	4.7E-4
C8 paraffin 2	3.2E-3	3.0E-3	6.0E-3	2.8E-3		3.7E-3	a		41	1.8E-4	4.7E-4
Indene	1.1E-3	1.5E-3	8.6E-4	1.0E-2		3.4E-3	a	d	133	7.2E-5	4.7E-4
2,5-diemthylhexane	2.6E-3	2.5E-3	3.9E-3	3.7E-3		3.2E-3	a		22	1.9E-4	4.7E-4
C10 aromatic 5	1.1E-3	3.5E-3	3.0E-3	5.1E-3		3.1E-3	a		52	8.2E-5	4.7E-4
Octene-1	5.3E-4	5.0E-3	3.0E-3	3.2E-3		2.9E-3	a		62	1.0E-5	4.7E-4
2,2,5-trimethylhexane	1.6E-3	9.9E-4	4.3E-3	4.6E-3		2.9E-3	a		64	9.2E-5	4.7E-4
sec-butylbenzene	5.3E-4	1.5E-3	8.6E-4	8.3E-3		2.8E-3	a	d	132	3.1E-5	4.7E-4
C9 olefin 4	1.1E-3	9.9E-4	1.3E-3	6.0E-3		2.3E-3	a	d	105	3.1E-5	4.7E-4
C11 paraffin B	5.3E-4	2.5E-3	2.2E-3	3.7E-3		2.2E-3	a		59	5.1E-5	4.7E-4
C11 aromatic 3	ND	ND	ND	1.8E-3	<	1.8E-3	e		n/a	ND	4.7E-4
C9 paraffin 1	ND	ND	8.6E-4	2.3E-3	<	1.6E-3		d	64	2.1E-5	4.7E-4
C8 olefin 1	1.1E-3	9.9E-4	8.6E-4	1.8E-3		1.2E-3	a		37	5.1E-5	4.7E-4
C8 paraffin 3	5.3E-4	5.0E-4	8.6E-4	2.8E-3		1.2E-3	a	d	93	6.2E-5	4.7E-4
C8 paraffin 1	ND	9.9E-4	ND	ND	<	9.9E-4	e		n/a	1.0E-5	4.7E-4
C9 paraffin 3	ND	5.0E-4	ND	1.4E-3	<	9.4E-4		d	67	3.1E-5	4.7E-4
2,6-dimethylheptane	ND	9.9E-4	4.3E-4	1.4E-3	<	9.3E-4	a		51	1.0E-5	4.7E-4
Dodecene-1	ND	ND	ND	9.2E-4	<	9.2E-4	e		n/a	ND	4.7E-4
2,3-dimethylhexane	1.1E-3	5.0E-4	8.6E-4	9.2E-4		8.3E-4			29	2.1E-5	4.7E-4
C8 olefin 2	ND	5.0E-4	8.6E-4	4.6E-4	<	6.0E-4	a		37	2.1E-5	4.7E-4
C8 olefin 3	5.3E-4	5.0E-4	4.3E-4	9.2E-4		5.9E-4	a		37	4.1E-5	4.7E-4
1,1-dimethylcyclohexane	5.3E-4	5.0E-4	4.3E-4	9.2E-4		5.9E-4	a		37	6.2E-5	4.7E-4
2,4-diemthylhexane	5.3E-4	5.0E-4	8.6E-4	4.6E-4		5.9E-4	a		32	4.1E-5	4.7E-4
4,4-dimethylheptane	5.3E-4	5.0E-4	ND	4.6E-4	<	4.9E-4			7	1.0E-5	4.7E-4
C9 olefin 1	5.3E-4	ND	ND	4.6E-4	<	4.9E-4	a		10	ND	4.7E-4
2,4-dimethylheptane	ND	5.0E-4	ND	4.6E-4	<	4.8E-4			5	2.1E-5	4.7E-4
3,3-dimethylheptane	ND	ND	ND	4.6E-4	<	4.6E-4	e		n/a	ND	4.7E-4
2-methyloctane	ND	ND	ND	ND		ND	e		n/a	1.6E-4	4.7E-4
Other VOCs (Carbon Number 7 or less)											
Acetone	5.6E-1	2.1E-1	1.3E+0	3.5E-1		5.9E-1	a		78	7.8E-3	4.7E-4
n-butane	1.9E-1	5.3E-1	3.7E-1	1.2E+0		5.7E-1	a		77	1.3E-2	4.7E-4
Toluene	5.6E-1	2.5E-1	5.4E-1	5.3E-1		4.7E-1	a		31	1.3E-2	4.7E-4
Ethane	3.8E-1	4.0E-1	3.6E-1	3.9E-1		3.8E-1	a		5	8.7E-3	4.7E-4
Ethene	4.0E-1	3.6E-1	2.7E-1	3.0E-1		3.3E-1	a		17	5.0E-3	4.7E-4
Propane	2.0E-1	2.3E-1	2.7E-1	6.0E-1		3.3E-1	a		58	5.9E-3	4.7E-4
Ethanol + ACN	6.0E-1	7.3E-2	1.4E-1	9.7E-2		2.3E-1	a	d	110	2.6E-3	4.7E-4
n-hexane	2.1E-1	1.9E-1	2.5E-1	1.9E-1		2.1E-1	a		13	1.7E-3	4.7E-4
Chloromethane	2.1E-1	1.7E-1	1.9E-1	2.6E-1		2.1E-1	a		19	4.3E-3	4.7E-4
Isobutane	7.7E-2	8.9E-2	8.1E-2	5.7E-1		2.0E-1	a	d	120	4.6E-3	4.7E-4
Acetaldehyde	1.9E-1	1.5E-1	2.3E-1	2.0E-1		2.0E-1	a		17	3.6E-3	4.7E-4
Isopentane	1.4E-1	1.5E-1	1.4E-1	2.3E-1		1.6E-1	a		27	7.6E-3	4.7E-4
Acetylene	1.6E-1	1.3E-1	1.2E-1	1.5E-1		1.4E-1	a		14	2.6E-3	4.7E-4
Propene	1.3E-1	1.6E-1	1.2E-1	1.2E-1		1.3E-1	a		15	1.9E-3	4.7E-4
Methylcyclopentane	8.3E-2	7.4E-2	1.6E-1	9.0E-2		1.0E-1	a		37	1.3E-3	4.7E-4
F 12	2.6E-2	3.4E-2	5.9E-2	2.7E-1		9.8E-2	a	d	120	8.6E-4	4.7E-4

Table 4-14b. Volatile Organic Compounds from Canisters (Delta – Oil) (Continued).

Parameter	Value							
Units	mg/dscm					(%)	mg/dscm	
Run Number Date	Oil-Run 1 22-Mar-02	Oil-Run 2 23-Mar-02	Oil-Run 3 25-Mar-02	Oil-Run 4 26-Mar-02	Stack Average	RSD	Oil-Ambient 8-Apr-02	MDL (1)
Cyclohexane	9.4E-2	7.8E-2	1.1E-1	8.8E-2	9.3E-2 a	14	7.4E-4	4.7E-4
Iso-butene	8.3E-2	8.1E-2	1.0E-1	1.0E-1	9.2E-2 a	13	1.9E-3	4.7E-4
Methylene chloride	6.6E-2	8.3E-2	6.0E-2	1.1E-1	7.8E-2 a	26	2.6E-3	4.7E-4
2-methylpentane	4.0E-2	3.1E-2	1.4E-1	7.6E-2	7.2E-2 a	70	3.8E-3	4.7E-4
Methanol	8.7E-2	1.4E-2	1.2E-1	5.8E-2	7.0E-2 a	65	3.0E-4	4.7E-4
n-pentane	6.0E-2	5.6E-2	6.3E-2	1.0E-1	7.0E-2 a	30	3.1E-3	4.7E-4
Benzene	7.4E-2	5.6E-2	6.1E-2	6.3E-2	6.3E-2 a	12	1.8E-3	4.7E-4
F 113	4.6E-2	5.3E-2	8.1E-2	6.3E-2	6.1E-2 a	25	1.5E-3	4.7E-4
3-methylpentane	3.5E-2	2.8E-2	9.4E-2	4.7E-2	5.1E-2 a	58	2.0E-3	4.7E-4
c-2-butene	3.1E-2	3.5E-2	3.5E-2	2.8E-2	3.2E-2	11	5.1E-4	4.7E-4
3-methylhexane + pentanal	2.7E-2	2.4E-2	4.0E-2	3.2E-2	3.1E-2 a	22	2.4E-3	4.7E-4
1-pentene	1.8E-2	2.0E-2	4.6E-2	3.1E-2	2.9E-2 a	45	4.1E-4	4.7E-4
Methylcyclohexane	2.4E-2	2.0E-2	3.0E-2	3.9E-2	2.8E-2 a	30	1.4E-3	4.7E-4
n-heptane	2.0E-2	1.8E-2	3.2E-2	2.8E-2	2.5E-2 a	27	1.5E-3	4.7E-4
t-2-butene	2.7E-2	1.7E-2	1.9E-2	2.2E-2	2.2E-2	21	6.3E-4	4.7E-4
2-methylhexane	1.4E-2	1.1E-2	2.7E-2	1.9E-2	1.8E-2 a	38	1.5E-3	4.7E-4
C7 olefin 1	ND	ND	1.4E-2	2.1E-2	< 1.7E-2 a d	26	3.4E-4	4.7E-4
1-butene	1.6E-2	2.0E-2	1.3E-2	1.7E-2	1.7E-2	17	6.4E-4	4.7E-4
2,3-dimethylbutane	1.2E-2	8.9E-3	2.8E-2	1.5E-2	1.6E-2 a	54	6.2E-4	4.7E-4
Hexanal	1.3E-2	1.6E-2	1.2E-2	1.5E-2	1.4E-2 a	15	8.5E-4	4.7E-4
Cyclopentane	1.1E-2	9.4E-3	2.1E-2	1.4E-2	1.4E-2 a	36	3.4E-4	4.7E-4
2-propanol	ND	ND	2.0E-2	6.9E-3	< 1.4E-2 d	70	6.1E-4	4.7E-4
2-methyl-2-butene	9.5E-3	9.4E-3	9.5E-3	1.3E-2	1.0E-2 a	19	6.2E-4	4.7E-4
2-methyl-1-butene	7.9E-3	7.9E-3	1.1E-2	1.2E-2	9.7E-3 a	22	4.6E-4	4.7E-4
t-2-pentene	4.2E-3	9.4E-3	9.5E-3	1.2E-2	8.8E-3 a	37	5.0E-4	4.7E-4
2,2-dimethylbutane	5.8E-3	5.0E-3	1.2E-2	1.0E-2	8.3E-3 a	43	5.2E-4	4.7E-4
2,3-dimethylpentane	7.4E-3	5.4E-3	1.1E-2	9.2E-3	8.2E-3 a	28	6.8E-4	4.7E-4
Chlorobenzene	7.4E-3	8.9E-3	1.2E-2	4.1E-3	8.1E-3 a	41	6.0E-4	4.7E-4
2,4-dimethylpentane	4.7E-3	4.0E-3	1.3E-2	6.0E-3	6.9E-3 a	59	3.1E-4	4.7E-4
1,3-butadiene	6.9E-3	5.9E-3	6.9E-3	6.9E-3	6.6E-3 a	7	2.8E-4	4.7E-4
Benzaldehyde	4.7E-3	3.0E-3	1.3E-3	1.7E-2	6.6E-3 a d	111	1.5E-4	4.7E-4
1-hexene	4.7E-3	6.4E-3	6.5E-3	6.4E-3	6.0E-3 a	14	1.1E-4	4.7E-4
c-2-pentene	5.3E-3	4.5E-3	4.7E-3	6.4E-3	5.2E-3 a	17	2.7E-4	4.7E-4
1,3-dimethylcyclopentane	4.7E-3	4.5E-3	6.5E-3	5.1E-3	5.2E-3 a	17	3.4E-4	4.7E-4
MTBE	3.7E-3	3.5E-3	4.7E-3	8.3E-3	5.0E-3	44	3.3E-4	4.7E-4
t-3-hexene + chloroform	1.6E-3	3.0E-3	4.3E-3	4.1E-3	3.2E-3	39	1.1E-4	4.7E-4
2-methyl-2-pentene	1.1E-3	3.0E-3	4.3E-3	4.6E-3	3.2E-3 a	50	3.1E-4	4.7E-4
2,2,3-trimethylbutane	3.2E-3	3.0E-3	3.0E-3	3.7E-3	3.2E-3 a	10	1.6E-4	4.7E-4
Cyclopentene	3.2E-3	2.5E-3	3.0E-3	3.2E-3	3.0E-3 a	11	1.0E-4	4.7E-4
t-2-hexene	2.1E-3	3.0E-3	2.6E-3	3.2E-3	2.7E-3	18	1.8E-4	4.7E-4
3-methyl-1-butene	2.1E-3	2.5E-3	3.0E-3	3.2E-3	2.7E-3 a	19	1.3E-4	4.7E-4
trans-3-methyl-2-pentene	2.6E-3	2.0E-3	3.4E-3	2.3E-3	2.6E-3 a	24	1.5E-4	4.7E-4
2-methyl-1-pentene	1.6E-3	1.5E-3	3.9E-3	2.3E-3	2.3E-3 a	48	1.3E-4	4.7E-4
Cyclohexene	1.1E-3	9.9E-4	4.7E-3	2.3E-3	2.3E-3 a	77	1.3E-4	4.7E-4
3,3-dimethylpentane	3.2E-3	9.9E-4	2.6E-3	2.3E-3	2.3E-3 a	41	1.5E-4	4.7E-4
1-methylcyclopentene	1.6E-3	2.0E-3	1.3E-3	1.4E-3	1.6E-3 a	20	1.6E-4	4.7E-4
c-2-hexene	1.6E-3	1.5E-3	1.3E-3	4.6E-4	1.2E-3 a	42	9.2E-5	4.7E-4
t-3-heptene	1.1E-3	9.9E-4	8.6E-4	1.4E-3	1.1E-3 a	21	2.1E-5	4.7E-4
C6 olefin	5.3E-4	9.9E-4	1.3E-3	1.4E-3	1.0E-3 a	37	3.1E-5	4.7E-4
Isoprene	ND	ND	8.6E-4	9.2E-4	< 8.9E-4 a d	5	7.8E-4	4.7E-4

Table 4-14b. Volatile Organic Compounds from Canisters (Delta – Oil) (Continued).

Parameter	Value							
Units	mg/dscm					(%)	mg/dscm	
Run Number Date	Oil-Run 1 22-Mar-02	Oil-Run 2 23-Mar-02	Oil-Run 3 25-Mar-02	Oil-Run 4 26-Mar-02	Stack Average	RSD	Oil-Ambient 8-Apr-02	MDL (1)
C7 olefin 2	ND	ND	8.6E-4	ND	< 8.6E-4 e	n/a	2.1E-5	4.7E-4
4-methyl-1-pentene	1.1E-3	5.0E-4	1.3E-3	4.6E-4	8.2E-4 a	50	4.1E-5	4.7E-4
cis-3-methyl-2-pentene	5.3E-4	9.9E-4	8.6E-4	9.2E-4	8.2E-4	25	1.1E-4	4.7E-4
c-3-hexene	ND	5.0E-4	4.3E-4	4.6E-4	< 4.6E-4 a	7	2.1E-5	4.7E-4
4-methylhexene	ND	ND	4.3E-4	4.6E-4	< 4.4E-4	5	4.1E-5	4.7E-4

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Natural Gas Combustion. Results of the stack emissions for the natural gas operation are presented in Table 4-15a. Ag, Au, Ba, Cd, Ga, Hg, In, La, Mo, P, Pd, Rb, Sb, Se, Sn, U, Y, and Zr were below detectable levels for all sample runs. S is the most abundant element in the diluted samples with an average concentration of 0.030 mg/dscm followed by Si at 0.0041 mg/dscm. All stack sample averages were greater than the concentrations measured in the ambient sample and about 57% of the stack sample averages were over an order of magnitude greater than the concentrations measured in the ambient sample. Ambient levels were greater than the stack sample averages 95% confidence lower bounds for about 19% of the detected elements. DSB levels were greater than the stack sample averages 95% confidence lower bounds for about 52 percent of the detected elements; DSB levels were greater than the stack sample averages for about 10 percent of the detected compounds. With the exception of Mg, FB concentrations were lower than DSB levels. Cl, Cr, Mn, Pb, and Sr levels were less than twice method detection limit levels. Please refer to Section 6 for additional discussion of blank results.

Oil Combustion. Results of the stack emissions for the oil operation are presented in Table 4-15b. Ag, Au, Br, Cl, Cd, Hg, In, Na, Pd, and Rb were below detectable levels for all sample runs. S has the highest average concentration of 1.0 mg/dscm followed by Ni at 0.30 mg/dscm. S, Ni, Si, Zn, Fe, Ca and Al account for more than 90 percent of the elemental mass. Average stack sample concentrations for all metals were over an order of magnitude greater than ambient

Table 4-15a. Dilution Sampler Elements Results (Delta – NG).

Parameter	Value							
Units	mg/dscm					%	mg/dscm	
Run Date	NG-Run 1 02-Apr-02	NG-Run 2 03-Apr-02	NG-Run 3 04-Apr-02	NG-Run 4 05-Apr-02	Average	RSD	NG-Ambient 08-Apr-02	MDL (2)
Al	3.5E-03	9.8E-4	1.1E-3	6.9E-4	1.6E-3 a b d	83	1.1E-4	1.9E-4
As	ND	7.6E-5	ND	ND	< 7.6E-5 e	n/a	1.1E-6	3.1E-5
Br	3.5E-05	6.3E-5	4.4E-5	2.8E-5	4.2E-5 a	35	6.8E-6	1.9E-5
Ca	3.4E-03	2.6E-3	3.9E-3	4.0E-3	3.5E-3 a	18	3.5E-4	8.6E-5
Cl	ND	2.3E-4	ND	ND	< 2.3E-4 e	n/a	9.5E-5	1.9E-4
Co	7.4E-05	3.3E-5	1.0E-4	4.4E-5	6.3E-5 a	49	5.6E-6	1.7E-5
Cr	5.3E-05	ND	4.7E-5	ND	< 5.0E-5	8	3.4E-6	3.6E-5
Cu	3.1E-04	2.1E-4	6.0E-4	2.0E-4	3.3E-4 a	58	1.8E-5	2.1E-5
Fe	4.4E-03	3.7E-3	2.6E-3	1.7E-3	3.1E-3	39	6.4E-4	2.9E-5
K	1.4E-03	1.1E-3	1.1E-3	7.9E-4	1.1E-3	23	2.2E-4	1.2E-4
Mg	3.9E-04	4.6E-4	6.8E-4	2.3E-4	4.4E-4 a b	42	1.2E-5	(1)
Mn	7.0E-05	6.3E-5	5.8E-5	3.4E-5	5.6E-5	27	3.4E-5	3.1E-5
Na	1.1E-03	1.1E-3	3.1E-3	1.9E-3	1.8E-3 a b d	51	9.6E-5	(1)
Ni	5.9E-04	1.8E-4	1.4E-3	5.8E-4	6.9E-4 a	75	4.2E-5	1.7E-5
Pb	ND	ND	ND	5.3E-5	< 5.3E-5 e	n/a	7.6E-6	5.7E-5
S	4.3E-02	1.9E-2	2.8E-2	2.8E-2	3.0E-2 a	34	1.7E-3	9.5E-5
Si	4.6E-03	3.6E-3	4.8E-3	3.6E-3	4.1E-3	15	4.3E-4	1.2E-4
Sr	ND	ND	ND	2.2E-5	< 2.2E-5 e	n/a	1.7E-6	2.1E-5
Ti	ND	1.8E-4	2.0E-4	8.8E-5	< 1.5E-4 a d	38	1.9E-5	5.5E-5
V	ND	7.9E-5	2.9E-4	8.8E-5	< 1.5E-4 a d	79	9.9E-6	4.8E-5
Zn	1.3E-03	1.0E-3	1.3E-3	9.6E-4	1.1E-3	15	6.4E-5	2.1E-5
Zr	ND	ND	ND	ND	ND e	n/a	8.8E-7	3.2E-5

(1) No detection limits given. Zeroes treated as non-detect. Data is semi-quantitative.

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-15b. Dilution Sampler Elements Results (Delta – Oil).

Parameter	Value							
Units	mg/dscm					%	mg/dscm	
Run	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Oil-Ambient	MDL
Date	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02			08-Apr-06	(2)
Al	7.2E-02	7.1E-2	6.7E-2	6.7E-2	6.9E-2	4	1.1E-4	5.3E-4
As	6.9E-04	7.4E-4	9.4E-4	6.5E-4	7.6E-4 d	17	1.1E-6	8.4E-5
Ba	3.5E-03	3.8E-3	5.7E-3	3.7E-3	4.2E-3	25	ND	2.7E-3
Br	ND	ND	ND	ND	ND e	n/a	6.8E-6	5.3E-5
Ca	1.1E-01	1.3E-1	1.6E-1	1.4E-1	1.4E-1	16	3.5E-4	2.4E-4
Cl	ND	ND	ND	ND	ND e	n/a	9.5E-5	5.3E-4
Co	1.9E-02	1.7E-2	2.0E-2	1.8E-2	1.9E-2	7	5.6E-6	4.6E-5
Cr	2.2E-03	2.2E-3	2.4E-3	2.2E-3	2.2E-3	4	3.4E-6	1.0E-4
Cu	7.6E-03	9.1E-3	1.3E-2	1.1E-2	1.0E-2	22	1.8E-5	5.8E-5
Fe	1.3E-01	1.3E-1	1.6E-1	1.5E-1	1.4E-1	10	6.4E-4	7.9E-5
Ga	4.6E-04	7.6E-4	7.6E-4	9.0E-4	7.2E-4	26	ND	1.0E-4
K	1.2E-02	1.5E-2	1.9E-2	1.6E-2	1.6E-2	19	2.2E-4	3.2E-4
La	1.5E-02	1.4E-2	1.4E-2	1.3E-2	1.4E-2	6	ND	3.3E-3
Mg	ND	9.7E-6	3.9E-4	1.8E-3	< 7.4E-4 b d	129	1.2E-5	(1)
Mn	1.5E-03	1.6E-3	1.9E-3	1.7E-3	1.7E-3	9	3.4E-5	8.4E-5
Mo	3.6E-03	3.9E-3	6.7E-3	4.8E-3	4.7E-3	29	ND	1.4E-4
Na	ND	ND	ND	ND	ND e	n/a	9.6E-5	(1)
Ni	2.8E-01	2.8E-1	3.2E-1	3.0E-1	3.0E-1	7	4.2E-5	4.7E-5
P	3.2E-03	1.4E-2	2.3E-2	1.9E-2	1.5E-2	58	ND	3.0E-4
Pb	6.2E-03	7.9E-3	1.1E-2	8.8E-3	8.6E-3	25	7.6E-6	1.6E-4
S	1.2E+00	8.2E-1	1.1E+0	1.1E+0	1.0E+0	15	1.7E-3	2.6E-4
Sb	1.2E-02	1.2E-2	1.5E-2	1.2E-2	1.2E-2	11	ND	9.5E-4
Se	8.3E-05	ND	ND	ND	< 8.3E-5 e	n/a	ND	6.3E-5
Si	1.9E-01	1.8E-1	1.9E-1	1.9E-1	1.9E-1	3	4.3E-4	3.3E-4
Sn	1.8E-03	1.9E-3	3.4E-3	2.5E-3	2.4E-3	32	ND	9.0E-4
Sr	9.1E-04	8.7E-4	1.1E-3	9.7E-4	9.5E-4	8	1.7E-6	5.8E-5
Ti	6.0E-03	5.8E-3	6.2E-3	6.7E-3	6.2E-3	7	1.9E-5	1.5E-4
Tl	1.7E-04	ND	2.0E-4	1.6E-4	< 1.8E-4	11	ND	1.3E-4
V	4.1E-02	4.9E-2	5.5E-2	5.2E-2	4.9E-2	12	9.9E-6	1.3E-4
Y	ND	1.0E-4	1.4E-4	1.2E-4	< 1.2E-4	16	ND	6.9E-5
Zn	1.1E-01	1.4E-1	2.1E-1	1.8E-1	1.6E-1	26	6.4E-5	5.8E-5
Zr	1.9E-04	2.3E-4	2.4E-4	2.3E-4	2.2E-4	11	8.8E-7	9.0E-5

(1) No detection limits given. Zeroes treated as non-detect. Data is semi-quantitative.

(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.

MDL- Method Detection Limit

n/a- not applicable

ND - Not Detected

RSD- Relative Standard Deviation

< - detected in fewer than all test runs

a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.

d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

levels. The DSB levels were an order of magnitude lower than stack sample averages for all detected elements except S (factor of 8). Only As and Mg had blank levels were greater than the stack sample averages 95% confidence lower bounds due to high measurement uncertainties. Ba, Se, Tl, and Y levels were less than twice method detection limit levels. Please refer to Section 6 for additional discussion of blank results.

Carbonyls (Aldehydes and Ketones)

Carbonyls were measured because they can adsorb on fine particles. Carbonyls were captured with the dilution sampler using two DNPH-impregnated silica gel cartridges assembled in series, and subsequently analyzed in the lab by HPLC. The second cartridges were used to check for breakthrough, and the results presented in Tables 4-16a and 4-16b are the sum of the two cartridges. The formaldehyde concentrations detected in the backup were below detection limits except for one sample at 10 percent, indicating very little breakthrough. The results are field blank corrected; thus, samples with lower concentrations than the field blank are reported as non-detect.

Natural Gas Combustion. Formaldehyde emissions were 0.23 mg/dscm (186 parts per billion by volume (ppbv)) for natural gas operation. Ambient sample levels were an order of magnitude lower than the average stack sample levels for all carbonyls. DSB levels were greater than the stack sample averages 95% confidence lower bounds for formaldehyde, acetaldehyde, and acetone. FB levels were greater than the stack sample averages 95% confidence lower bounds for acetaldehyde, acetone, and MEK.

Oil Combustion. Formaldehyde emissions were 0.22 mg/dscm (177 ppbv) for oil operation. Ambient sample levels were an order of magnitude lower than the average stack sample levels for all carbonyls. DSB levels were greater than or equal to the stack sample averages for formaldehyde, acetone, and MEK. FB levels were greater than the stack sample averages 95% confidence lower bounds for acetaldehyde, acetone, and MEK.

Table 4-16a. Dilution Sampler Carbonyl (Aldehyde) Results (Delta – NG).

Run		NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD (%)	NG-Ambient	MDL
Date	Units	02-Apr-02	03-Apr-02	04-Apr-02	05-Apr-02			08-Apr-02	(1)
Formaldehyde	mg/dscm	2.2E-1	3.7E-1	1.9E-1	1.5E-1	2.3E-1 a	42	9.6E-3	2.5E-3
	ppb	176	299	149	121	186	42	8	2
Acetaldehyde	mg/dscm	6.9E-2	8.3E-2	4.3E-2	4.3E-2	5.9E-2 a b	34	2.6E-3	6.8E-3
Acetone	mg/dscm	1.3E-1	8.0E-2	9.0E-2	6.8E-2	9.3E-2 a b	31	4.7E-3	3.1E-2
MEK	mg/dscm	1.2E-2	1.1E-2	7.2E-3	8.4E-3	9.5E-3 b	22	5.0E-4	3.7E-3
Butyraldehyde	mg/dscm	ND	ND	ND	ND	ND e	n/a	3.2E-4	3.0E-3
Benzaldehyde	mg/dscm	2.3E-3	ND	ND	ND	< 2.3E-3 e	n/a	1.4E-4	1.5E-3
Glyoxal	mg/dscm	4.3E-3	5.1E-3	2.5E-3	ND	< 4.0E-3	33	ND	1.1E-3
Valeraldehyde	mg/dscm	ND	5.2E-3	ND	ND	< 5.2E-3 e	n/a	ND	1.7E-3

* All results are field blank corrected.
(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the average Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-16b. Dilution Sampler Carbonyl (Aldehyde) Results (Delta – Oil).

Run		Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD (%)	Ambient	MDL
Date	Units	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02			08-Apr-02	(1)
Formaldehyde	mg/dscm	1.7E-1	2.5E-1	2.4E-1	ND	< 2.2E-1 a	19	9.6E-3	3.5E-2
	ppb	139	198	194	ND	177	19	8	28
Acetaldehyde	mg/dscm	1.2E-1	7.0E-2	1.6E-1	ND	< 1.1E-1 b	38	2.6E-3	5.1E-2
Acetone	mg/dscm	4.6E-1	5.4E-1	3.4E-1	1.2E-2	3.4E-1 a b	68	4.7E-3	8.8E-3
MEK	mg/dscm	4.7E-2	6.2E-2	4.9E-2	2.7E-2	4.6E-2 a b	31	5.0E-4	1.0E-2
Butyraldehyde	mg/dscm	ND	ND	ND	ND	ND e	n/a	3.2E-4	1.4E-2
Benzaldehyde	mg/dscm	ND	2.8E-2	ND	ND	< 2.8E-2 e	n/a	1.4E-4	5.1E-3
Valeraldehyde	mg/dscm	ND	3.5E-2	ND	ND	< 3.5E-2 e	n/a	ND	1.5E-2
Hexanaldehyde	mg/dscm	2.5E-2	2.3E-2	ND	ND	< 2.4E-2	4	ND	2.2E-3

* All results are field blank corrected.
(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the average Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Inorganic Fine Particle Precursors

NO_X, SO_2 and NH_3 emitted as gases can form secondary fine particles in the atmosphere through photochemical and other reactions. Gaseous NH_3 was captured on a citric acid-impregnated cellulose-fiber filter downstream of the quartz filter used for ions and OC/EC analysis. NO_x emissions were characterized using the plant's existing continuous emissions monitoring system. Gaseous sulfur oxides, which are reported as SO_2 since this is the predominant species expected in combustion exhaust but also would include gaseous SO_3 and vapor-phase H_2SO_4 if present, were captured on a potassium carbonate impregnated cellulose-fiber filter placed in the filter holder downstream of a quartz filter to remove aerosol sulfates.

Natural Gas Combustion. Only trace concentrations of NH_3 and SO_2 (less than 1 ppmv) were measured during natural gas firing (Table 4-17a). SO_2 levels in the ambient sample levels were greater than the stack sample average 95% confidence lower bound. DSB levels were greater than the stack sample averages 95% confidence lower bounds for both NH_3 and SO_2. FB levels were less than DSB levels and less than the stack sample averages 95% confidence lower bounds for both NH_3 and SO_2. Please refer to Section 6 for additional discussion of blank results.

Oil Combustion. Only trace concentrations of NH_3 (about 0.01 ppmv) were measured during natural gas firing (Table 4-17b). SO_2 levels were much higher than during natural gas combustion due to higher fuel sulfur levels. NH_3 levels in the ambient sample and DSB were greater than the stack sample average 95% confidence lower bound. Please refer to Section 6 for additional discussion of blank results.

Table 4-17a. Secondary PM Gaseous Precursor Results (Delta – NG).

Parameter	Units	Value							
Run Number	-	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	RSD	NG-Ambient	MDL
Date	-	2-Apr-02	3-Apr-02	4-Apr-02	5-Apr-02		(%)	8-Apr-02	(1)
Ammonia (DS)	mg/dscm	4.2E-1	8.6E-1	4.4E-1	-	5.7E-1 a	43	1.1E-2	5.9E-4
	ppm	5.9E-1	1.2E+0	6.3E-1	-	8.1E-1	43	1.5E-2	
	lb/hr	1.5E-2	2.5E-2	1.9E-2	-	2.0E-2	26	n/a	
Sulfur Dioxide (DS)	mg/dscm	3.5E+0	1.2E+0	1.5E+0	-	2.1E+0 a d	59	2.2E-2	1.5E-3
	ppm	1.3E+0	4.7E-1	5.7E-1	-	7.8E-1	59	8.2E-3	
	lb/hr	1.2E-1	3.6E-2	6.5E-2	-	7.5E-2	60	n/a	
Nitrigen Oxides (NOx as NO2) (CEMS	mg/dscm	1.2E+2	1.1E+2	9.4E+1	1.0E+2	1.1E+2	12	n/a	
	ppm	6.4E+1	5.8E+1	4.9E+1	5.3E+1	5.6E+1	12	n/a	5.0E+0
	lb/hr	4.4E+0	3.2E+0	4.0E+0	4.7E+0	4.1E+0	16	n/a	

CEMS - Continuous Emissions Monitoring System.
DS - Dilution Sampler
(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
Run 4 samples invalidated by analytical lab.
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 4-17b. Secondary PM Gaseous Precursor Results (Delta – Oil).

Parameter	Units	Value							
Run Number	-	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average	RSD	Oil-Ambient	MDL
Date	-	22-Mar-02	23-Mar-02	25-Mar-02	26-Mar-02		(%)	8-Apr-06	(1)
Ammonia (DS)	mg/dscm	1.0E-2	6.4E-3	6.3E-3	7.5E-3	7.6E-3 a b d	25	1.1E-2	1.6E-3
	ppm	1.5E-2	9.1E-3	8.9E-3	1.1E-2	1.1E-2	25	1.5E-2	
	lb/hr	5.8E-4	3.6E-4	3.7E-4	4.4E-4	4.4E-4	23	n/a	
Sulfur Dioxide (DS)	mg/dscm	5.3E+1	5.5E+1	4.9E+1	5.1E+1	5.2E+1	5	2.2E-2	4.1E-3
	ppm	2.0E+1	2.1E+1	1.9E+1	1.9E+1	2.0E+1	5	8.2E-3	
	lb/hr	3.0E+0	3.1E+0	2.9E+0	3.0E+0	3.0E+0	3	n/a	
Nitrigen Oxides (NOx	mg/dscm	3.2E+2	3.0E+2	3.5E+2	3.3E+2	3.3E+2	6	-	
as NO2) (CEMS	ppm	1.7E+2	1.6E+2	1.8E+2	1.7E+2	1.7E+2	6	-	5.0E+0
	lb/hr	1.8E+1	1.7E+1	2.0E+1	2.0E+1	1.9E+1	9	-	

CEMS - Continuous Emissions Monitoring System.
DS - Dilution Sampler
(1) Average MDL for dilution ratio. Ambient sample MDLs are smaller than test runs MDLs due to 1:1 dilution ratio.
MDL- Method Detection Limit
n/a- not applicable
ND - Not Detected
RSD- Relative Standard Deviation
< - detected in fewer than all test runs
a - 95% Confidence Lower Bound of the Average concentration is less than the Dilution Sampler Blank concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the Field Blank concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

SO_2 results from the dilution sampler for oil firing (Table 4-17b) are considerably lower than the CCT results presented earlier in Table 4-5, the portable SO_2 analyzer results presented earlier in Table 4-3, and the calculated SO_2 concentration based on fuel analysis and flue gas excess O_2. This strongly suggests that the capacity of the potassium carbonate-impregnated filter was exceeded. Based on the filter results, the sulfur oxides capacity of the filter (expressed as SO_2) is approximately 13 mg, which corresponds to an in-stack equivalent of 32 mg/dscm (12 ppmv) for a 4-hour sampling time at filter sampling rate of 75 sLpm and dilution ratio of 45:1. Future tests with elevated SO_2 concentrations should use a modified procedure or alternative method for determining SO_2. For example, the in-stack SO_2 capacity of the potassium carbonate-impregnated filter could be extended by reducing the sample flow rate through the filter. Using the SO_2 concentration of 90 ppmv from Table 4-3 as a guide, the optimum filter sample flow rate (with a safety factor of 5) would be approximately 2.0 sLpm for the same dilution ratio and total sampling time used in these tests. The SO_2 results are discussed further in Section 7.

Section 5

EMISSION FACTORS AND SPECIATION PROFILES

Emission factors are a cost-effective means of developing area-wide emission inventories, which are one of the fundamental tools for air quality management. They also are useful for estimating emissions impacts of new facilities. In response to requests from the U.S. Congress and the U.S. EPA, the National Research Council established the Committee on Research Priorities for Airborne Particulate Matter. The blue-ribbon panel of experts from industry, academia and the regulatory community on the committee identified characterization of source emissions as one of the ten key national research priorities, especially the size distribution, chemical composition, and mass emission rates of particulate matter emitted from the collection of primary particle sources in the United States, and the emissions of reactive gases that lead to secondary particle formation through atmospheric chemical reactions (NRC, 1999). Emission factors were derived from the results of these tests to facilitate data analysis and application. Although the test data quality is considered high (i.e., the tests were performed using a generally sound methodology or EPA reference methods, and data quality is well documented), emission factors derived from a single test are necessarily considered below average or poor quality because a single unit rarely represents a random sample of an entire source category population due to differences in design, configuration, maintenance condition, operating conditions and other factors (U.S. EPA, 1997b). The emission factors derived from this test may best be used in conjunction with similar test results from other units within the source category population to develop more robust, reliable emission factors.

EMISSION FACTORS

Emission factors were determined by dividing the emission rate, in lb/hr, by the measured heat input, in MMBtu/hr, to give pounds per million British thermal units (lb/MMBtu) for each test run. Heat input is the product of the measured fuel flow rate and the fuel heating value. Average emission factors were determined by taking the arithmetic mean of the detected data for valid test runs. Undetected data were excluded from calculations. This treatment of undetected data differs from the procedure used by EPA for development of emission factor documents (U.S. EPA, 1997b), in which one-half of the MDL is substituted for undetected data and used in sums and averaged data. The approach used in this report was chosen to avoid ambiguity when using the results for source apportionment analysis. Because one-half the detection limit is not included in the average results and uncertainty cannot be determined based on a single datum, emission factors are reported for only those substances detected in at least two of the four test runs. Emission factors based on data detected in at least three test runs are considered the most reliable. Emission factors based on only two detected test runs typically have higher uncertainties and may not be suitable for quantitative analysis. Unless otherwise indicated, emission factors are considered non-representative and have been excluded from tables if they have an uncertainty greater than 100 percent, an average stack concentration less than the DSB or FB, were not detected in any runs, or were detected in only one run. Compounds with average concentrations less than 5 times the highest blank are flagged "B" indicating they may be present due to contamination.

UNCERTAINTY

An uncertainty analysis was performed to determine the 95 percent confidence interval and to estimate the upper limit of the measured emission factor and the mass speciation results (ASME, 1998). The total uncertainty includes the bias (systematic error, or accuracy) and precision (random error, or variability) in each of the underlying measurements, summed using normal error propagation analysis. The total emission factor uncertainty includes uncertainty in the sample volumes, dilution ratios, fuel flow rate, fuel heating value and run-to-run variability in addition to the analytical uncertainty. In the tables that follow, the reported results, the total relative uncertainty, and a 95 percent confidence upper bound are given for each of the substances of interest. The total relative uncertainty represents the 95 percent confidence interval based on a two-tailed Student "t" distribution. The 95 percent confidence upper bound estimate is based on the single-tailed Student "t" distribution at the 95 percent confidence level. It is likely that emission factors with relative uncertainty greater than 100 percent are not representative of actual emissions, since they cannot be distinguished from zero with high confidence. As expected, many of the reported emission factors derived from the results of this test have high uncertainty due to the extremely low concentrations present in gas combustion exhaust and the small number of tests. Although the absolute value of the emission is therefore uncertain, the 95 percent confidence upper bound results allow a plausible upper bound for the emissions (i.e., it is likely that the actual emissions are below the upper bound).

Primary PM Emission Factors

Emission factors for primary particulate matter including PM2.5 mass, elements, and ions, were derived from the dilution sampling results (Table 5-1a (natural gas operation) and Table 5-1b (oil operation)). In addition, total PM (for oil only) and SO_3 were measured with in-stack methods; however, the total PM for oil-firing and SO_3 for gas-firing emission factors have been excluded from the tables because they have uncertainties greater than 100%.

Table 5-1a. Primary Emission Factors – Particulate Mass, Elements, and Ions (Delta – NG).

Substance		Emission Factor (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Elements	S	5.0E-5	B	69	7.6E-5	4
	Si	7.0E-6	B	49	9.7E-6	4
	Fe	5.1E-6	B	75	8.0E-6	4
	Zn	1.9E-6	B	49	2.7E-6	4
	K	1.8E-6	B	56	2.6E-6	4
	Mn	9.4E-8	B	61	1.4E-7	4
	Br	7.2E-8	B	71	1.1E-7	4
Ions	SO4=	1.2E-4	B	99	2.0E-4	3
	NH4+	3.1E-5	B	99	5.2E-5	3
	Soluble Na	1.7E-6	B	67	2.6E-6	3

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank and/or Field Blank.

Table 5-1b. Primary Emission Factors – Particulate Mass, Elements, and Ions (Delta – Oil).

Substance		Emission Factor (lb/MMBtu)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Particulate Mass (DS)	PM2.5 mass	1.6E-2	40	2.1E-2	4
Elements (DS)	S	1.2E-3	30	1.5E-3	4
	Ni	3.4E-4	20	4.0E-4	4
	Si	2.1E-4	18	2.5E-4	4
	Zn	1.8E-4	45	2.5E-4	4
	Fe	1.6E-4	24	2.0E-4	4
	Ca	1.5E-4	30	1.9E-4	4
	Al	7.8E-5	18	9.1E-5	4
	V	5.5E-5	26	6.7E-5	4
	Co	2.1E-5	21	2.5E-5	4
	K	1.8E-5	35	2.3E-5	4
	P	1.7E-5	97	2.9E-5	4
	La	1.6E-5	20	1.9E-5	4
	Sb	1.4E-5	25	1.7E-5	4
	Cu	1.1E-5	40	1.5E-5	4
	Pb	9.7E-6	44	1.3E-5	4
	Ti	7.0E-6	22	8.4E-6	4
	Mo	5.4E-6	49	7.4E-6	4
	Ba	4.7E-6	45	6.4E-6	4
	Sn	2.7E-6	53	3.8E-6	4
	Cr	2.5E-6	29	3.2E-6	4
	Mn	1.9E-6	23	2.3E-6	4
	Sr	1.1E-6	22	1.3E-6	4
	Ga	8.2E-7	46	1.1E-6	4
	Zr	2.5E-7	25	3.0E-7	4
	Y	< 1.4E-7	53	1.9E-7	3
Ions (DS)	Cl-	1.7E-5 B	36	2.2E-5	4
	SO4=	6.2E-3	48	8.5E-3	4
	NH4+	3.3E-4 B	39	4.4E-4	4
	Soluble Na	1.7E-5 B	65	2.7E-5	4
(CCT)	SO3	2.1E-2	43	2.8E-2	4

CCT - Controlled Condensation Train

DS - Dilution Sampler

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank, and/or Field Blank.

Particulate Carbon Emission Factors

Tables 5-2a (natural gas operation) and 5-2b (oil operation) present emission factors for particulate carbon (OC, EC, and total carbon) and particulate carbon species (SVOCs) derived from the dilution sampler measurements. SVOC emission factors are in general very low and many SVOCs have been excluded from the tables because their uncertainty is greater than 100 percent or their average emission factor is less than the levels in the blanks.

The natural gas OC and EC results are suspect because the DSB levels were higher than the average stack levels; thus, the OC and EC emission factors are not considered reliable and not included in Table 5-2a. SVOC emission factors are extremely small. 1,3+1,6+1,7-dimethylnaphthalene has the highest emission factor, 2.5×10^{-5} lb/MMBtu, for natural gas operation. The sum of all SVOCs emitted during natural gas operation (including those excluded from Table 5-2a), calculated from the average emission of each specie from all four runs, equals 8.7×10^{-5} lb/MMBtu. The sum of all SVOCs emitted during natural gas operation and included in Table 5-2a, calculated from each species' average emission factor from all four runs, equals 5.5×10^{-5} lb/MMBtu. The OC results for natural gas run 4 were invalidated; therefore, the SVOC results from runs 1, 2, and 3 only were averaged to improve comparability with the OC emission factor. The sum of all SVOCs emitted during natural gas operation, calculated from the average emission of each species from runs 1, 2 and 3, equals 1.0×10^{-4} lb/MMBtu. The carbon fraction in these emissions was calculated to be 9.3×10^{-5} lb/MMBtu, which corresponds to approximately 27 percent of the OC measured by TOR. The gap between OC and total carbon from speciated SVOCs exists for at least three possible reasons: only the PAH portion of SVOCs was determined in the laboratory analysis procedure; the definition of OC as measured by TOR and speciated SVOC measurements using GC/MS may not be comparable; and the OC measurement is likely not reliable as discussed above and is probably biased high due to VOC adsorption on the quartz filters; the Backup Filter OC concentration (Table 4-11a) equals the OC concentration, indicating the VOC adsorption bias may be significant for these tests.

Table 5-2a. Primary Emission Factors – Particulate Carbon (Delta – NG).

Substance	Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Semi-Volatile Organic Compounds					
1,3+1,6+1,7-dimethylnaphthalene	2.5E-5	B	73	3.8E-5	4
2-methylnaphthalene	7.7E-6	B	68	1.2E-5	4
1-methylnaphthalene	4.4E-6	B	68	6.6E-6	4
2,6+2,7-dimethylnaphthalene	4.3E-6	B	73	6.6E-6	4
1+2-ethylnaphthalene	3.1E-6	B	95	5.3E-6	4
A-trimethylnaphthalene	2.0E-6	B	86	3.4E-6	4
1,4+1,5+2,3-dimethylnaphthalene	2.0E-6	B	84	3.3E-6	4
C-trimethylnaphthalene	1.9E-6	B	98	3.2E-6	4
B-trimethylnaphthalene	1.7E-6	B	92	2.8E-6	4
1,2-dimethylnaphthalene	1.1E-6	B	75	1.7E-6	4
2,3,5+I-trimethylnaphthalene	1.0E-6	B	87	1.7E-6	4
F-trimethylnaphthalene	8.8E-7	B	94	1.5E-6	4
Biphenyl	4.0E-7	B	62	6.0E-7	4

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

The sum of all SVOCs emitted during oil operation and included in Table 5-2b, calculated from the average emission of each specie from all four runs, equals 1.1 $\times 10^{-5}$ lb/MMBtu. The sum of all SVOCs emitted during oil operation, (including those excluded from Table 5-2b), calculated from the average emission of each specie from all four runs, equals 1.1 $\times 10^{-4}$ lb/MMBtu and the carbon fraction comprises approximately 13 percent of the total OC. The gap between OC and total carbon in speciated emissions may exist for the same reasons described earlier. A-trimethylnaphthalene has the highest value, with an emission factor of 2.2×10^{-6} lb/MMBtu.

Table 5-2b. Primary Emission Factors – Particulate Carbon (Delta – Oil).

Substance	Average (lb/MMBtu)			Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
Organic Carbon (OC) **		7.2E-4	B	40	9.5E-4	4
Elemental Carbon		6.7E-4		63	9.8E-4	4
Total Carbon*		1.4E-3		32	1.7E-3	4
Semi-Volatile Organic Compounds						
A-trimethylnaphthalene		2.2E-6	B	92	3.9E-6	4
Phenanthrene		1.8E-6		66	2.7E-6	4
2,3,5+I-trimethylnaphthalene		1.1E-6	B	99	2.1E-6	4
B-MePy/MeFl		9.7E-7		80	1.6E-6	4
9-fluorenone		9.0E-7	B	41	1.2E-6	4
F-trimethylnaphthalene		8.9E-7	B	76	1.4E-6	4
Fluoranthene		7.0E-7		81	1.1E-6	4
Dibenzofuran		4.8E-7	B	51	6.8E-7	4
Anthrone		4.5E-7		84	7.3E-7	4
Anthraquinone		4.1E-7		83	6.6E-7	4
C-MePy/MeFl		3.5E-7		89	5.8E-7	4
2,4,5-trimethylnaphthalene		3.2E-7	B	90	5.3E-7	4
Benzo(a)pyrene	<	1.2E-7	B	99	2.3E-7	3
Fluorene	<	5.8E-7		56	7.8E-7	2
Backup Filter OC ***		1.2E-4	B	57	1.8E-4	4

* TC Average calculated as average of TC runs, not OC Average + EC Average.

** OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote *** and Sections 6 & 7 for further discussion.

*** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion. Note, Dilution System Blank > Sample Average; it is likely the reported emission factor value is not representative of actual emissions. Data users should exercise appropriate caution.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Secondary Particle Precursor Emission Factors

Emissions of NO_X, SO_2, NH_3 and VOC with carbon number greater than 7 (VOC^{8+}) are considered secondary fine particle precursors. The emission factor for NO_X was derived from the plant's continuous emission monitoring results. Emission factors for SO_2, NH_3 and VOC^{8+} were derived from the dilution sampler results.

Secondary Organic Aerosol Precursors and Other VOCs Emission Factors - Tenax Sampling. Emission factors for VOCs obtained from the Tenax samples are presented in Table 5-3a for natural gas operation and Table 5-3b for oil operation. These tables group the Tenax VOC results as Particulate Carbon Precursors (VOC with carbon number 8 or greater) and Other VOCs (VOC with carbon number 7 or less). Benzaldehyde, benzoic acid, hexadecanoic acid, phenol, and acetophenone are potential Tenax degradation products, causing their emission factors to have a high degree of uncertainty. The emission factors for these compounds have been excluded from the tables. The sum of all average VOCs measured by Tenax sampling and emitted during natural gas operation (including those excluded from Table 5-3a) equals $1.4\text{x}10^{-3}$ lb/MMBtu, and the VOC sum for Table 5-3a compounds only is $6.8\text{x}10^{-4}$ lb/MMBtu with m & p-xylene being the most abundant at $1.0\text{x}10^{-4}$ lb/MMBtu. The sum of all average VOCs measured by Tenax sampling and emitted during oil operation (including those excluded from Table 5-3b) equals $1.8\text{x}10^{-3}$ lb/MMBtu, and the VOC sums for Table 5-3b compounds are $4.6\text{x}10^{-4}$ lb/MMBtu for Particulate Carbon Precursors, with pentadecane being the most abundant at $8.8\text{x}10^{-5}$ lb/MMBtu, and $7.4\text{x}10^{-5}$ lb/MMBtu for Other VOCs, with 1,3-dichlorobenzene being the most abundant at $4.6\text{x}10^{-5}$ lb/MMBtu.

Secondary Organic Aerosol Precursors and Other VOCs Emission Factors - Canister Sampling Emission factors for VOCs obtained from the Canisters samples are presented in Table 5-4a for natural gas operation and Table 5-4b for oil operation. These tables group the Canister VOC results as Particulate Carbon Precursors (VOC with carbon number 8 or greater) and Other VOCs (VOC with carbon number 7 or less). Some VOC were measured by both Tenax and Canister sampling. There are no redundant VOC in Tables 5-3b and 5-4b for oil-fired operation. However, for natural gas operation, m-&p-xylene, o-xylene, m-ethyltoluene, ethylbenzene, 1,3,5-trimethylbenzene, and p-ethyltoluene were measured by both methods and included in both Tables 5-3a and 5-4a for natural gas-fired operation. The Canister measurements are higher for all compounds and are likely more accurate than the Tenax measurements, assuming the primary difference between the measurements is incomplete recoveries from the Tenax. The differences between the Canister and Tenax measurements ranged from approximately 20% for p-ethlytoluene to 240% for 1,3,5-trimethylbenzene.

Table 5-3a. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Tenax (Delta – NG).

Substance	Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (lb/MMBtu) (b)	Number of Detected Runs
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)					
m & p-xylene	1.0E-4	B	54	1.4E-4	4
(+/-)-limonene	8.8E-5	B	90	1.5E-4	4
Octadecane	5.9E-5	B	71	9.0E-5	4
Hexadecane	5.7E-5	B	69	8.7E-5	4
Heptadecane	5.6E-5	B	66	8.4E-5	4
m-ethyltoluene	3.8E-5	B	80	6.1E-5	4
Pentadecane	3.8E-5	B	87	6.3E-5	4
Eicosane	3.3E-5	B	93	5.7E-5	4
Ethylbenzene	3.0E-5	B	60	4.3E-5	4
o-xylene	2.9E-5	B	48	4.0E-5	4
Tetradecane	2.9E-5	B	66	4.3E-5	4
p-ethyltoluene	1.6E-5	B	66	2.4E-5	4
1,3,5-trimethylbenzene	1.3E-5	B	85	2.1E-5	4
Tridecane	1.3E-5	B	68	1.9E-5	4
1,6+1,3+1,7-dimethylnaphthalene	1.2E-5	B	83	2.0E-5	4
p-isopropyltoluene	1.2E-5	B	76	1.9E-5	4
1-methylindan	9.6E-6	B	89	1.6E-5	4
o-ethyltoluene	9.2E-6	B	90	1.6E-5	4
2-methylnaphthalene	9.1E-6	B	89	1.5E-5	4
Propylbenzene	7.0E-6	B	73	1.1E-5	4
Propylcyclohexane	5.5E-6	B	71	8.4E-6	4
B-dimethylindane	5.4E-6	B	74	8.4E-6	4
1-methylnaphthalene	4.7E-6	B	89	7.8E-6	4
2,6+2,7-dimethylnaphthalene	< 4.2E-6	B	99	7.1E-6	3
Indan	3.5E-6		100	6.1E-6	4
Phenanthrene	< 3.5E-6		72	5.2E-6	3
Total VOC^{C8+} (c)	6.8E-4				

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

c - Sum of VOC with carbon number 8 or greater.

d - Sum of Other VOC with carbon number 7 or less.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Table 5-3b. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Tenax (Delta – Oil).

Substance	Average (lb/MMBtu)	Uncertainty (%) (a)	95% Confidence Upper Bound (lb/MMBtu) (b)	Number of Detected Runs
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)				
Pentadecane	8.8E-5 B	61	1.3E-4	4
Hexadecane	6.7E-5 B	38	8.6E-5	4
Heptadecane	5.1E-5 B	21	6.0E-5	4
Tetradecane	5.1E-5 B	59	7.3E-5	4
Octadecane	3.7E-5 B	37	4.8E-5	4
1,6+1,3+1,7-dimethylnaphthalene	3.2E-5 B	94	5.5E-5	4
2-methylnaphthalene	2.5E-5 B	89	4.1E-5	4
p-isopropyltoluene	2.4E-5 B	49	3.3E-5	4
Tridecane	1.9E-5 B	63	2.8E-5	4
Octanal	1.6E-5 B	38	2.1E-5	4
1-methylnaphthalene	1.4E-5 B	92	2.4E-5	4
2,6+2,7-dimethylnaphthalene	1.0E-5 B	83	1.7E-5	4
Biphenyl	< 6.2E-6 B	89	1.0E-5	3
2,3-benzofuran	5.3E-6 B	89	8.9E-6	4
2,3+1,5+1,4-dimethylnaphthalene	3.9E-6 B	82	6.3E-6	4
Phenanthrene	3.6E-6 B	59	5.3E-6	4
1+2-ethylnaphthalene	3.3E-6 B	96	5.7E-6	4
1,2-dimethylnaphthalene	< 1.8E-6	61	2.4E-6	2
Total VOC^{C8+} (c)	4.6E-4			
Other VOCs (Carbon Number 7 or less)				
1,3-dichlorobenzene	4.6E-5 B	88	7.5E-5	4
Cyclohexanone	< 2.6E-5	89	4.2E-5	3
2-heptanone	< 2.8E-6	53	3.6E-6	2
Total VOC^{C7-} (d)	7.4E-5			

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

c - Sum of VOC with carbon number 8 or greater.

d - Sum of Other VOC with carbon number 7 or less.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Table 5-4a. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Canisters (Delta – NG).

Substance	Average (lb/MMBtu)		Uncertainty (%)	95% Confidence Upper Bound	Number of Detected Runs
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)					
1-decene	3.2E-4	B	79	5.2E-4	4
m- & p-xylene	1.3E-4	B	72	2.0E-4	4
n-decane	7.5E-5	B	84	1.2E-4	4
o-xylene	5.1E-5	B	79	8.2E-5	4
m-ethyltoluene	4.8E-5	B	91	8.1E-5	4
n-nonane	4.2E-5	B	88	7.1E-5	4
Ethylbenzene	3.9E-5	B	79	6.2E-5	4
1,2,3-trimethylbenzene	3.2E-5	B	94	5.6E-5	4
1,3,5-trimethylbenzene	3.1E-5	B	86	5.1E-5	4
n-octane	2.5E-5	B	79	4.0E-5	4
Isopropylcyclohexane	2.4E-5	B	86	4.0E-5	4
2,2,4-trimethylpentane	2.1E-5	B	88	3.6E-5	4
p-ethyltoluene	1.9E-5	B	95	3.3E-5	4
3-methyloctane	1.6E-5	B	69	2.5E-5	4
o-ethyltoluene	1.6E-5	B	88	2.6E-5	4
n-propylbenzene	1.5E-5	B	91	2.6E-5	4
2-methylheptane	1.4E-5	B	70	2.1E-5	4
3-methylheptane	1.3E-5	B	76	2.1E-5	4
3-ethylpentane	9.3E-6	B	64	1.4E-5	4
3,6-dimethyloctane	9.3E-6	B	77	1.5E-5	4
C9 olefin 3	8.9E-6	B	92	1.5E-5	4
Isopropylbenzene	8.8E-6	B	95	1.5E-5	4
1,2,3,5-tetramethylbenzene	6.1E-6	B	74	9.6E-6	4
C10 olefin 2	6.0E-6	B	72	9.4E-6	4
4-methylheptane	5.8E-6	B	62	8.6E-6	4
C8 paraffin 2	5.4E-6	B	94	9.3E-6	4
2,4,4-trimethyl-1-pentene	4.8E-6	B	70	7.5E-6	4
Nonene-1	3.9E-6	B	73	6.2E-6	4
2,5-diemthylhexane	3.7E-6	B	77	5.9E-6	4
Octene-1	2.7E-6	B	90	4.6E-6	4
1,2,4-trimethylbenzene	2.5E-6	B	56	3.7E-6	4
C10 paraffin A	2.3E-6	B	89	3.9E-6	4
C10 aromatic 5	1.7E-6	B	98	3.0E-6	4
C9 olefin 4	1.6E-6	B	73	2.5E-6	4
sec-butylbenzene	1.3E-6	B	59	1.9E-6	4
C8 olefin 1	1.3E-6	B	59	1.9E-6	4
C8 olefin 3	8.8E-7	B	72	1.4E-6	4
2,3-dimethylhexane	8.6E-7	B	79	1.4E-6	4
2,6-dimethylheptane	7.2E-7	B	83	1.2E-6	4
2,5-dimethylheptane	7.2E-7	B	83	1.2E-6	4
2,4-diemthylhexane	7.2E-7	B	83	1.2E-6	4
Total VOC^{C8+} (c)	1.0E-3				
Other VOCs (Carbon Number 7 or less)					
Ethane	5.1E-4	B	58	7.4E-4	4
Toluene	5.0E-4	B	100	8.8E-4	4
Propane	4.8E-4	B	89	8.1E-4	4
F 12	3.1E-4		71	4.8E-4	4
Chloromethane	2.8E-4	B	72	4.4E-4	4
Ethene	2.6E-4	B	55	3.7E-4	4
Acetaldehyde	2.4E-4	B	59	3.5E-4	4
Isopentane	2.3E-4	B	85	3.8E-4	4
Ethanol + ACN	2.1E-4	B	82	3.3E-4	4
Isobutane	1.9E-4	B	79	3.0E-4	4

Table 5-4a. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Canisters (Delta – NG) (Continued).

Substance	Average (lb/MMBtu)		Uncertainty (%)	95% Confidence Upper Bound	Number of Detected Runs
Methylene chloride	1.5E-4	B	90	2.6E-4	4
Cyclohexane	1.5E-4	B	63	2.2E-4	4
Acetylene	1.4E-4	B	61	2.0E-4	4
Propene	1.1E-4	B	71	1.8E-4	4
n-pentane	8.7E-5	B	89	1.5E-4	4
Iso-butene	7.8E-5	B	66	1.2E-4	4
Benzene	5.6E-5	B	62	8.3E-5	4
Methylcyclopentane	5.2E-5	B	94	9.0E-5	4
3-methylhexane + pentanal	4.3E-5	B	63	6.5E-5	4
3-methylpentane	4.1E-5	B	99	7.1E-5	4
Methylcyclohexane	4.0E-5	B	99	7.0E-5	4
n-heptane	2.9E-5	B	76	4.7E-5	4
Hexanal	2.4E-5	B	63	3.7E-5	4
2-methylhexane	2.3E-5	B	70	3.5E-5	4
1-butene	2.2E-5	B	75	3.5E-5	4
t-2-butene	2.1E-5	B	75	3.3E-5	4
Chlorobenzene	1.8E-5	B	92	3.0E-5	4
2,3-dimethylbutane	1.6E-5	B	79	2.5E-5	4
2-methyl-1-butene	1.3E-5	B	82	2.2E-5	4
t-2-pentene	1.3E-5	B	70	2.0E-5	4
2,2-dimethylbutane	1.2E-5	B	83	2.0E-5	4
Cyclopentane	1.2E-5	B	82	2.0E-5	4
2-methyl-2-butene	1.1E-5	B	77	1.8E-5	4
2,3-dimethylpentane	1.0E-5	B	70	1.5E-5	4
1,3-dimethylcyclopentane	7.6E-6	B	55	1.1E-5	4
MTBE	7.3E-6	B	92	1.3E-5	4
c-2-pentene	7.1E-6	B	73	1.1E-5	4
2-methyl-2-pentene	6.8E-6	B	94	1.2E-5	4
2,4-dimethylpentane	6.2E-6	B	86	1.0E-5	4
1,3-butadiene	6.0E-6	B	87	1.0E-5	4
t-2-hexene	3.8E-6	B	63	5.7E-6	4
3-methyl-1-butene	3.8E-6	B	81	6.1E-6	4
Cyclopentene	3.3E-6	B	75	5.3E-6	4
2-methyl-1-pentene	3.0E-6	B	93	5.2E-6	4
1-methylcyclopentene	2.8E-6	B	69	4.3E-6	4
3,3-dimethylpentane	2.3E-6	B	73	3.6E-6	4
cis-3-methyl-2-pentene	1.9E-6	B	54	2.7E-6	4
c-2-hexene	1.9E-6	B	54	2.7E-6	4
C6 olefin	1.6E-6	B	73	2.5E-6	4
4-methyl-1-pentene	1.1E-6	B	79	1.8E-6	4
t-3-heptene	8.8E-7	B	72	1.4E-6	4
C7 olefin 2	< 5.9E-7	B	68	8.9E-7	3

Table 5-4a. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Canisters (Delta – NG) (Continued).

Substance	Average (lb/MMBtu)	Uncertainty (%)	95% Confidence Upper Bound	Number of Detected Runs
4-methylhexene	5.9E-7 B	48	8.3E-7	4
c-3-hexene	5.9E-7	48	8.3E-7	4
Total VOC^{C7-} (d)	4.4E-3			

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

c - Sum of VOC with carbon number 8 or greater.

d - Sum of Other VOC with carbon number 7 or less.

B - Stack average is less than five times the Dilution System Blank.

Table 5-4b. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Canisters (Delta – Oil).

Substance	Average (lb/MMBtu)		Uncertainty (%)	95% Confidence Upper Bound	Number of Detected Runs
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)					
1,3-diethylbenzene	4.7E-5		76	7.5E-5	4
C10 paraffin C	2.7E-5	B	93	4.7E-5	4
1,2-diethylbenzene	1.5E-5	B	86	2.5E-5	4
1,4-diethylbenzene	1.3E-5	B	99	2.3E-5	4
2-methylheptane	1.2E-5	B	48	1.6E-5	4
3-methylheptane	1.1E-5	B	42	1.5E-5	4
3-ethylpentane	8.0E-6	B	46	1.1E-5	4
1,2,3,5-tetramethylbenzene	7.6E-6	B	67	1.2E-5	4
2,4,4-trimethyl-1-pentene	6.4E-6	B	42	8.6E-6	4
4-methylheptane	5.5E-6	B	54	7.8E-6	4
C8 paraffin 2	4.2E-6	B	71	6.5E-6	4
2,5-diemthylhexane	3.6E-6	B	45	4.9E-6	4
C10 aromatic 5	3.6E-6	B	88	6.0E-6	4
C8 olefin 1	1.4E-6	B	65	2.1E-6	4
2,3-dimethylhexane	9.5E-7	B	53	1.4E-6	4
C8 olefin 2	< 6.8E-7	B	96	1.1E-6	3
C8 olefin 3	6.8E-7	B	65	1.0E-6	4
2,4-diemthylhexane	6.6E-7	B	57	9.6E-7	4
4,4-dimethylheptane	< 5.6E-7		34	7.3E-7	3
2,4-dimethylheptane	< 5.4E-7		73	7.7E-7	2
Total VOC^{C8+} (c)	1.7E-4				
Other VOCs (Carbon Number 7 or less)					
Toluene	5.3E-4	B	56	7.8E-4	4
Ethene	3.7E-4	B	38	5.0E-4	4
n-hexane	2.4E-4	B	35	3.1E-4	4
Acetaldehyde	2.2E-4	B	38	3.0E-4	4
Isopentane	1.9E-4	B	51	2.7E-4	4
Propene	1.5E-4	B	36	2.0E-4	4
Methylcyclopentane	1.1E-4	B	65	1.7E-4	4
Iso-butene	1.0E-4	B	35	1.4E-4	4
Cyclohexane	1.0E-4	B	36	1.4E-4	4
n-pentane	8.0E-5	B	55	1.2E-4	4
Benzene	7.2E-5	B	33	9.3E-5	4
3-methylpentane	5.8E-5	B	97	1.0E-4	4
c-2-butene	3.6E-5	B	32	4.7E-5	4
3-methylhexane + pentanal	3.5E-5	B	44	4.8E-5	4
1-pentene	3.3E-5	B	76	5.2E-5	4
n-heptane	2.8E-5	B	51	4.0E-5	4
t-2-butene	2.4E-5	B	43	3.3E-5	4
2-methylhexane	2.0E-5	B	66	3.1E-5	4
1-butene	1.9E-5	B	39	2.5E-5	4
2,3-dimethylbutane	1.8E-5	B	90	3.1E-5	4
Cyclopentane	1.6E-5	B	64	2.3E-5	4
2-methyl-1-butene	1.1E-5	B	44	1.5E-5	4
t-2-pentene	9.9E-6	B	65	1.5E-5	4
2,2-dimethylbutane	9.5E-6	B	73	1.5E-5	4
2,3-dimethylpentane	9.3E-6	B	52	1.3E-5	4
2,4-dimethylpentane	7.8E-6	B	98	1.4E-5	4
1-hexene	6.8E-6	B	35	8.9E-6	4
c-2-pentene	5.9E-6	B	38	7.9E-6	4
1,3-dimethylcyclopentane	5.9E-6	B	38	7.8E-6	4

Table 5-4b. Secondary Organic Aerosol Precursors and Other VOCs Emission Factors Measured by Canisters (Delta – Oil) (Continued).

Substance	Average (lb/MMBtu)	Uncertainty (%)	95% Confidence Upper Bound	Number of Detected Runs
MTBE	5.8E-6 B	75	9.2E-6	4
t-3-hexene + chloroform	3.7E-6 B	67	5.6E-6	4
2,2,3-trimethylbutane	3.6E-6 B	32	4.7E-6	4
Cyclopentene	3.4E-6 B	33	4.4E-6	4
t-2-hexene	3.1E-6 B	39	4.1E-6	4
3-methyl-1-butene	3.1E-6 B	40	4.1E-6	4
2-methyl-1-pentene	2.6E-6 B	81	4.2E-6	4
3,3-dimethylpentane	2.6E-6 B	70	4.0E-6	4
c-2-hexene	1.3E-6 B	73	2.1E-6	4
t-3-heptene	1.2E-6 B	42	1.7E-6	4
C6 olefin	1.2E-6 B	64	1.8E-6	4
cis-3-methyl-2-pentene	9.3E-7 B	48	1.3E-6	4
4-methylhexene	< 5.2E-7	68	7.3E-7	2
Total VOC^{C7-} (d)	2.6E-3			

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

c - Sum of VOC with carbon number 8 or greater

d - Sum of Other VOCs with carbon number 7 or less.

B - Stack average is less than five times the Dilution System Blank.

The sum of all average VOCs measured by Canister sampling and emitted during natural gas operation (including those excluded from Table 5-4a) equals 7.9x10^{-3} lb/MMBtu, and the OC sums for Table 5-4a compounds are 1.0x10^{-3} lb/MMBtu for Particulate Carbon Precursors, with 1-decene being the most abundant at 3.2x10^{-4} lb/MMBtu, and 4.4x10^{-3} lb/MMBtu for Other VOCs, with ethane being the most abundant at 5.1x10^{-4} lb/MMBtu. The sum of all average VOCs measured by Canister sampling and emitted during oil operation (including those excluded from Table 5-4b) equals 7.8x10^{-3} lb/MMBtu, and the VOC sums for Table 5-4b compounds is 1.7x10^{-4} lb/MMBtu for Particulate Carbon Precursors, with 1,3-diethylbenzene being the most abundant at 4.7x10^{-5} lb/MMBtu, and 2.6x10^{-3} lb/MMBtu for Other VOCs, with toluene being the most abundant at 5.3x10^{-4} lb/MMBtu.

Inorganic Secondary Particulate Precursors Emission Factors. Emission factors for inorganic secondary particulate precursors: SO_2 and NH_3 as measured by the dilution sampler, SO_2 as measured by the controlled condensation train, and NO_x (as NO_2) measured by the plant CEMS are presented in Table 5-5a for natural gas operation and Table 5-5b for oil operation. The SO_2 and NH_3 emission factors from natural gas combustion have a very high degree of uncertainty and are presented for qualitative purposes only.

Carbonyls

Emission factors for carbonyls are presented in Table 5-6a for natural gas operation and Table 5-6b for oil operation. Acetone is used to clean the dilution sampler; thus, acetone measurements are not considered reliable and are excluded from the tables. Formaldehyde was the most abundant carbonyl emitted during natural gas operation at 3.9×10^{-4} lb/MMBtu. The emission factor for formaldehyde is higher than that found in the EPA FIRE 6.23 and AP-42 databases (7.7×10^{-5} lb/MMBtu) for a natural gas-fired commercial/industrial external combustion boiler with no emission controls; it should be noted the measurement methods used were not the same. Acetaldehyde was the most abundant carbonyl reliably measured during oil operation at 1.3×10^{-4} lb/MMBtu. Formaldehyde was measured during oil operation at 2.4×10^{-4} lb/MMBtu; however, this value was lower than the DSB level and is thus suspect and is not presented in Table 5-6b. The emission factor for formaldehyde is within the range of formaldehyde emission factors found in the EPA FIRE 6.23 and AP-42 databases (1.6×10^{-4} to 4.0×10^{-4} lb/MMBtu) for a No. 6 oil fired commercial/industrial external combustion boiler with no emission controls.

Table 5-5a. Inorganic Secondary Particulate Precursors Emission Factors (Delta – NG).

Substance	Average (lb/MMBtu)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
NH3 (DS)	9.5E-4 B	130	1.8E-3	3
SO2 (DS)	3.3E-3	160	7.0E-3	3
SO2 (CCT)	1.6E-3	110	2.9E-3	4
NOx as NO2 (CEMS)	1.8E-1	47	2.5E-1	4

DS - Dilution Sampler

CCT - Controlled Condensation Train

CEMS - Continous Emissions Monitoring System.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty). Uncertainty greater than 100% indicates it is likely the reported emission factor value is not representative of actual emissions. Data users should exercise appropriate caution.

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank and/or Field Blank.

Table 5-5b. Inorganic Secondary Particulate Precursors Emission Factors (Delta – Oil).

Substance	Average (lb/MMBtu)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
SO2 (DS)	5.9E-2	19	6.9E-2	4
SO2 (CCT)	1.8E-1	47	2.4E-1	4
NOx as NO2 (CEMS)	3.7E-1	21	4.4E-1	4

DS - Dilution Sampler

CEMS - Continous Emissions Monitoring System.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank and/or Field Blank.

Table 5-6a. Carbonyl (Aldehyde) Emission Factors (Delta – NG).

Substance	Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (lb/MMBtu) (b)	Number of Detected Runs
Formaldehyde	3.9E-4	B	82	6.3E-4	4
Acetaldehyde	9.8E-5	B	72	1.5E-4	4
MEK	1.6E-5	B	62	2.4E-5	4

* All results are field blank corrected.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank or Field Blank.

Table 5-6b. Carbonyl (Aldehyde) Emission Factors (Delta – Oil).

Substance		Average (lb/MMBtu)		Uncertainty (%) (a)	95% Confidence Upper Bound (lb/MMBtu) (b)	Number of Detected Runs
Acetaldehyde	<	1.3E-4	B	100	2.2E-4	3
Hexanaldehyde	<	2.6E-5		65	3.7E-5	2

* All results are field blank corrected.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

< - detected in fewer than all test runs

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

B - Stack average is less than five times the Dilution System Blank and/or Field Blank.

PM2.5 MASS SPECIATION PROFILES

Speciation profiles for particulate matter provide a means of estimating the emissions of PM species based on a measurement or emission factor for total PM emissions. One of the principal applications of speciation profiles is for source-receptor and source apportionment type models, such as CMB8 (Watson et al., 1997). Receptor models require profiles that express the speciated substance abundances in terms of the mass fraction of the substance in the total emissions stream and the uncertainty associated with that mass fraction. Speciated PM emission factors also are useful for estimating impacts of PM species emissions on air quality, e.g., atmospheric visibility (Ryan, 2002). EPA's SPECIATE database contains one of the largest compilations of speciation profiles (U.S. EPA, 2002a).

Primary Emissions

The PM2.5 speciation profile for on natural gas operation, based dilution sampler results, is given in Table 5-7a. This profile excludes natural gas run 4 because the data set is incomplete. The PM2.5 speciation profile for No. 6 fuel oil operation, based on dilution sampler results, is given in Table 5-7b. Results from the ED-XRF analysis of the dilution sampler TMFs, the ion analysis of the dilution sampler quartz filters, and the OC/EC analysis of the dilution sampler quartz filters have been used to calculate the mass fractions. The mass fractions presented are the ratio of the emission factor of the emitted compound over the sum of the species emission factors. Because of the very low concentrations of total PM mass measured by the dilution sampler in these tests, it is considered more appropriate to normalize the PM2.5 speciation profile using the reconstructed PM2.5 mass, rather than the measured PM2.5 mass. Two assumptions were made about the form of some species in the dilution sampler and the ratios have been adjusted accordingly. First, it was assumed that all elements measured by ED-XRF were in their highest stable oxide form, and the elemental mass was adjusted accordingly. Second, it was assumed that all OC was present on the filter as SVOC; thus, the organic mass will be greater than the OC mass due to the association of hydrogen (H) and oxygen (O) atoms with the OC. The measured OC mass was adjusted upward to account for H and O (factor of approximately 1.08) based on the speciated SVOC results. S, Cl and N are assumed to be present as $SO_4^{=}$, Cl^-, NO_3^- and NH_4^+ (the IC rather than the ED-XRF analysis results were used for these ions/anions). Mg is not included in the reconstructed mass because the ED-XRF analysis is semi-quantitative for this element, and only soluble Na is included for the same reason. Substances excluded from Tables 5-1 and 5-2 (e.g. those with uncertainties > 100% and/or blanks > stack averages) are not presented in Tables 5-7a and 5-7b. For example, OC, which has the highest measured stack concentration for natural gas operation (about 58% of the sum of species) has been excluded from Table 5-1a due to a DSB level that is higher than the stack average. Compounds detected at a concentration less than 0.01% of the sum of the species are also not included in the tables. The average emission factor for the "reconstructed" sum of species ($6.6x10^{-4}$ lb/MMBtu) during natural gas operation runs 1 through 3 is about 128 percent of the average emission factor for total PM2.5 mass ($5.2x10^{-4}$ lb/MMBtu, measured gravimetrically). The discrepancy between the sum of species and the PM2.5 mass emissions may be due in part to the positive OC bias caused by VOC adsorption on the filters discussed previously. OC comprised about 58 percent of the mass emissions during natural gas operation.

Table 5-7a. Speciation Profile for Primary Emissions (Delta – NG).

Substance	Average Mass Fraction (1) (2) (%)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs*** (c)
SO4=	18	53	24	3
NH4+	4.7	60	6.7	3
Si	2.3	12	2.6	3
Fe	1.3	68	1.9	3
Soluble Na	0.64	23	0.76	3
K	0.55	30	0.67	3
Zn	0.45	9	0.49	3
Mn	0.03	35	0.04	3
Br	0.02	110	0.03	3

*** Non-detect runs set equal to zero for speciation calculations. Number of Detected Runs is number of runs with complete data set.

1- Mass fraction is emission factor (EMF) of species divided by EMF of sum of species - calculated from highest stable oxide form of elements for runs 1 - 4 and OC corrected for C, H in SVOC. NDs assumed to be zero for speciation calculations. The average sum of species EMF (6.6E-4 lb/MMBtu) is greater than average PM2.5 EMF (5.2E-4 lb/MMBtu: Runs 1 - 3 only (c)); the difference is less than the 95% CI of the measurements. Only substances with Emission Factors included in Table 5-1a are presented in this table.

2 - These speciation profiles should only be applied to PM2.5 mass results measured with a dilution sampler. They should not be applied to PM emissions factors measured by other methods (e.g. hot filter, wet impinger). When dilution sampler results for PM2.5 mass are not available, use species emission factors given in Tables 5-1 and 5-2.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty). Uncertainty greater than 100% indicates it is likely the reported emission factor value is not representative of actual emissions. Data users should exercise appropriate caution.

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

c - NG-Run 4 was invalidated for OC, EC, and ions; thus, speciation profiles based on results of NG-Run 1, NG-Run 2, and NG-Run 3 only.

Table 5-7b. Speciation Profile for Primary Emissions (Delta – Oil).

Substance	Average Mass Fraction (1) (2) (%)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs***
SO4=	60	23	70	4
OC*	7.9	46	11	4
EC	7.1	94	12	4
Ni	4.7	24	5.6	4
Si	4.5	27	5.5	4
NH4+	3.2	21	3.8	4
Ca	2.8	26	3.3	4
Zn	2.7	34	3.4	4
Fe	2.3	21	2.7	4
Al	1.5	36	1.9	4
V	0.99	32	1.2	4
Soluble Na	0.41	54	0.62	4
P	0.37	88	0.62	4
K	0.32	30	0.40	4
Co	0.29	22	0.33	4
Sb	0.19	24	0.22	4
La	0.19	31	0.23	4
Cl-	0.16	25	0.20	4
Cu	0.14	31	0.17	4
Ti	0.12	25	0.14	4
Pb	0.11	35	0.14	4
Mo	0.08	32	0.10	4
Ba	0.06	37	0.07	4
Cr	0.05	36	0.06	4
Mn	0.04	23	0.05	4
Sn	0.03	34	0.04	4
Sr	0.01	20	0.02	4
Ga	0.01	51	0.02	4
Backup Filter OC **	1.4	65	2.1	4

* OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote ** and Sections 6 & 7 for further discussion.

** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter - not included in sum of species calculations. Refer to Sections 6 & 7 for further discussion.

*** Non-detect runs set equal to zero for speciation calculations. Number of Detected Runs is number of runs with complete data set.

1- Mass fraction is emission factor (EMF) of species divided by EMF of sum of species - calculated from highest stable oxide form of elements for runs 1 - 4 and OC corrected for C, H in SVOC. NDs assumed to be zero for speciation calculations. The average sum of species EMF (1.0E-2 lb/MMBtu) is less than average (1.0E-2 lb/MMBtu) is less than average PM2.5 EMF (1.6E-2 lb/MMBtu); the difference is less the difference is less than the 95% CI of the measurements. Only substances with Emission Factors included in Table 5-1a are presented in this table.

2 - These speciation profiles should only be applied to PM2.5 mass results measured with a dilution sampler. They should not be applied to PM emissions factors measured by other methods (e.g. hot filter, wet impinger). When dilution sampler PM2.5 mass results are not available, use species emission factors given in Tables 5-1 and 5-2.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty).

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

The average emission factor for the sum of species ($1.0x10^{-2}$ lb/MMBtu) during oil operation is about 63 percent of the average emission factor for total PM2.5 mass ($1.6x10^{-2}$ lb/MMBtu, measured gravimetrically). The gap between sums of species and PM2.5 masses may be due to: the use of different filters to quantify mass and species; uneven deposition of compounds on the TMFs used for mass and elements versus the quartz filters used for ions and OC/EC, the OC bias caused by VOC adsorption on the filters, and/or loss of volatile species from the quartz filters.

Figure 5-1a shows the data presented in Table 5-7a. The majority of the mass (18 percent) is composed of $SO_4^=$, with NH_4^+ being the next most abundant constituent (4.7 percent). Figure 5-1b shows the data presented in Table 5-7b. The majority of the mass (60 percent) is composed of $SO_4^=$, with OC and EC being the next most abundant constituents (8 and 7 percent, respectively).

Particulate Carbon

Table 5-8a and Figure 5-2a show the particulate carbon speciation profile, expressed as a mass fraction normalized by the OC mass measured by TOR on the quartz fiber filters, for the natural gas operation. The particulate carbon species listed only include Table 5-2a compounds (i.e. uncertainties < 100% and average emission factor less than blank levels). This profile excludes natural gas run 4 because the data set for run 4 is incomplete. The most abundant fraction of the speciated organic aerosol is 1,3+1,6+1,7 dimethylnaphthalene. Table 5-8b and Figure 5-2b show the particulate carbon speciation profile, expressed as a mass fraction, for the oil operation. The particulate carbon species listed only include Table 5-2b compounds (i.e. uncertainties < 100% and average emission factor less than blank levels). A-trimethylnaphthalene is the most abundant speciated organic aerosol fraction. The mass fractions were determined by dividing the carbon fraction (excluding the H and O contribution to the SVOC mass emissions as discussed previously) of the average SVOC emission factor by the average emission factor of total OC, both in units of lb/MMBtu. The speciated OC listed in Table 5-2a, measured as SVOCs, accounts for approximately 16 percent of the total OC during natural gas operation and the speciated OC listed in Table 5-2b, measured as SVOCs, accounts for approximately 2 percent of the total OC during oil operation. Total speciated OC, including all measured SVOCs (i.e. including SVOCs with uncertainties > 100% and average emission

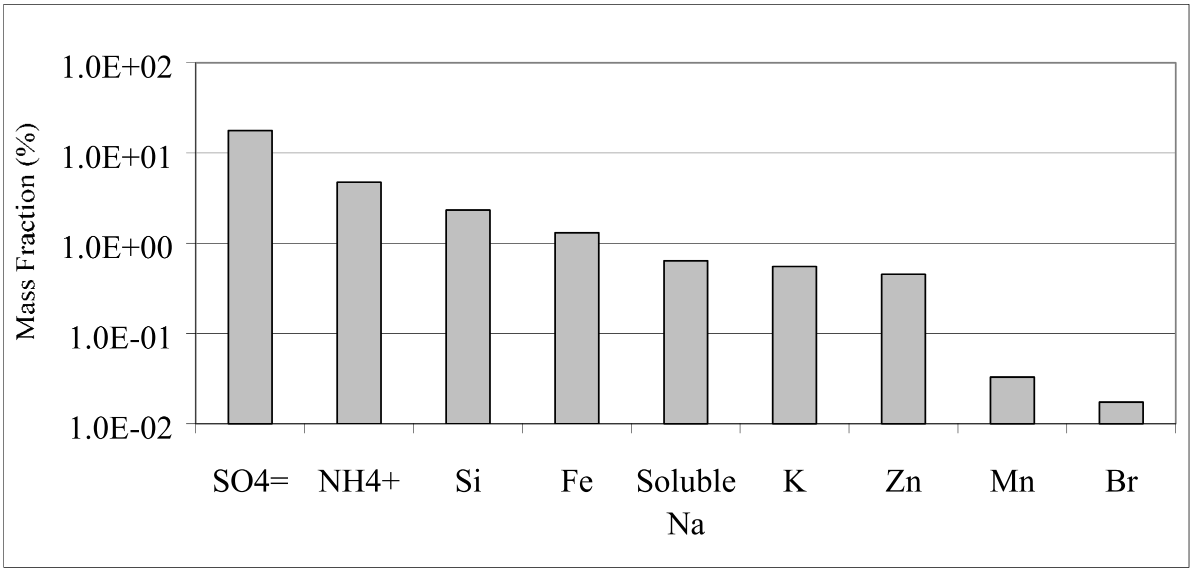

Figure 5-1a. Primary Emissions Speciation Profile for Natural Gas Operation (Delta).

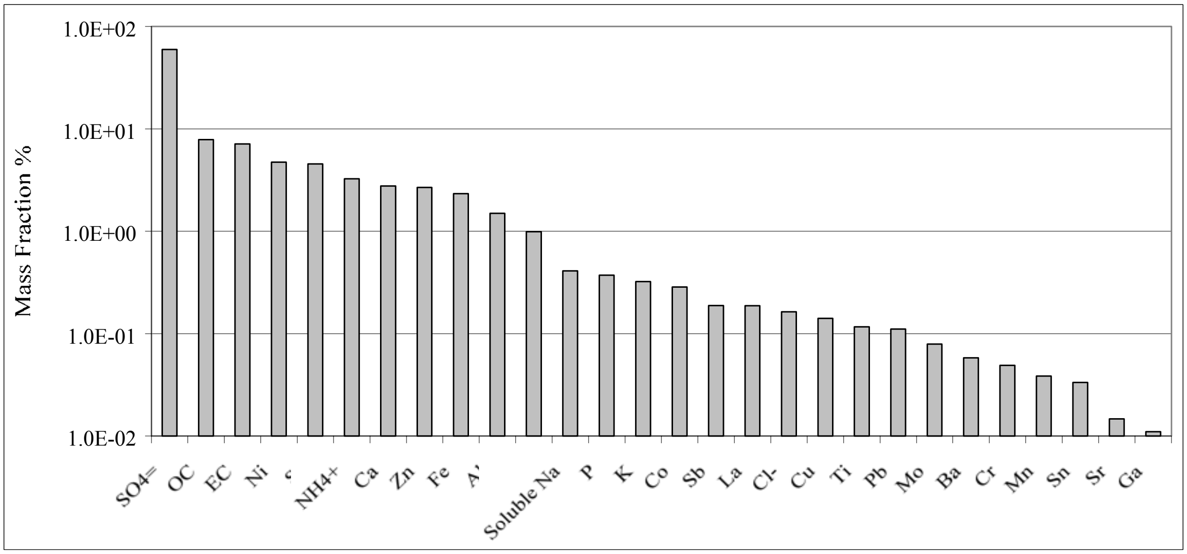

Figure 5-1b. Primary Emissions Speciation Profile for Oil Operation (Delta).

Table 5-8a. Particulate Carbon Speciation Profile (Delta – NG).

Substance	Average Mass Fraction (1) (%)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs
1,3+1,6+1,7-dimethylnaphthalene	7.6	70	11	3
2-methylnaphthalene	2.3	76	3.5	3
1-methylnaphthalene	1.3	73	2.0	3
2,6+2,7-dimethylnaphthalene	1.3	73	2.0	3
1+2-ethylnaphthalene	0.99	110	1.7	3
A-trimethylnaphthalene	0.64	92	1.0	3
1,4+1,5+2,3-dimethylnaphthalene	0.61	97	1.0	3
C-trimethylnaphthalene	0.59	110	1.1	3
B-trimethylnaphthalene	0.53	100	0.90	3
1,2-dimethylnaphthalene	0.34	69	0.50	3
2,3,5+I-trimethylnaphthalene	0.33	81	0.52	3
F-trimethylnaphthalene	0.28	99	0.47	3
Biphenyl	0.12	71	0.18	3

1- SVOC carbon mass expressed as a percent of total organic carbon mass.

* Speciated Particulate Carbon non-detect runs set equal to zero for speciation calculations. Number of Detected Runs is number of detected organic carbon runs.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty). Uncertainty greater than 100% indicates it is likely the reported emission factor value is not representative of actual emissions. Data users should exercise appropriate caution.

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

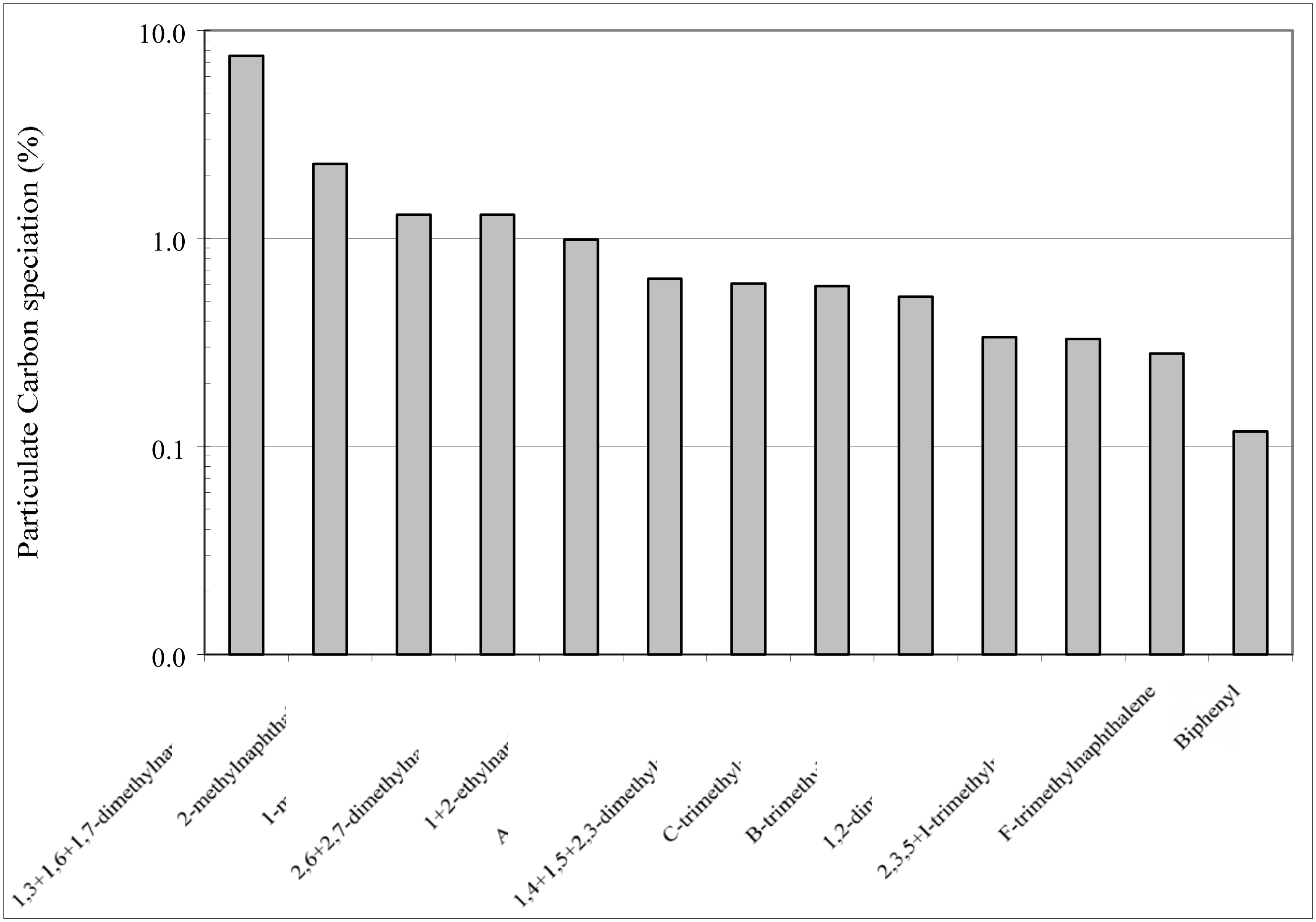

Figure 5-2a. Particulate Carbon Speciation Profile (Delta – NG).

Table 5-8b. Particulate Carbon Speciation Profile (Delta – Oil).

Substance	Average Mass Fraction (1) (%)	Uncertainty (%) (a)	95% Confidence Upper Bound (%) (b)	Number of Detected Runs*
A-trimethylnaphthalene	0.30	94	0.53	4
Phenanthrene	0.24	51	0.34	4
2,3,5+I-trimethylnaphthalene	0.15	97	0.28	4
B-MePy/MeFl	0.13	77	0.21	4
9-fluorenone	0.12	68	0.18	4
F-trimethylnaphthalene	0.12	81	0.20	4
Fluoranthene	0.09	61	0.14	4
Dibenzofuran	0.06	73	0.10	4
Anthrone	0.06	120	0.12	4
C-MePy/MeFl	0.05	70	0.07	4
Anthraquinone	0.05	61	0.07	4
2,4,5-trimethylnaphthalene	0.04	91	0.07	4
Fluorene	0.04	190	0.09	4
Benzo(a)pyrene	0.01	160	0.03	4

1- SVOC carbon mass expressed as a percent of total organic carbon mass.

* Speciated Particulate Carbon non-detect runs set equal to zero for speciation calculations. Number of Detected Runs is number of detected organic carbon runs.

Group 1 - Emission factors based on 3 or more runs with detectable levels of substance.

Group 2 - Emission factors based on less than 3 runs with detectable levels of substance; may not be suitable for quantitative analysis.

a - Uncertainty is calculated at the 95% confidence level using the two-tailed Student t distribution. The 95 percent confidence interval of the emission factor is two times the uncertainty (i.e., mean +/- uncertainty). Uncertainty greater than 100% indicates it is likely the reported emission factor value is not representative of actual emissions. Data users should exercise appropriate caution.

b - 95% upper confidence bound is calculated at the 95% confidence level using the single-tailed Student t distribution. The 95% upper confidence bound provides a plausible upper bound (i.e. it is likely emissions are lower) for emissions.

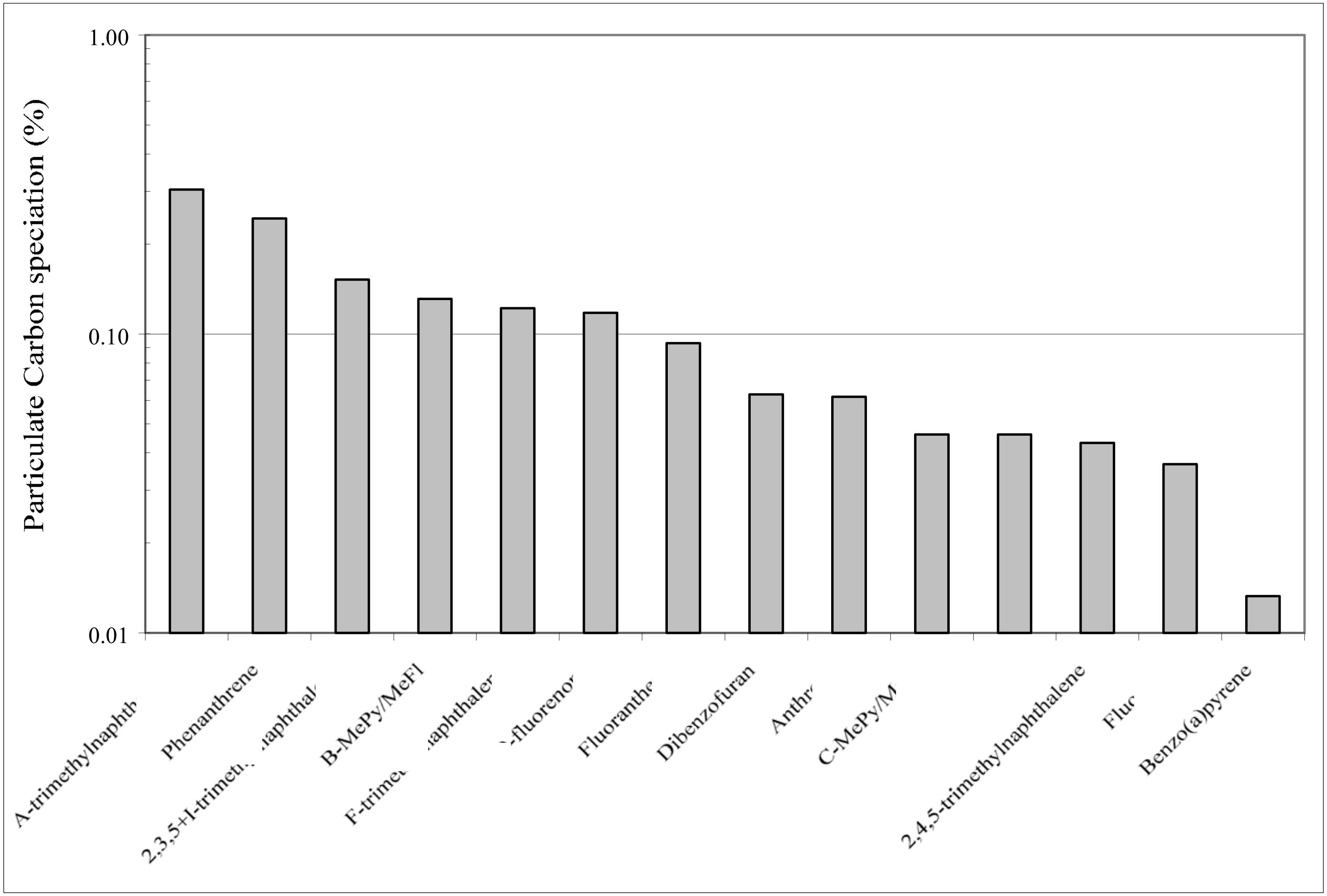

Figure 5-2b. Particulate Carbon Speciation Profile (Delta – Oil).

factor greater than blank levels), accounts for about 28% of the OC during natural gas firing and 13% of the OC during oil operation. These low percentages are not unusual and consistent with other research studies; approximately 84 percent of the organic compound mass in fine particles was unaccounted for (either it was unextractable or would not elute from the GC column) in a study in Bakersfield, CA (Schauer and Cass, 2000). Two possible explanations are that there is a significant positive bias in the OC results (e.g., due to the VOC adsorption artifact as discussed elsewhere in this report) or that all of the organic compounds were not extractable or elutable by the analytical methods employed. Given the prominence of backup OC in the natural gas results, the former argument seems more likely for natural gas operation data.

Section 6

QUALITY ASSURANCE

SAMPLE STORAGE AND SHIPPING

All samples required to be kept cool were stored on-site in a refrigerator prior to shipment to the lab for analysis. All of the samples except the in-stack and impinger filters were shipped via overnight shipment to the lab in an ice chest with blue ice. Upon receipt of samples at the lab, those requiring refrigeration were stored at 4° C (nominal). Samples were stored and shipped in a manner to prevent breakage.

CONTROLLED CONDENSATION TRAIN ANALYSIS

Analytical quality assurance/quality control (QA/QC) procedures included method blanks, method spike samples analysis and replicate samples analysis. All blank levels were below method detection limits. Method spike samples recoveries ranged from 98 to 110 percent. Replicate samples analyses had relative percent differences [RPD = 100 * (Sample - Replicate Sample)/(Sample + Replicate Sample)/2] of 6 percent and 0 percent.

DILUTION SAMPLER SAMPLES

DSB and field blank (FB) air quality assurance (QA) samples were collected and analyzed. Two DSB samples were collected: one after the oil fired boiler tests and one after the natural gas fired boiler tests. The dilution sampler was cleaned between the oil fired and natural gas fired test series. The DSBs were collected after the emissions sampling, before the dilution sampler was cleaned. The DSBs were conducted by drawing filtered air through the dilution sampler and collecting samples per the normal procedures. DSB results are an indication of the background levels in the dilution sampler, likely from deposition of species on dilution sampler surfaces during sampling or HEPA and/or carbon filter breakthrough. FBs were collected by setting up and breaking down the dilution sampler sampling equipment without drawing gas through the sampling media. FB results are an indication of the species collected on the sampling media during the handling and transport of the materials. The following tables present the results of the DSB and FB samples. The DSB and FB are presented as in-stack equivalents using the average dilution factor of the sampling runs. Each blank is compared to the 95 percent confidence lower bound of the average of the test series. The procedures used for calculating the confidence intervals were described in Section 5. If the blank level is greater than the 95 percent lower bound the data is flagged. Flags suggest the field data may not be significantly different than the blank data. Further discussion on these results is presented in Section 7.

Gravimetric Analysis

Prior to testing, unused filters were stored for at least one month in a controlled environment, followed by one week of equilibration in the weighing environment to achieve stable filter tare weights. New and used filters were equilibrated at 20±5°C and a relative humidity of 30±5 percent for a minimum of 24 hours prior to weighting. Weighing was performed on a Cahn 31 electro-microbalance with ±1 microgram sensitivity. The electrical charge on each filter was neutralized by exposure to a polonium source for 30 seconds prior to the filter being placed on the balance pan. The balance was calibrated with a 20 mg Class M weight and the tare was set prior to weighing each batch of filters. After every 10 filters were weighed, the calibration and tare were rechecked. If the results of these performance tests deviated by more than ±5 µg, the balance was recalibrated. If the difference exceeded ±15 µg, the balance was recalibrated and the previous 10 samples were reweighed. One hundred percent of initial weights and at least 30 percent of exposed weights were checked by an independent technician and samples were reweighed if these check-weights did not agree with the original weights within ±0.015 mg. Pre- and post-weights, check weights and reweights (if required) were recorded on data sheets, as well as being directly entered into a database via an RS232 connection.

Table 6-1a lists the PM2.5 blanks concentrations for the natural gas fired boiler. The natural gas operation PM2.5 DSB level was slightly higher than the average stack sample level. The high DSB levels may have been a result of the prescribed testing schedule of oil-firing before natural gas operation. The dilution sampler was cleaned between the two sets of tests; however, the conditions for cleaning were not ideal and there is some suspicion that residue remained in the dilution sampler prior to the natural gas tests. This issue is further discussed in Section 7. Table 6-1b lists the PM2.5 blanks concentrations for the oil-fired boiler tests. The average stack sample level was more than ten times greater than the blanks. PM2.5 was not detected in the FBs.

Table 6-1a. PM2.5 Mass Blanks Results (Delta – NG).

	mg/dscm	
	NG-DSB	NG-FB
PM2.5 mass	3.4E-1 a	ND

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-1b. PM2.5 Mass Blanks Results (Delta – Oil).

	mg/dscm	
	Oil-DSB	Oil-FB
PM2.5 mass	2.0E-2	ND

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Ions and Secondary PM Gaseous Precursors Analysis

The primary standard solutions were prepared with reagent grade salts, that were dried in an oven at 105 °C for one hour and then brought to room temperature in a desiccator. These anhydrous salts were weighed to the nearest 0.10 mg on a routinely calibrated analytical balance under controlled temperature (approximately 20 °C) and relative humidity (±30 percent) conditions. These salts were diluted in precise volumes of DI water. Calibration standards were prepared at least once within each month by diluting the primary standard solution to concentrations covering the range of concentrations expected in the filter extracts and stored in a refrigerator. The calibration concentrations prepared were at 0.1, 0.2, 0.5, 1.0, and 2.0 µg/ml for each of the analysis species. Calibration curves were performed weekly. Chemical compounds were identified by matching the retention time of each peak in the unknown sample with the retention times of peaks in the chromatograms of the standards. A DI water blank was analyzed after every 20 samples and a calibration standard was analyzed after every 10 samples. These quality control checks verified the baseline and calibration, respectively. Environmental Research Associates (ERA, Arvada, CO) standards were used daily as an independent QA check. These standards (ERA Wastewater Nutrient and ERA Mineral WW) were traceable to National Institute of Standards and Technology (NIST) simulated rainwater standards. If the values obtained for these standards did not coincide within a pre-specified uncertainty level (typically three standard deviations of the baseline level or ±5 percent), the samples between that standard and the previous calibration standards were reanalyzed.

After analysis, the printout for each sample in the batch was reviewed for the following: 1) proper operational settings; 2) correct peak shapes and integration windows; 3) peak overlaps; 4) correct background subtraction; and 5) quality control sample comparisons. When values for replicates differed by more than ±10 percent or values for standards differed by more than ±5 percent, samples before and after these quality control checks are designated for reanalysis in a subsequent batch. Individual samples with unusual peak shapes, background subtractions, or deviations from standard operating parameters are also designated for reanalysis.

Table 6-2a lists the blanks samples concentrations for ions and the inorganic secondary PM precursors for the natural gas fired boiler. Similar to the PM2.5, DSB levels were equal to or slightly lower than the average stack sample levels. No substances were measured in the FB at concentrations greater than the 95 percent lower bound for the stack sample average. Table 6-2b lists the blanks samples concentrations for ions and the secondary PM gaseous precursors for the oil fired tests. Only NH_3 was present in the blanks at levels greater than the 95 percent lower bound for the stack sample average.

Table 6-2a. Ions and Secondary PM Precursor Blanks Results (Delta – NG).

	mg/dscm		
	NG-DSB		NG-FB
Cl-	9.0E-5	a	ND
NO3-	9.0E-5	a	ND
SO4=	2.0E-3	a	ND
NH4+	4.2E-4	a	ND
NH3	8.2E-3	a	2.6E-3
SO2	1.2E-2	a	ND
Soluble Na	1.6E-5		5.5E-4

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-2b. Ions and Secondary PM Precursor Blanks Results (Delta – Oil).

	mg/dscm			
	Oil-DSB		Oil-FB	
Cl-	8.4E-3		ND	
NO3-	ND	e	ND	e
SO4=	3.8E-1		ND	
NH4+	8.9E-2		ND	
NH3	5.3E-2	a	7.2E-3	b
SO2	7.1E+0		ND	
Soluble Na	3.8E-3		1.5E-3	

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Elemental (XRF) Analysis

Three types of XRF standards were used for calibration, performance testing and auditing: 1) vacuum-deposited thin-film elements and compounds (supplied by Micromatter, Deer Harbor, WA); 2) polymer films; and 3) NIST thin-glass films. The vacuum deposit standards cover the largest number of elements and were used as calibration standards. The polymer film and NIST standards were used as quality control standards.

NIST standards are the definitive standard reference material, but are only available for the species Al, Ca, Co, Cu, Mn, and Si (SRM 1832) and Fe, Pb, K, Si, Ti, and Zn (SRM 1833). A separate Micromatter thin-film standard was used to calibrate the system for each element. A quality control standard and a replicate from a previous batch were analyzed with each set of 14 samples. When a quality control value differed from specifications by more than ±5 percent or when a replicate concentration differed from the original value (when values exceed 10 times the detection limits) by more than ±10 percent, the samples were reanalyzed. If further tests of standards showed that the system calibration had changed by more than ±2 percent, the instrument was recalibrated as described above. All XRF results were entered directly into the DRI databases.

Table 6-3a lists the blanks concentrations for elements for the natural gas-fired boiler. About half the detected elements were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Al, Mg, and Na were measured in the FB at concentrations greater than the 95 percent lower bound. Table 6-3b lists the blanks concentrations for elements for the oil-fired boiler. No elements were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Only Mg was measured in the FB at concentrations greater than the 95 percent lower bound.

Organic and Elemental Carbon Analysis

The TOR system was calibrated by analyzing samples of known amounts of methane, carbon dioxide, and potassium hydrogen phthalate (KHP). The FID response was compared to a reference level of methane injected at the end of each sample analysis. Performance tests of the instrument calibration were conducted at the beginning and end of each day's operation. Intervening samples were reanalyzed when calibration changes of more than ±10 percent were found.

Table 6-3a. Elements Blank Results (Delta – NG).

Element	mg/dscm			
	NG-DSB		NG-FB	
Al	3.1E-04	a	2.3E-04	b
As	ND	e	ND	e
Br	2.7E-05	a	ND	
Ca	3.9E-03	a	ND	
Cl	ND	e	ND	e
Co	2.7E-05	a	ND	
Cr	ND		ND	
Cu	1.1E-04	a	ND	
Fe	1.3E-03		ND	
K	5.1E-04		ND	
Mg	3.2E-04	a	3.9E-04	b
Mn	3.1E-05		ND	
Na	2.7E-03	a	2.1E-03	b
Ni	3.8E-04	a	ND	
Pb	ND	e	ND	e
S	2.9E-02	a	ND	
Si	3.0E-03		2.0E-04	
Sr	ND	e	ND	e
Ti	7.1E-05	a	ND	
V	9.0E-05	a	ND	
Zn	8.3E-04		ND	
Zr	ND	e	ND	e

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-3b. Elements Blank Results (Delta – Oil).

	mg/dscm			
	Oil-DSB		Oil-FB	
Al	4.5E-03		6.3E-04	
As	ND		ND	
Ba	ND		ND	
Br	ND	e	ND	e
Ca	8.4E-03		ND	
Cl	ND	e	ND	e
Co	6.2E-04		ND	
Cr	1.7E-04		ND	
Cu	3.5E-04		ND	
Fe	7.9E-03		ND	
Ga	ND		ND	
K	1.2E-03		ND	
La	ND		ND	
Mg	ND		1.1E-03	b
Mn	1.2E-04		ND	
Mo	ND		ND	
Na	ND	e	5.8E-03	e
Ni	9.7E-03		ND	
P	ND		ND	
Pb	2.3E-04		ND	
S	1.4E-01		ND	
Sb	ND		ND	
Se	ND	e	ND	e
Si	1.4E-02		5.4E-04	
Sn	ND		ND	
Sr	ND		ND	
Ti	5.8E-04		ND	
Tl	ND		ND	
V	2.0E-03		ND	
Y	ND		ND	
Zn	4.1E-03		ND	
Zr	ND		ND	

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Known amounts of American Chemical Society (ACS) certified reagent-grade crystal sucrose and KHP were committed to TOR as a verification of the organic carbon fractions. Fifteen different standards were used for each calibration. Widely accepted primary standards for elemental and/or organic carbon are still lacking. Results of the TOR analysis of each filter were entered into the DRI database.

Table 6-4a lists the blanks concentrations for organic and elemental carbon for the natural gas fired boiler. Both were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. OC was present in the DSB at a concentration greater than the stack sample average; thus, the OC measurements are likely biased high from residue in the dilution sampler from the oil-fired testing. This issue is further discussed in Section 7. FB concentrations were less than the 95 percent lower bound. Table 6-4b lists the blanks concentrations for organic and elemental carbon for the oil-fired boiler. Neither was present in the DSB or FB samples at concentrations greater than the 95 percent lower bound for the stack sample average.

The quartz fiber filters used for OC/EC analysis have the potential for positive OC bias due to adsorption of VOCs on the filter. A backup quartz fiber filter sampled behind the TMF to indicate the potential magnitude of the bias caused by this artifact showed high concentrations of OC that are significant in all the samples. The backup OC is approximately 100 percent of the average OC measured in the field samples during natural gas operation. The ratios of backup OC sample OC are 1.0 and 1.8 for the natural gas-fired DSB and FB, respectively. The backup OC is approximately 17 percent of the average OC measured in the field samples during No. 6 oil operation. The ratios of backup OC sample OC are 0.62 and 1.8 for the oil-fired DSB and FB, respectively. Please refer to Section 7 for further discussion of the OC artifact.

SVOC Analysis

Prior to sampling, the XAD-4 resin was Soxhlet extracted with methanol, followed by dichloromethane, each for 24 hours. The cleaned resin was dried in a vacuum oven heated to 40°C and stored in sealed glass containers in a clean freezer. The PUF plugs were Soxhlet extracted with acetone, followed by 10 percent diethyl ether in hexane. The TIGF filters were

Table 6-4a. Organic and Elemental Carbon Blanks Results (Delta – NG).

	mg/dscm			
	NG-DSB		NG-FB	
OC*	2.5E-01	a	5.2E-02	
EC	2.1E-02	a	ND	
Backup Filter OC**	2.5E-01	a	9.1E-02	

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).
* OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote ** and Sections 6 & 7 for further discussion.
** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion.

Table 6-4b. Organic and Elemental Carbon Blanks Results (Delta – Oil).

	mg/dscm			
	Oil-DSB		Oil-FB	
OC*	4.4E-01		1.4E-01	
EC	1.2E-01		ND	
Backup Filter OC**	2.8E-01	a	2.5E-01	b

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).
* OC measurements are subject to a potential positive bias from adsorption of VOC species. Refer to footnote ** and Sections 6 & 7 for further discussion.
** OC measured on a "backup" quartz fiber filter placed downstream of Teflon membrane filter. Refer to Sections 6 & 7 for further discussion.

cleaned by sonification in dichloromethane for 30 minutes followed by another 30-minute sonification in methanol. Then they were dried, placed in aluminum foil, and labeled. Each batch of precleaned XAD-4 resin and approximately 10 percent of the precleaned TIGF filters and PUF plugs were checked for purity by solvent extraction and GC/MS analysis of the extracts. The PUF plugs and XAD-4 resins were assembled into glass cartridges (10 g of XAD between two PUF plugs), wrapped in hexane-rinsed aluminum foil and stored in a clean freezer prior to shipment to the field.

Prior to extraction, the following deuterated internal standards were added to each filter-sorbent pair:

naphthalene-d8	9.76	ng/µl	
acenaphthene-d8	10.95	ng/µl	(for acenapththene and acenaphthylene)
biphenyl-d10	7.56	ng/µl	
phenanthrene-d10	4.61	ng/µl	
anthracene-d10	3.5	ng/µl	
pyrene-d10	5.28	ng/µl	(for fluoranthene and pyrene)
chrysene-d12	3.54	ng/µl	(for benz[a]anthracene and chrysene)
benzo[e]pyrene-d12	4.20	ng/µl	
benzo[a]pyrene-d12	4.68	ng/µl	
benzo[k]fluoranthene-d12	2.0	ng/µl	
benzo[g,h]perylene-d12	1.0	ng/µl	(for indeno[1,2,3-cd]pyrene, dibenzo[ah+ac]anthracne, benzo[ghi]perylene and coronene)

Calibration curves for the GC/MS/MID quantification were made for the molecular ion peaks of the PAH and all other compounds of interest using the corresponding deuterated species (or the deuterated species most closely matched in volatility and retention characteristics) as internal standards. NIST Standard Reference Material (SRM) 1647 (certified PAH), with the addition of deuterated internal standards and compounds not present in the SRM, was used to make calibration solutions. Three concentration levels for each analyte were employed, and each calibration solution was injected twice. After the three-level calibration was completed, a standard solution was injected to perform calibration checks. If deviation from the true value exceeded 20 percent, the system was recalibrated. The MSD was tuned daily for mass sensitivity using perfluorotributylamine. In addition, one level calibration solution was run daily. If the difference between true and measured concentrations exceeded 20 percent, the system was recalibrated.

Table 6-5a lists the blanks concentrations for SVOCs for the natural gas fired boiler. About 64 percent of the detected SVOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. About 17 percent of the detected SVOCs were measured in the FB at concentrations greater than the 95 percent lower bound. Table 6-5b lists the blanks concentrations for SVOCs for the oil-fired boiler. About 44 percent the detected SVOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. About 11 percent of the detected SVOCs were measured in the FB at concentrations greater than the 95 percent lower bound.

VOC Analysis

Calibration curves were performed weekly. VOCs were identified by matching the response factors of each unknown sample with the response factors of the standards. Tenax cartridges spiked with a mixture of paraffinic (in the C9-C20 range) and aromatic (C4, C5, and C6 benzenes) hydrocarbons were periodically analyzed by GC/FID to verify quantitative recovery from the cartridges. Three to five different concentrations of the HC standard and one zero standard were injected, and the response factors obtained. If the percent difference of the response factor from the mean was more than 5 percent, the response factors were corrected before proceeding with the analysis.

Table 6-6a lists the blanks concentrations for VOCs for the natural gas fired boiler measured using Tenax. About 55 percent the detected VOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Two (3 percent) of the detected VOCs were measured in the FB at concentrations greater than the 95 percent lower bound. Table 6-6b lists the blanks concentrations for VOCs for the oil-fired boiler measured using Tenax. About 67 percent the detected VOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. About 10 percent of the detected VOCs were measured in the FB at concentrations greater than the 95

Table 6-5a. PUF-XAD SVOCs Blanks Results (Delta-NG).

	mg/dscm			
Substance	NG-DSB		NG-FB	
1,3+1,6+1,7-dimethylnaphthalene	3.3E-3		2.3E-3	
Naphthalene	ND		4.8E-3	b
2-methylnaphthalene	1.3E-3		1.3E-3	
1-methylnaphthalene	6.0E-4		7.1E-4	
2,6+2,7-dimethylnaphthalene	6.6E-4		4.5E-4	
2-Methylbiphenyl	ND		5.7E-3	b
1+2-ethylnaphthalene	4.8E-4		1.9E-3	b
3-Methylbiphenyl	ND		2.9E-3	b
A-trimethylnaphthalene	8.9E-4	a	1.9E-5	
9-fluorenone	6.1E-3	a	ND	
1,4+1,5+2,3-dimethylnaphthalene	3.6E-4		3.1E-4	
C-trimethylnaphthalene	1.0E-3	a	ND	
B-trimethylnaphthalene	7.7E-4	a	1.0E-5	
Phenanthrene	1.3E-3	a	1.6E-5	
1,2-dimethylnaphthalene	1.6E-4		ND	
2,3,5+I-trimethylnaphthalene	2.5E-4		1.3E-5	
E-trimethylnaphthalene	4.0E-4	a	7.6E-6	
Acenaphthene	9.8E-4	a	ND	
F-trimethylnaphthalene	4.9E-4	a	1.4E-5	
Fluorene	4.0E-4	a	ND	
4-Methylbiphenyl	ND		1.3E-3	b
Pyrene	2.3E-4	a	7.6E-6	
A-methylfluorene	6.0E-4	a	ND	
Chrysene	5.9E-5	a	5.9E-6	b
C-methylphenanthrene	3.6E-4	a	ND	
Anthrone	2.6E-4	a	ND	
Biphenyl	2.1E-4	a	ND	
2-methylphenanthrene	2.8E-4	a	1.3E-5	
Dibenzofuran	3.1E-4	a	ND	
J-trimethylnaphthalene	2.6E-4	a	ND	
4-methylpyrene	1.1E-4	a	4.2E-6	
Acenaphthylene	ND		ND	
9-Anthraldehyde	ND	e	ND	e
1-methylfluorene	3.9E-4	a	ND	
A-methylphenanthrene	2.9E-4	a	ND	
9-methylanthracene	2.5E-4	a	ND	
C-dimethylphenanthrene	1.3E-4	a	ND	
2,4,5-trimethylnaphthalene	1.5E-4	a	ND	
Benzanthrone	1.5E-4	a	ND	
Fluoranthene	1.9E-4	a	9.3E-6	
B-MePy/MeFl	5.3E-5	a	2.5E-6	
Benz(a)anthracene	3.5E-4	a	ND	
D-MePy/MeFl	7.4E-5	a	5.9E-6	
Anthraquinone	ND		ND	
D-dimethylphenanthrene	ND		ND	
1-methylpyrene	8.0E-5	a	ND	
3,6-dimethylphenanthrene	ND	e	ND	e
A-dimethylphenanthrene	ND	e	ND	e
5+6-methylchrysene	5.4E-5	a	1.7E-6	b
Anthracene	8.8E-5	a	1.7E-6	
1-methylphenanthrene	ND		ND	
E-dimethylphenanthrene	ND		ND	
Xanthone	8.5E-5	a	7.1E-5	b

Table 6-5a. PUF-XAD SVOCs Blanks Results (Delta-NG). (Continued)

Substance	mg/dscm			
	NG-DSB		NG-FB	
C-MePy/MeFl	5.9E-6	a	4.2E-6	b
Benzo(a)pyrene	6.8E-5	a	1.5E-5	b
7-methylbenzo(a)pyrene	ND	e	ND	e
Benzo(b+j+k)fluoranthene	7.7E-5	a	ND	
7-methylbenz(a)anthracene	3.4E-5	a	ND	
Benzonaphthothiophene	2.2E-5	a	ND	
Acenaphthenequinone	2.7E-5	e	ND	e
Benzo(e)pyrene	2.1E-5	e	ND	e
B-methylphenanthrene	2.3E-5	e	ND	e

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-5b. PUF/XAD SVOCs Blanks Results (Delta-Oil).

	mg/dscm			
Substance	Oil-DSB		Oil-FB	
1,3+1,6+1,7-dimethylnaphthalene	3.1E-2	a	4.7E-3	
Naphthalene	ND		9.9E-3	b
2-Methylbiphenyl	6.6E-3	e	1.2E-2	e
2-methylnaphthalene	8.8E-3	a	2.8E-3	
1-methylnaphthalene	5.5E-3	a	1.5E-3	
2,6+2,7-dimethylnaphthalene	5.3E-3	a	9.3E-4	
3-Methylbiphenyl	6.6E-3	a	6.1E-3	b
4-Methylbiphenyl	1.7E-3	e	2.6E-3	e
1+2-ethylnaphthalene	4.8E-3	a	3.9E-3	b
Pyrene	2.3E-4	a	1.6E-5	
A-trimethylnaphthalene	1.7E-3	a	4.0E-5	
1,4+1,5+2,3-dimethylnaphthalene	3.1E-3	a	6.4E-4	
Phenanthrene	2.9E-4		3.3E-5	
C-trimethylnaphthalene	1.5E-3	a	ND	
B-trimethylnaphthalene	1.3E-3	a	2.1E-5	
4-methylpyrene	2.3E-4		8.7E-6	
C-methylphenanthrene	1.1E-4	a	ND	
C-dimethylphenanthrene	ND		ND	
1,2-dimethylnaphthalene	1.3E-3	a	ND	
2,3,5+I-trimethylnaphthalene	9.3E-4	a	2.6E-5	
2-methylphenanthrene	7.8E-5		2.6E-5	
Acenaphthene	ND		ND	
B-MePy/MeFl	1.1E-4		5.2E-6	
E-trimethylnaphthalene	8.6E-4	a	1.6E-5	
9-fluorenone	5.5E-4		ND	
F-trimethylnaphthalene	6.8E-4	a	3.0E-5	
D-MePy/MeFl	1.1E-4		1.2E-5	
A-methylphenanthrene	ND		ND	
1-methylphenanthrene	ND		ND	
Acenaphthylene	ND	e	ND	e
Fluoranthene	7.3E-5		1.9E-5	
A-methylfluorene	ND	e	ND	e
D-dimethylphenanthrene	ND		ND	
Fluorene	ND		ND	
Benz(a)anthracene	1.9E-4	a	ND	
1-methylpyrene	9.2E-5	a	ND	
Biphenyl	3.0E-4	a	ND	
Dibenzofuran	3.1E-4	a	ND	
3,6-dimethylphenanthrene	ND		ND	
Anthrone	5.7E-5		ND	
1-methylfluorene	ND		ND	
A-dimethylphenanthrene	ND		ND	

Table 6-5b. PUF/XAD SVOCs Blanks Results (Delta-Oil) (Continued).

	mg/dscm			
Substance	Oil-DSB		Oil-FB	
Anthraquinone	ND		ND	
C-MePy/MeFl	3.1E-5		8.7E-6	
Chrysene	2.0E-4	a	1.2E-5	
J-trimethylnaphthalene	1.4E-4	a	ND	
2,4,5-trimethylnaphthalene	2.5E-4	a	ND	
1,7-dimethylphenanthrene	ND		ND	
B-dimethylphenanthrene	ND		ND	
B-methylphenanthrene	ND	e	ND	e
E-dimethylphenanthrene	ND		ND	
Anthracene	6.9E-6	a	3.5E-6	b
Benzonaphthothiophene	ND		ND	
9-Anthraldehyde	ND	e	ND	e
Benzanthrone	1.5E-4	a	ND	
Benzo(a)pyrene	8.9E-5	a	3.1E-5	b
Xanthone	ND		1.5E-4	b
7-methylbenzo(a)pyrene	ND		ND	
Benzo(c)phenanthrene	ND	e	ND	e
Acenaphthenequinone	ND		ND	
Benzo(b+j+k)fluoranthene	ND	e	ND	e
5+6-methylchrysene	7.3E-5	a	3.5E-6	b
9-methylanthracene	ND	e	ND	e
Benzo(e)pyrene	ND	e	ND	e

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
d - 95% Confidence Lower Bound of the Average concentration is less than the Ambient concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-6a. Tenax VOCs Blanks Results (Delta-NG).

Substance	NG-DSB		NG-FB	
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)				
m & p-xylene	4.4E-2	a	ND	
(+/-)-limonene	2.3E-2	a	ND	
Undecane	8.6E-3	a	3.8E-3	b
Decane	1.6E-2	a	1.3E-3	
Nonane	2.6E-2	a	ND	
Octadecane	1.4E-2		ND	
Hexadecane	1.8E-2		ND	
Decanal	ND	e	1.8E-2	e
Heptadecane	1.7E-2		ND	
m-ethyltoluene	1.5E-2	a	ND	
Pentadecane	1.5E-2	a	ND	
Eicosane	7.5E-3	a	ND	
1,2,4-trimethylbenzene	2.1E-2	a	ND	
Tetradecane	1.3E-2	a	ND	
Ethylbenzene	1.4E-2	a	ND	
o-xylene	1.4E-2	a	ND	
Dodecane	4.5E-3		4.0E-3	
Acetophenone	3.8E-3		1.6E-3	
Nonanal	4.1E-3		2.0E-2	b
p-ethyltoluene	7.2E-3	a	ND	
3-methyloctane	1.2E-2	a	ND	
Nonadecane	3.9E-3	a	ND	
1,3,5-trimethylbenzene	5.6E-3	a	ND	
Tridecane	6.0E-3	a	ND	
1,6+1,3+1,7-dimethylnaphthalene	4.6E-3	a	ND	
p-isopropyltoluene	3.8E-3		ND	
Styrene	7.6E-3	a	ND	
Naphthalene	4.5E-3	a	ND	
Dimethyloctane	6.8E-3	a	ND	
1-methylindan	2.5E-3	a	ND	
o-ethyltoluene	4.0E-3	a	ND	
2-methylnaphthalene	3.6E-3	a	ND	
2-methyloctane	5.2E-3	a	ND	
Propylbenzene	3.3E-3	a	ND	
1-decene	4.0E-3	a	ND	
1-undecene	ND	e	ND	e
Octanal	3.5E-3	a	ND	
B-dimethylindane	2.9E-3	a	ND	
Propylcyclohexane	2.5E-3	a	ND	
1-methylnaphthalene	1.4E-3	a	ND	
2,6+2,7-dimethylnaphthalene	1.1E-3		ND	
4-ethyl-o-xylene	1.4E-3	a	ND	
2-methylindan	ND		ND	
Indan	ND		ND	
Phenanthrene	ND		ND	
5-ethyl-m-xylene	1.3E-3	a	ND	
Isopropylbenzene	1.2E-3	e	ND	e
Dodecene	ND		ND	

Table 6-6a. Tenax VOCs Blanks Results (Delta-NG) (Continued).

Substance	NG-DSB		NG-FB	
A-dimethylindane	ND	e	ND	e
4-n-propyltoluene + 1,4-diethylbenzene	ND		ND	
1,2,3,5-tetramethylbenzene	ND		ND	
D-dimethylindan	ND		ND	
m-isopropyltoluene	ND	e	ND	e
2-ethyl-p-xylene	ND		ND	
1,3-diethylbenzene	ND		ND	
1,2,4,5-tetramethylbenzene	ND	e	ND	e
2,3+1,5+1,4-dimethylnaphthalene	ND	e	ND	e
1-nonene	ND	e	ND	e
1,2,3,4-tetramethylbenzene	ND	e	ND	e
2,3-benzofuran	1.3E-2	a	ND	
2-n-propyltoluene	ND	e	ND	e
alpha-Pinene	ND	e	ND	e
Butylbenzene	ND	e	ND	e
4-methylstyrene	ND	e	ND	e
1,2,3-trimethylbenzene	ND	e	ND	e
1+2-ethylnaphthalene	ND	e	ND	e
Pentylbenzene	ND	e	ND	e
Isobutylbenzene	ND	e	ND	e
1,2-diethylbenzene	ND	e	ND	e
Other VOCs (Carbon Number 7 or less)				
1,3-dichlorobenzene	5.9E-2	a	6.3E-3	
Cyclohexanone	4.3E-2	a	ND	
Benzaldehyde	2.5E-2	a	1.4E-3	
Phenol	1.9E-3		2.0E-3	
Heptanal	ND	e	ND	e
Butyl acetate	ND		ND	
1,2-dichlorobenzene	5.4E-3	a	ND	
t-2-heptenal	2.2E-3	e	ND	e
m & p-methylphenol	ND	e	ND	e
2-heptanone	ND	e	ND	e

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

f - QA/QC sample not collected

Table 6-6b. Tenax VOCs Blanks Results (Delta-Oil).

Substance	Oil-DSB		Oil-FB	
~~Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)~~				
Decane	9.7E-2	a	2.1E-3	b
Nonane	7.9E-2	a	ND	
Undecane	3.8E-2	a	6.2E-3	b
Pentadecane	2.7E-2		ND	
Hexadecane	4.6E-2	a	ND	
m & p-xylene	1.3E-1	a	ND	
(+/-)-limonene	4.9E-2	a	ND	
Heptadecane	4.2E-2	a	ND	
Tetradecane	2.0E-2		ND	
Dodecane	2.1E-2	a	6.5E-3	b
Decanal	ND		3.0E-2	b
Octadecane	2.9E-2	a	ND	
Dimethyloctane	1.6E-2	a	ND	
1,6+1,3+1,7-dimethylnaphthalene	2.0E-2	a	ND	
1,2,4-trimethylbenzene	1.7E-2	a	ND	
2-methylnaphthalene	1.6E-2	a	ND	
p-isopropyltoluene	1.5E-2	a	ND	
m-ethyltoluene	2.0E-2	a	ND	
Naphthalene	1.8E-2	a	ND	
o-xylene	3.1E-2	a	ND	
Ethylbenzene	3.9E-2	a	ND	
Propylcyclohexane	1.2E-2	a	ND	
Tridecane	8.0E-3		ND	
Octanal	3.5E-3		ND	
Eicosane	1.5E-2	a	ND	
3-methyloctane	8.7E-3	a	ND	
1-methylnaphthalene	7.3E-3	a	ND	
1-decene	ND		ND	
1-methylindan	6.7E-3	a	ND	
Nonanal	1.3E-2	a	3.3E-2	b
p-ethyltoluene	1.2E-2	a	ND	
1,3,5-trimethylbenzene	6.1E-3	a	ND	
Styrene	1.6E-2	a	ND	
2,6+2,7-dimethylnaphthalene	5.8E-3	a	ND	
1,2,4,5-tetramethylbenzene	ND	e	ND	e
Nonadecane	1.0E-2	a	ND	
2-ethyl-p-xylene	ND	e	ND	e
Acetophenone	3.3E-2	a	2.7E-3	b
2-methyloctane	3.6E-3	a	ND	
o-ethyltoluene	5.2E-3	a	ND	
B-dimethylindane	4.6E-3	a	ND	
Biphenyl	2.4E-3	a	ND	
2,3-benzofuran	1.9E-3	a	ND	
2-methylindan	3.0E-3	a	ND	
1,2,3,4-tetramethylbenzene	ND	e	ND	e
1,2,3,5-tetramethylbenzene	1.9E-3	a	ND	
Propylbenzene	4.5E-3	a	ND	
4-ethyl-o-xylene	2.5E-3	a	ND	
5-ethyl-m-xylene	1.7E-3	a	ND	

Table 6-6b. Tenax VOCs Blanks Results (Delta-Oil) (Continued).

Substance	Oil-DSB		Oil-FB	
Indan	2.5E-3	a	ND	
A-dimethylindane	ND	e	ND	e
m-isopropyltoluene	ND	e	ND	e
2,3+1,5+1,4-dimethylnaphthalene	2.4E-3	a	ND	
2-n-propyltoluene	ND	e	ND	e
Phenanthrene	3.2E-3	a	ND	
1+2-ethylnaphthalene	2.0E-3	a	ND	
1,3-diisopropylbenzene	ND	e	ND	e
4-n-propyltoluene + 1,4-diethylbenzene	ND		ND	
D-dimethylindan	ND		ND	
4-methylstyrene	ND		ND	
1,3-diethylbenzene	ND		ND	
1-nonene	ND		ND	
1,2-dimethylnaphthalene	ND		ND	
Isopropylbenzene	1.6E-3	e	ND	e
alpha-Pinene	ND	e	ND	e
Butylbenzene	ND	e	ND	e
1,2,3-trimethylbenzene	ND	e	ND	e
Pentylbenzene	ND	e	ND	e
Isobutylbenzene	ND	e	ND	e
1,2-diethylbenzene	ND	e	ND	e
Other VOCs (Carbon Number 7 or less)				
1,3-dichlorobenzene	2.3E-2	a	1.0E-2	
Benzaldehyde	8.7E-2	a	2.3E-3	b
Cyclohexanone	ND		ND	
Butyl acetate	ND	e	ND	e
Phenol	5.9E-2	a	3.2E-3	
t-2-heptenal	3.7E-3	a	ND	
1,2-dichlorobenzene	7.0E-3	a	ND	
2-heptanone	ND		ND	
m & p-methylphenol	ND	e	ND	e
Heptanal	ND	e	ND	e

DSB - Dilution Sampler Blank
FB - Field Blank
ND - Not Detected
a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.
b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.
e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zer or one valid run).

percent lower bound. Table 6-7a lists the blanks concentrations for VOCs for the natural gas fired boiler measured using Canisters. About 88 percent the detected VOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Table 6-7b lists the blanks concentrations for VOCs for the oil-fired boiler measured using Canisters. About 85 percent the detected VOCs were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average.

Carbonyls Analysis

Table 6-8a lists the blanks concentrations for carbonyls for the natural gas fired boiler. Formaldehyde, acetaldehyde, and acetone were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Acetaldehyde, acetone, and MEK were present in the FB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Table 6-8b lists the blanks concentrations for carbonyls for the oil-fired boiler. Formaldehyde, acetone, and MEK were present in the DSB sample at concentrations greater than the 95 percent lower bound for the stack sample average. Acetaldehyde, acetone, and MEK were present in the FB sample at concentrations greater than the 95 percent lower bound for the stack sample average.

Table 6-7a. Canisters VOCs Blanks Results (Delta-NG).

	mg/dscm		
Substance	NG-DSB		NG-FB
Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)			
1-decene	9.6E-2	a	f
2,3,5-trimethylhexane	6.3E-2	a	f
m- & p-xylene	4.2E-2	a	f
Limonene	2.3E-2	a	f
n-undecane	1.1E-2	a	f
n-decane	2.0E-2	a	f
Styrene + heptanal	1.5E-2	a	f
o-xylene	1.6E-2	a	f
m-ethyltoluene	1.6E-2	a	f
n-nonane	1.5E-2	a	f
Ethylbenzene	1.1E-2	a	f
Isobutylbenzene	3.1E-2	a	f
1,2,3-trimethylbenzene	1.1E-2	a	f
1,3,5-trimethylbenzene	9.4E-3	a	f
2,2,5-trimethylhexane	2.1E-3	a	f
2-methyloctane	7.3E-3	a	f
n-octane	1.1E-2	a	f
Isopropylcyclohexane	1.0E-2	a	f
n-dodecane	4.5E-3	a	f
Nonanal	2.0E-2	a	f
alpha-pinene	5.2E-3	a	f
2,2,4-trimethylpentane	6.9E-3	a	f
2,3,-trimethylpentane	3.1E-3	a	f
Octanal	1.0E-2	a	f
p-ethyltoluene	5.2E-3	a	f
3-methyloctane	1.0E-2	a	f
o-ethyltoluene	4.5E-3	a	f
n-propylbenzene	5.2E-3	a	f
Indan	2.8E-3	a	f
2-methylheptane	7.3E-3	a	f
3-methylheptane	5.5E-3	a	f
1,4-diethylbenzene	5.5E-3	a	f
C11 paraffin A	6.9E-4	a	f
Naphthalene	3.1E-3	a	f
1,2,4,5-tetramethylbenzene	1.7E-3	a	f
3-ethylpentane	4.5E-3	a	f
3,6-dimethyloctane	4.5E-3	a	f
2,6-dimethyloctane	2.4E-3	e	f
C9 olefin 3	3.8E-3	a	f
Isopropylbenzene	3.1E-3	a	f
C10 aromatic 2	3.1E-3	a	f
Isopropyltoluene	1.4E-3	a	f
1,3-diethylbenzene	2.4E-3	a	f
1-methylindan	1.0E-3	a	f
C10 aromatic 6	6.9E-4	a	f
1,2,3,4-trimethylbenzene	1.0E-3	a	f
C10 aromatic 4	1.4E-3	a	f
1,2,3,5-tetramethylbenzene	2.4E-3	a	f
C10 olefin 2	5.2E-3	a	f

Table 6-7a. Canisters VOCs Blanks Results (Delta-NG) (Continued).

Substance	mg/dscm		
	NG-DSB		NG-FB
C8 paraffin 3	6.9E-4	a	f
4-methylheptane	3.1E-3	a	f
C8 paraffin 2	2.8E-3	a	f
C10 paraffin C	1.7E-3	a	f
2-propyltoluene	1.0E-3	a	f
2,4,4-trimethyl-1-pentene	3.8E-3	a	f
beta-pinene	2.4E-3	a	f
C11 paraffin B	6.9E-4	a	f
Nonene-1	2.1E-3	a	f
1,2-diethylbenzene	6.9E-4	a	f
2,5-diemthylhexane	1.4E-3	a	f
C9 paraffin 2	1.4E-3	a	f
C11 aromatic 3	ND		f
Octene-1	1.4E-3	a	f
1,1-dimethylcyclohexane	1.0E-3	a	f
C8 olefin 2	3.5E-4	a	f
Indene	3.5E-4	a	f
1,2,4-trimethylbenzene	1.7E-3	a	f
C10 paraffin A	6.9E-4	a	f
Dodecene-1	ND	e	f
C11 aromatic 1	3.5E-4	a	f
C10 aromatic 5	1.0E-3	a	f
C9 olefin 4	6.9E-4	a	f
sec-butylbenzene	1.0E-3	a	f
C8 olefin 1	3.5E-4		f
C8 paraffin 1	ND		f
C10 aromatic 1	ND	e	f
C9 paraffin 1	2.8E-3	a	f
C9 olefin 1	3.5E-4	a	f
2,3-dimethylhexane	3.5E-4	a	f
C8 olefin 3	6.9E-4	a	f
C9 paraffin 3	ND		f
4,4-dimethylheptane	3.5E-4	a	f
2,5-dimethylheptane	3.5E-4	a	f
2,6-dimethylheptane	3.5E-4	a	f
2,4-diemthylhexane	3.5E-4	a	f
2,4-dimethylheptane	ND	e	f
Other VOCs (Carbon Number 7 or less)			
n-butane	3.5E-1	a	f
Acetone	5.3E-1	a	f
Toluene	1.4E-1	a	f
Ethane	2.4E-1	a	f
Propane	1.3E-1	a	f
F 12	2.2E-2		f
Chloromethane	1.3E-1	a	f
Ethene	1.1E-1	a	f
Acetaldehyde	1.1E-1	a	f
Isopentane	7.3E-2	a	f

Table 6-7a. Canisters VOCs Blanks Results (Delta-NG) (Continued).

	mg/dscm			
Substance	NG-DSB		NG-FB	
Ethanol + ACN	4.7E-1	a		f
Isobutane	8.1E-2	a		f
n-hexane	1.3E-1	a		f
Methylene chloride	7.8E-2	a		f
Cyclohexane	3.7E-2			f
Acetylene	5.9E-2	a		f
Propene	3.6E-2			f
n-pentane	2.7E-2	a		f
Methanol	1.2E-1	a		f
Iso-butene	2.7E-2			f
2-methylpentane	2.1E-2	a		f
F 113	2.1E-2	a		f
Benzene	2.4E-2	a		f
Methylcyclopentane	3.2E-2	a		f
3-methylhexane + pentanal	1.8E-2	a		f
3-methylpentane	1.5E-2	a		f
Methylcyclohexane	1.2E-2	a		f
1-pentene	6.2E-3	a		f
2-propanol	6.1E-2	a		f
n-heptane	1.1E-2	a		f
Hexanal	1.9E-2	a		f
2-methylhexane	9.4E-3	a		f
1-butene	1.0E-2	a		f
t-2-butene	7.6E-3	a		f
C7 olefin 1	ND			f
Chlorobenzene	8.0E-3	a		f
c-2-butene	7.3E-3	a		f
2,3-dimethylbutane	6.2E-3	a		f
Isoprene	5.5E-3	a		f
2-methyl-1-butene	4.9E-3	a		f
t-2-pentene	1.1E-2	a		f
2,2-dimethylbutane	2.8E-3			f
Cyclopentane	5.2E-3	a		f
2-methyl-2-butene	6.9E-3	a		f
2,2,3-trimethylbutane	2.1E-3	a		f
2,3-dimethylpentane	3.8E-3	a		f
Benzaldehyde	2.8E-3	a		f
1-hexene	1.4E-3	a		f
1,3-dimethylcyclopentane	3.5E-3	a		f
MTBE	6.2E-3	a		f
c-2-pentene	3.5E-3	a		f
2-methyl-2-pentene	3.1E-3	a		f
2,4-dimethylpentane	3.1E-3	a		f
1,3-butadiene	2.8E-3	a		f
t-3-hexene + chloroform	1.7E-3	a		f
3-methyl-1-butene	1.0E-3			f
t-2-hexene	2.1E-3	a		f
Cyclopentene	1.4E-3	a		f
2-methyl-1-pentene	1.0E-3	a		f

Table 6-7a. Canisters VOCs Blanks Results (Delta-NG) (Continued).

	mg/dscm		
Substance	NG-DSB		NG-FB
trans-3-methyl-2-pentene	1.7E-3	a	f
1-methylcyclopentene	2.1E-3	a	f
Cyclohexene	1.0E-3	a	f
3,3-dimethylpentane	6.9E-4		f
cis-3-methyl-2-pentene	1.0E-3	a	f
c-2-hexene	6.9E-4		f
C6 olefin	3.5E-4		f
4-methyl-1-pentene	3.5E-4	a	f
t-3-heptene	6.9E-4	a	f
C7 olefin 2	3.5E-4	a	f
4-methylhexene	3.5E-4	a	f
c-3-hexene	ND		f

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration

c - 95% Confidence Lower Bound of the Average concentration is less than the TB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

f - QA/QC sample not collected.

Table 6-7b. Canisters VOCs Blanks Results (Delta-Oil).

	mg/dscm		
Substance	Oil-DSB		Oil-FB
~~Particulate Carbon Precursors (VOC with Carbon Number 8 or greater)~~			
1-decene	3.5E-1	a	f
n-decane	1.2E-1	a	f
2,3,5-trimethylhexane	1.3E-1	a	f
m- & p-xylene	2.2E-1	a	f
n-undecane	6.1E-2	a	f
n-nonane	6.0E-2	a	f
Isopropylcyclohexane	5.8E-2	a	f
1,3-diethylbenzene	3.8E-3		f
o-xylene	7.7E-2	a	f
m-ethyltoluene	4.4E-2	a	f
Isobutylbenzene	3.3E-2	a	f
1,2,3-trimethylbenzene	3.1E-2	a	f
1,3,5-trimethylbenzene	3.4E-2	a	f
Limonene	7.4E-2	a	f
Ethylbenzene	6.6E-2	a	f
Nonanal	1.5E-2	a	f
2-propyltoluene	3.3E-3	a	f
C10 paraffin C	7.2E-3		f
Styrene + heptanal	6.9E-2	a	f
n-dodecane	3.2E-2	a	f
Indan	2.0E-2	a	f
n-octane	2.1E-2	a	f
2,2,4-trimethylpentane	1.7E-2	a	f
Octanal	2.9E-2	a	f
1,2-diethylbenzene	7.2E-3	a	f
C10 aromatic 1	ND	e	f
3,6-dimethyloctane	1.6E-2	a	f
C10 olefin 2	6.2E-3	a	f
1,4-diethylbenzene	7.2E-3	a	f
o-ethyltoluene	1.3E-2	a	f
n-propylbenzene	1.6E-2	a	f
2-methylheptane	1.0E-2	a	f
3-methyloctane	1.3E-2	a	f
2,6-dimethyloctane	7.6E-3	a	f
p-ethyltoluene	1.3E-2	a	f
3-methylheptane	9.1E-3	a	f
alpha-pinene	1.5E-2	a	f
Isopropylbenzene	1.2E-2	a	f
1,2,4,5-tetramethylbenzene	9.1E-3	a	f
C9 olefin 3	1.1E-2	a	f
1,2,4-trimethylbenzene	7.2E-3	a	f
Naphthalene	1.4E-2	a	f
3-ethylpentane	5.3E-3	a	f
beta-pinene	9.6E-3	a	f
1,2,3,5-tetramethylbenzene	6.2E-3	a	f
C11 paraffin A	5.7E-3	a	f
Nonene-1	7.2E-3	a	f
C9 paraffin 2	8.1E-3	a	f

Table 6-7b. Canisters VOCs Blanks Results (Delta-Oil) (Continued).

	mg/dscm		
Substance	Oil-DSB		Oil-FB
1-methylindan	5.7E-3	a	f
2,4,4-trimethyl-1-pentene	4.8E-3	a	f
2,3,-trimethylpentane	6.2E-3	a	f
Isopropyltoluene	6.7E-3	a	f
4-methylheptane	3.8E-3	a	f
2,5-dimethylheptane	4.8E-4	a	f
C10 aromatic 6	4.8E-3	a	f
C11 aromatic 1	2.9E-3	a	f
C10 aromatic 4	1.9E-3	a	f
C10 paraffin A	ND		f
C10 aromatic 2	4.3E-3	a	f
1,2,3,4-trimethylbenzene	4.8E-3	a	f
C8 paraffin 2	3.3E-3	a	f
Indene	2.4E-3	a	f
2,5-diemthylhexane	2.4E-3	a	f
C10 aromatic 5	1.4E-3	a	f
Octene-1	2.9E-3	a	f
2,2,5-trimethylhexane	4.3E-3	a	f
sec-butylbenzene	1.4E-3	a	f
C9 olefin 4	2.9E-3	a	f
C11 paraffin B	2.4E-3	a	f
C11 aromatic 3	4.8E-4	e	f
C9 paraffin 1	ND		f
C8 olefin 1	9.6E-4	a	f
C8 paraffin 3	1.9E-3	a	f
C8 paraffin 1	ND	e	f
C9 paraffin 3	ND		f
2,6-dimethylheptane	9.6E-4	a	f
Dodecene-1	1.4E-3	e	f
2,3-dimethylhexane	4.8E-4		f
C8 olefin 2	4.8E-4	a	f
C8 olefin 3	4.8E-4	a	f
1,1-dimethylcyclohexane	9.6E-4	a	f
2,4-diemthylhexane	4.8E-4	a	f
4,4-dimethylheptane	ND		f
C9 olefin 1	9.6E-4	a	f
2,4-dimethylheptane	ND		f
3,3-dimethylheptane	ND	e	f
2-methyloctane	ND	e	f
~~Other VOCs (Carbon Number 7 or less)~~			
Acetone	4.7E+0	a	f
n-butane	7.9E-1	a	f
Toluene	3.4E-1	a	f
Ethane	4.0E-1	a	f
Ethene	2.8E-1	a	f
Propane	3.8E-1	a	f
Ethanol + ACN	1.8E-1	a	f
n-hexane	1.9E-1	a	f

Table 6-7b. Canisters VOCs Blanks Results (Delta-Oil) (Continued).

	mg/dscm		
Substance	Oil-DSB		Oil-FB
Chloromethane	2.8E-1	a	f
Isobutane	3.0E-1	a	f
Acetaldehyde	1.6E-1	a	f
Isopentane	1.5E-1	a	f
Acetylene	1.5E-1	a	f
Propene	1.0E-1	a	f
Methylcyclopentane	8.3E-2	a	f
F 12	3.2E-1	a	f
Cyclohexane	8.9E-2	a	f
Iso-butene	7.8E-2	a	f
Methylene chloride	8.3E-2	a	f
2-methylpentane	4.9E-2	a	f
Methanol	7.6E-2	a	f
n-pentane	6.5E-2	a	f
Benzene	5.2E-2	a	f
F 113	7.7E-2	a	f
3-methylpentane	3.9E-2	a	f
c-2-butene	1.7E-2		f
3-methylhexane + pentanal	2.6E-2	a	f
1-pentene	2.4E-2	a	f
Methylcyclohexane	4.0E-2	a	f
n-heptane	1.9E-2	a	f
t-2-butene	1.4E-2		f
2-methylhexane	1.2E-2	a	f
C7 olefin 1	2.0E-2	a	f
1-butene	1.1E-2		f
2,3-dimethylbutane	1.0E-2	a	f
Hexanal	1.5E-2	a	f
Cyclopentane	8.6E-3	a	f
2-propanol	ND		f
2-methyl-2-butene	1.2E-2	a	f
2-methyl-1-butene	9.1E-3	a	f
t-2-pentene	8.1E-3	a	f
2,2-dimethylbutane	6.7E-3	a	f
2,3-dimethylpentane	6.2E-3	a	f
Chlorobenzene	1.0E-2	a	f
2,4-dimethylpentane	3.8E-3	a	f
1,3-butadiene	1.1E-2	a	f
Benzaldehyde	8.6E-3	a	f
1-hexene	5.7E-3	a	f
c-2-pentene	4.8E-3	a	f
1,3-dimethylcyclopentane	3.8E-3	a	f
MTBE	1.9E-3		f
t-3-hexene + chloroform	1.4E-3		f
2-methyl-2-pentene	4.8E-3	a	f
2,2,3-trimethylbutane	2.9E-3	a	f
Cyclopentene	2.4E-3	a	f
t-2-hexene	9.6E-4		f
3-methyl-1-butene	2.4E-3	a	f

Table 6-7b. Canisters VOCs Blanks Results (Delta-Oil) (Continued).

Substance	mg/dscm			
	Oil-DSB		Oil-FB	
trans-3-methyl-2-pentene	4.8E-3	a		f
2-methyl-1-pentene	1.4E-3	a		f
Cyclohexene	1.9E-3	a		f
3,3-dimethylpentane	1.4E-3	a		f
1-methylcyclopentene	1.9E-3	a		f
c-2-hexene	9.6E-4	a		f
t-3-heptene	9.6E-4	a		f
C6 olefin	9.6E-4	a		f
Isoprene	1.5E-2	a		f
C7 olefin 2	ND	e		f
4-methyl-1-pentene	9.6E-4	a		f
cis-3-methyl-2-pentene	4.8E-4			f
c-3-hexene	4.8E-4	a		f
4-methylhexene	ND			f

DSB - Dilution Sampler Blank

FB - Field Blank

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

f - QA/QC sample not collected.

Table 6-8a. Carbonyls Blanks Results (Delta-NG).

	mg/dscm			
	NG-DSB		NG-FB	
Formaldehyde	1.5E-1	a	ND	
Acetaldehyde	4.4E-2	a	3.2E-2	b
Acetone	5.5E-1	a	7.1E-2	b
MEK	4.7E-3		1.0E-2	b
Butyraldehyde	ND	e	2.5E-3	e
Benzaldehyde	ND	e	ND	e
Glyoxal	ND		ND	
Valeraldehyde	ND	e	ND	e

DSB - Dilution Sampler Blank

FB - Field Blank (Average of all Field Blanks)

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Table 6-8b. Carbonyls Blanks Results (Delta-Oil).

	mg/dscm			
	Oil-DSB		Oil-FB	
Formaldehyde	2.8E-1	a	ND	
Acetaldehyde	ND		1.3E-1	b
Acetone	7.1E+0	a	2.6E-1	b
MEK	5.7E-2	a	4.4E-2	b
Butyraldehyde	ND	e	ND	e
Benzaldehyde	ND	e	ND	e
Valeraldehyde	ND	e	ND	e
Hexanaldehyde	ND		ND	

DSB - Dilution Sampler Blank

FB - Field Blank (Average of all Field Blanks)

ND - Not Detected

a - 95% Confidence Lower Bound of the Average concentration is less than the DSB concentration.

b - 95% Confidence Lower Bound of the Average concentration is less than the FB concentration.

e - Insufficient data to calculate 95% Confidence Lower Bound of the Average concentration (i.e. zero or one valid run).

Section 7

DISCUSSION AND FINDINGS

COMPARISON OF DILUTION AND HOT FILTER/ICED IMPINGER METHODS

The dilution sampler is designed to capture filterable matter and any aerosols that condense under simulated stack plume conditions on the same filter. Stack gas is cooled to approximately ambient temperatures, 103 to 116 °F during these tests, as it mixes with dilution air in the dilution sampler. The diluted sample temperatures at this particular sampling location reflect the elevated ambient temperatures during the tests. Samples for analysis are then collected from the diluted gases. Conventional in-stack methods are intended to collect particles that are filterable at the filter temperature (for these tests, the same as the stack temperature or about 415 °F for oil and 314 °F for natural gas) and those that condense in a series of aqueous impingers placed in an ice bath. The gas temperature leaving the impingers is typically 55 to 65 °F. Thus, both techniques cool the sample gas to temperatures well below the stack gas temperature. However, the impinger method cools the sample rapidly without dilution by quenching the gas sample in water maintained at near freezing temperature, while the dilution sampler cools and dilutes the sample more slowly by mixing it with purified ambient air. Since aerosol condensation depends on saturation ratio, temperature, concentration, quench rate, residence time and other factors, it is not surprising that the results of the two methods differ.

Filterable PM emissions from oil combustion measured by the CCT (7.5×10^{-3} lb/MMBtu) are lower than the dilution sampler value of 1.6×10^{-2} lb/MMBtu (Table 5-1b). This difference is most likely attributable to the difference in filter temperatures. The CCT uses a filter heated to a temperature of approximately 650 °F specifically to decompose any H_2SO_4 to SO_3 in the vapor phase. A more meaningful comparison is to look at the filterable PM combined with the condensable fraction captured in the CCT. Adding the two CCT fractions yields an emission factor of 3.3×10^{-2} lb/MMBtu (with condensable fraction as H_2SO_4), which is 2.1 times higher than the PM2.5 emission factor for oil firing obtained from the dilution sampler. The condensed portion of the CCT collects all SO_3/ H_2SO_4 in the sample, including that which would not condense under normal ambient cooling/dilution conditions. Therefore, it is not surprising that the filterable plus condensable mass from the CCT is substantially higher than the mass collected by the dilution sampler.

Emissions of PM2.5 from oil firing are over thirty times higher than those from combustion of natural gas in the boiler. This is accounted for mainly by higher S and ash content of the oil, which results in higher $SO_4^=$ and other elemental emissions compared to natural gas.

Table 7-1 presents a comparison of PM10 data collected during the current program (for DOE/CEC/NYSERDA/GTI/API) for gas-fired sources (Sites Alpha, Bravo, Charlie and Delta), its predecessor conducted for API/DOE/GTI (Sites A, B and C), and published emission factors from EPA's AP-42 database for commercial/industrial external combustion boilers. These data compare results from the filterable and condensable PM fractions; it should be noted that the data from the previous sites were collected using EPA Methods PRE-4 and 202 for filterable and condensable PM, respectively.

Table 7-1. Comparison of Previous and Current Test Data to EPA Emission Factor Data.

Source	Unit Type	Total PM10 (1)	Filterable PM10		Condensable PM		PM2.5 by DS (2)
		lb/MMBtu	lb/MMBtu	% of Total PM10	lb/MMBtu	% of Total PM10	lb/MMBtu
AP-42	Natural Gas External Combustion	0.0075	0.0019	25	0.0056	75	--
Site A	Refinery Gas-fired Boiler	0.0099	0.00016	2	0.0097	98	0.00036
Site B	Refinery Gas-fired Process Heater	0.0052	0.00064	12	0.0046	88	0.000054
Site C	Natural Gas-fired Steam Generator	0.0013	0.000077	6	0.0012	94	0.000056
Site Alpha	Refinery Gas-fired Process Heater	0.0084	0.00059	7	0.0078	93	0.000052
Site Bravo	Natural Gas-fired Combined Cycle Power Plant with supplementary firing, SCR, and oxidation catalyst.	0.0032	0.00029	9	0.0030	91	0.00025
Site Charlie	Natural Gas-fired Process Heater with SCR	0.0011	0.00010	9	0.0010	91	0.00016
Site Delta	Dual Fuel-fired Commercial Boiler (Nat. Gas)	0.0013 (3)	--	--	0.0013 (4)	--	0.00053 (5)
AP-42	Commercial Boiler (No. 6 Oil)	0.032	0.023	69	0.0099	31	--
Site Delta	Dual Fuel-fired Commercial Boiler (No. 6 Oil)	0.033 (3)	0.0075 (3)	23	0.025(4)	77	0.0160

(1) Data collected using EPA Method PRE-4/202 train, and is the sum of filterable PM10 and condensible PM.

(2) Data collected using dilution sampler method; data presented is for PM<2.5 microns and includes filterable and condensable PM.

(3) Data collected using controlled condensation train; filterable PM is total PM, not PM10.

(4) SO_3 expressed as H_2SO_4

(5) High blank levels indicate results may be biased high.

DS - Dilution Sampler

The dilution sampler PM2.5 result for Site Delta firing natural gas is comparable to that for the gas-fired boiler test at Site A, but is still the highest level seen of any gas-fired source to date. The high emission factor for Site Delta may be due to shedding of oil ash deposits from the boiler gas-side surfaces, and/or dilution sampler contamination. As noted previously, the oil-fired testing was performed prior to the natural gas fired testing and PM emissions were much higher during the oil-fired operation than during normal natural gas firing. The dilution sampler was cleaned in the field between the two sets of tests; however, the conditions for cleaning were not ideal and the dilution sampler blank results (as noted in Section 6) suggest that trace amounts of residue from the oil tests may have remained in the dilution sampler prior to the natural gas tests. If cleaning between tests is necessary in future, it will be performed in a cleaner environment and with more rigorous procedures. Either explanation suggests the natural gas-fired PM emissions data may be biased high.

The total PM10 emission factor for oil firing at Site Delta, obtained from the CCT method results (assuming all the filterable PM is PM10), is in good agreement with that found in the EPA's AP-42 emission factor database (0.033 lb/MMBtu from these tests versus 0.032 lb/MMBtu in AP-42) for a commercial boiler firing No. 6 oil. The test results show the majority of the PM to be in the condensable fraction whereas the AP-42 data indicate the majority of PM is in the filterable fraction (EPA, 2000). The AP-42 results were obtained using a different test method with a much lower filter temperature, which probably accounts for the different split between the filterable and condensable PM. Nevertheless, the semi-quantitative agreement of our results with those presented in the AP-42 database provides additional confidence in the validity of the results found here.

The variability of the PM results from the CCT method indicate that the actual mass collected on the filters was at, or below, the practical limits of the method as practiced in these tests. Because dilution sampling more closely simulates condensation conditions in the stack plume, compared to conditions in the impinger method, results obtained by this technique are considered more representative of the actual primary PM emissions.

SULFUR SPECIES

Tables 7-2a and 7-2b present comparisons of the various S species measurements, expressed as $SO_4^=$ in units of lb/MMBtu. For natural gas combustion, the ratio of $SO_4^=$ (as measured by IC) to S as $SO_4^=$ (as measured by XRF) determined by the dilution sampler is 0.80, close to the expected value of 1.0. The $SO_4^=$(IC): $SO_4^=$(XRF) ratio for oil combustion is 1.7. This may indicate an artifact of the pre-fired quartz filters used to collect the $SO_4^=$(IC) samples, which can potentially adsorb and/or catalyze oxidation of SO_2 due to their very high surface area. For natural gas combustion, the total S measured by the dilution sampler (sum of SO_2 and $SO_4^=$ equals 5.1 $x10^{-3}$ lb/MMBtu) is about 1.4 times the total S measured by the CCT (3.7 $x10^{-3}$ lb/MMBtu); this difference is not significant at a 95% confidence level. Both measurements are over three times higher than the S measured in the fuel (1.1 $x10^{-3}$ lb/MMBtu). The relatively good agreement between the CCT and the dilution sampler provides a fair amount of confidence in the measurements. Note, the low S levels in the natural gas were near the minimum detection limits of the fuel gas analysis procedure, and thus the measured fuel S content may not be reliable.

Table 7-2a. Comparison of Sulfur Species Measurements (lb/MMBtu) – Natural Gas Combustion.

	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average
Fuel S as $SO_4^=$	9.0E-4	7.7E-4	1.2E-3	1.3E-3	**1.1E-3**
DS S as $SO_4^=$ (XRF)	1.9E-4	9.1E-5	1.6E-4	1.6E-4	**1.5E-4**
DS $SO_4^=$ (IC)	1.3E-4	7.8E-5	1.4E-4		1.2E-4
DS SO_2 as $SO_4^=$	7.7E-3	3.0E-3	4.3E-3		5.0E-3
DS SO_2 as $SO_4^=$ + $SO_4^=$	7.8E-3	3.1E-3	4.4E-3		**5.1E-3**
CCT SO_3 as $SO_4^=$	2.2E-3	9.4E-4	9.0E-4	1.2E-3	1.3E-3
CCT SO_2 as $SO_4^=$	4.0E-3	1.3E-3	1.7E-3	2.7E-3	2.4E-3
CCT SO_2 as $SO_4^=$ + SO_3 as $SO_4^=$	6.2E-3	2.2E-3	2.6E-3	3.9E-3	**3.7E-3**

CCT - controlled condensation train
DS - dilution sampler
IC - ion chromatography
XRF - x-ray fluoresence

Table 7-2b. Comparison of Sulfur Species Measurements (lb/MMBtu) – Oil Combustion.

	Oil-Run 1	Oil-Run 2	Oil-Run 3	Oil-Run 4	Average
Fuel S as $SO_4^=$	3.9E-1	3.8E-1	4.1E-1	4.2E-1	**4.0E-1**
DS S as $SO_4^=$ (XRF)	4.0E-3	2.6E-3	3.9E-3	3.9E-3	**3.6E-3**
DS $SO_4^=$ (IC)	6.4E-3	3.4E-3	7.5E-3	7.6E-3	6.2E-3
DS SO_2 as $SO_4^=$	9.1E-2	8.7E-2	8.3E-2	9.2E-2	8.8E-2
DS SO_2 as $SO_4^=$ + $SO_4^=$	9.7E-2	9.0E-2	9.1E-2	1.0E-1	**9.4E-2**
CCT SO_3 as $SO_4^=$	2.9E-2	-	2.2E-2	2.5E-2	2.5E-2
CCT SO_2 as $SO_4^=$	3.2E-1	-	2.4E-1	2.6E-1	2.8E-1
CCT SO_2 as $SO_4^=$ + SO_3 as $SO_4^=$	3.5E-1	-	2.6E-1	2.9E-1	**3.0E-1**
Plant CEMS SO_2 as $SO_4^=$	4.1E-1	3.8E-1	4.4E-1	4.3E-1	**4.1E-1**

CEMS - continuous emissions monitoring system
CCT - controlled condensation train
DS - dilution sampler
IC - ion chromatography
XRF - x-ray fluoresence

For oil combustion, the portable gas analyzer results are believed to be the most reliable SO_2 concentration measurements from these tests. The portable gas analyzer SO_2 reading, expressed as $SO_4^=$ (4.1 x10^{-1} lb/MMBtu), is very close to expected levels from the fuel analysis (4.0 x10^{-1} lb/MMBtu). The CCT total S, expressed as $SO_4^=$ (3.0 x10^{-1} lb/MMBtu), is approximately 75 percent of the expected levels from the fuel; this difference is not significant at a 95% confidence level. The total S measured by the dilution sampler is far below the expected level, apparently due to insufficient capacity of the potassium carbonate-impregnated filter used to determine gaseous sulfur oxides. Preliminary investigation indicates that the amount of SO_2 absorbed during the oil runs was at or near the filter's capacity based on the amount of potassium added to the cellulose filters. Based on these tests, the upper collection limits of the K_2CO_3-impregnated cellulose-fiber filter is approximately 13 mg, which corresponds to an in-stack equivalent of 32 mg/dscm (12 ppmv) for a 4-hour sampling time at filter sampling rate of 75 sLpm and dilution ratio of 45:1. These oil-fired tests had an in-stack SO_2 concentration of approximately 90 ppmv, which would require a reduced sampling rate of 10 sLpm, or 2 sLpm with a safety factor of 5. Future tests of sources with elevated SO_2 concentrations should use a modified procedure or alternative method for determining gaseous sulfur oxides.

The typical ratio of SO_3 to SO_2 from combustion sources with significant SO_2 concentrations is approximately 1 to 3 percent; however, the SO_3 ratio for both the oil and gas is higher. For the oil runs the average ratio is approximately 5 percent based on the CCT SO_3 and the portable analyzer SO_2. This may indicate increased conversion of SO_2 to SO_3, possibly due to the high excess O2 and /or catalytic reactions with by ash deposits on the boiler gas-side surfaces. The SO_3 to SO_2 ratio for the natural gas runs (approximately 26 percent based on the CCT SO_3 and the dilution sampler SO_2) is much higher than expected. While the natural gas data should be viewed with some skepticism because the validity of the CCT to measure such extremely low concentrations of SO_3 has not been established, two possible explanations for the gas data might fit. First, the natural gas tests were performed only a few days after several months of firing No. 6 oil. The PM2.5 results for natural gas suggested that oil ash deposits in the boiler were still shedding into the flue gas because they were significantly higher than several other tests on gas-fired units. It is possible that SO_3 and H_2SO_4 evolved from sulfur in the oil ash deposits, either as they became entrained in the hot combustion gases or as they were heated on the filter of the CCT. This also could explain the excess of sulfur oxides compared to the expected level from the natural gas sulfur content. Elevated SO_3 levels also could be attributed to conversion of SO_2 to SO_3 catalyzed by the oil ash deposits (containing potentially active elements Fe, Ni and V), and to the equilibrium SO_3 concentration being further enhanced by the relatively low flue gas temperatures during the tests. While it is feasible these explanations apply, the quantitative results may not be representative of normal natural gas combustion and should be viewed with considerable skepticism in the absence of further tests of natural gas-fired systems.

FORMALDEHYDE

Formaldehyde emissions from the boiler were measured using DNPH cartridges downstream of the dilution sampler. A field blank was taken during each test day in addition to dilution sampler blanks, which sampled only filtered ambient air through the dilution sampler. Although the field blanks did not contain any detectable amounts of formaldehyde, the dilution sampler blanks did. As discussed previously, the dilution sampler blanks levels were more than an order of magnitude lower than the average stack sample, however, if expressed as “in-stack equivalent” by multiplying by an average dilution ratio, the levels of formaldehyde in the natural gas operation dilution sampler blank are about 65% of the average stack levels and the level of formaldehyde in the oil operation dilution sampler blank is greater than the average stack level. These results indicate that the levels in the samples may be due to artifacts from the sampling system. The formaldehyde emission factor for the No. 6 oil tests (2.4×10^{-4} lb/MMBtu) is within the range of formaldehyde emission factors found in the EPA FIRE 6.23 and AP-42 databases (1.6×10^{-4} to 4.0×10^{-4} lb/MMBtu) for a No. 6 oil fired commercial/industrial external combustion boiler with no emission controls. The emission factor from the natural gas tests (3.9×10^{-4} lb/MMBtu) is higher than that found in the EPA FIRE 6.23 and AP-42 databases (7.7×10^{-5} lb/MMBtu) for a natural gas-fired commercial/industrial external combustion boiler with no emission controls, but may be unrepresentative due to comparable levels in the sampler blank and contamination from the preceding oil tests.

POTENTIAL EMISSIONS MARKER SPECIES

The results obtained using the dilution sampler are believed to provide the best representation of the chemical species present in the stack gas emissions. Ions, carbon, and several elements were detected in both stack and ambient air samples. A comparison of the observed concentrations of these species in ambient and stack samples can provide an indication of which species are considered potential markers of natural gas and No. 6 oil combustion for this source. Any compounds with an emission factor uncertainty greater than 100 percent or that were only detected in one test run have been excluded from this analysis.

All detected species that have a higher in-stack average concentration than their concentrations in the ambient air sample, indicating that the species originate from the combustion process, are shown in Figures 7-1a and 7-1b.

Zn, Cl^-, $S/SO_4^=$, and NH_4^+ stack average concentrations were more than an order of magnitude greater than their ambient concentrations and might be the best potential marker species for natural gas combustion, albeit not especially unique ones (compared to other sources). Note, OC is the highest measured component of PM2.5 from gas combustion; however, it is not considered a reliable marker because of probable measurement artifacts (see discussion later is this section).

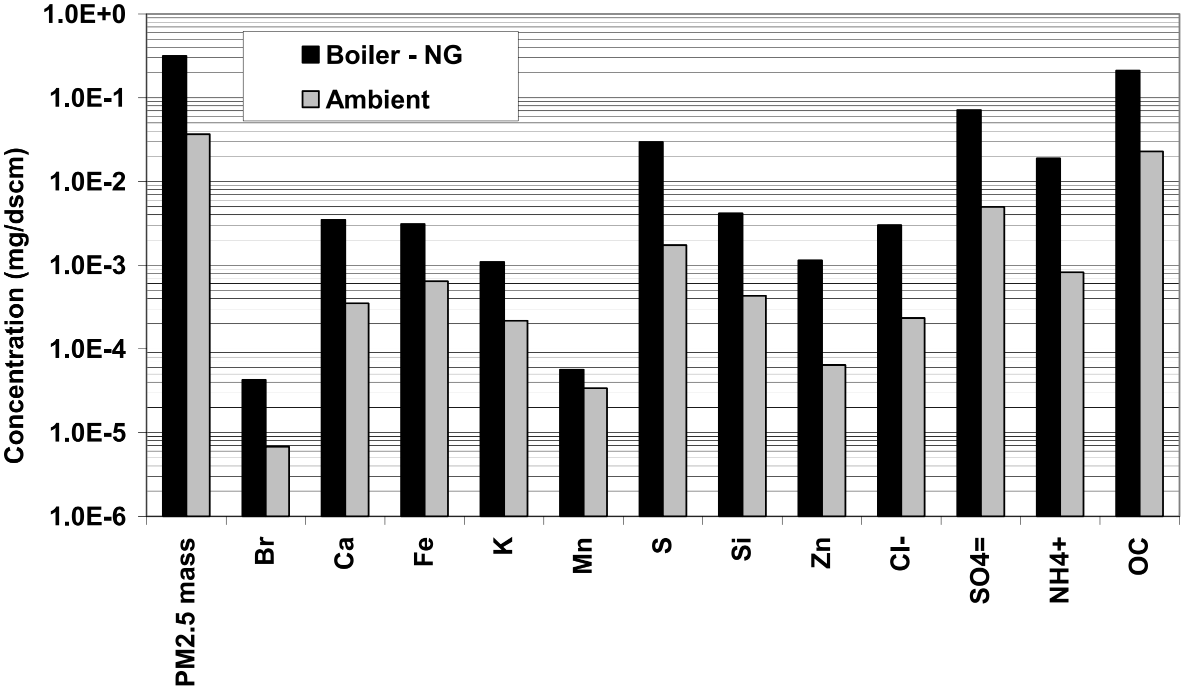

Figure 7-1a. Mass Speciation – DS Ambient and Stack Samples (Delta – NG).

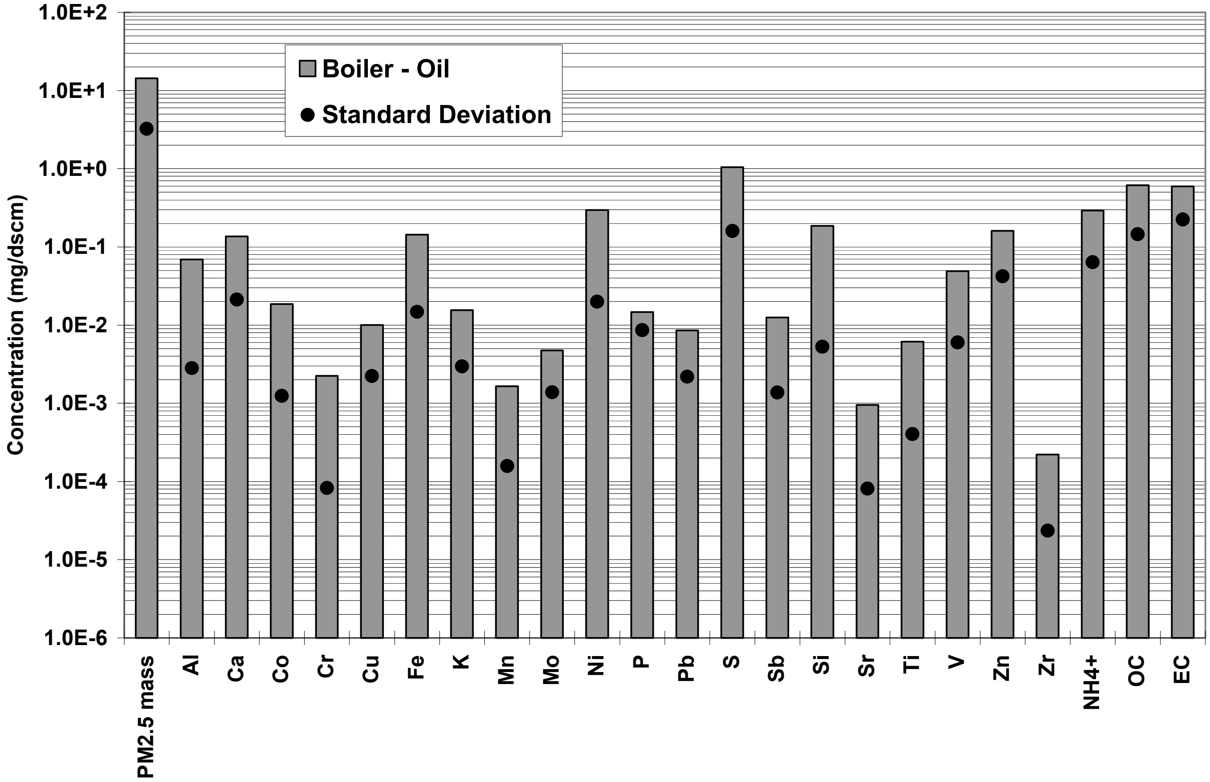

Figure 7-1b. Mass Speciation - DS Ambient and Stack Samples (Delta – Oil).

For oil combustion, all the species in Figure 7-1b had stack average concentrations that were more than an order of magnitude greater than their ambient concentrations and are potential marker species for No. 6 oil combustion.

However, some species cannot reliably be distinguished because their in-stack concentrations are within a factor of ten from the minimum method detection limits (MDL). The circles on Figures 7-2a and 7-2b highlight the species that may not be sufficiently above the detection limit to be reliable markers. These include:

- For natural gas combustion (Figure 7-2a): Br, K, Mn, Cl^-, and NH_4^+; and
- For No. 6 oil combustion (Figure 7-2b): Ba, Ga, La, Sn, Y, Zr, and Cl^-.

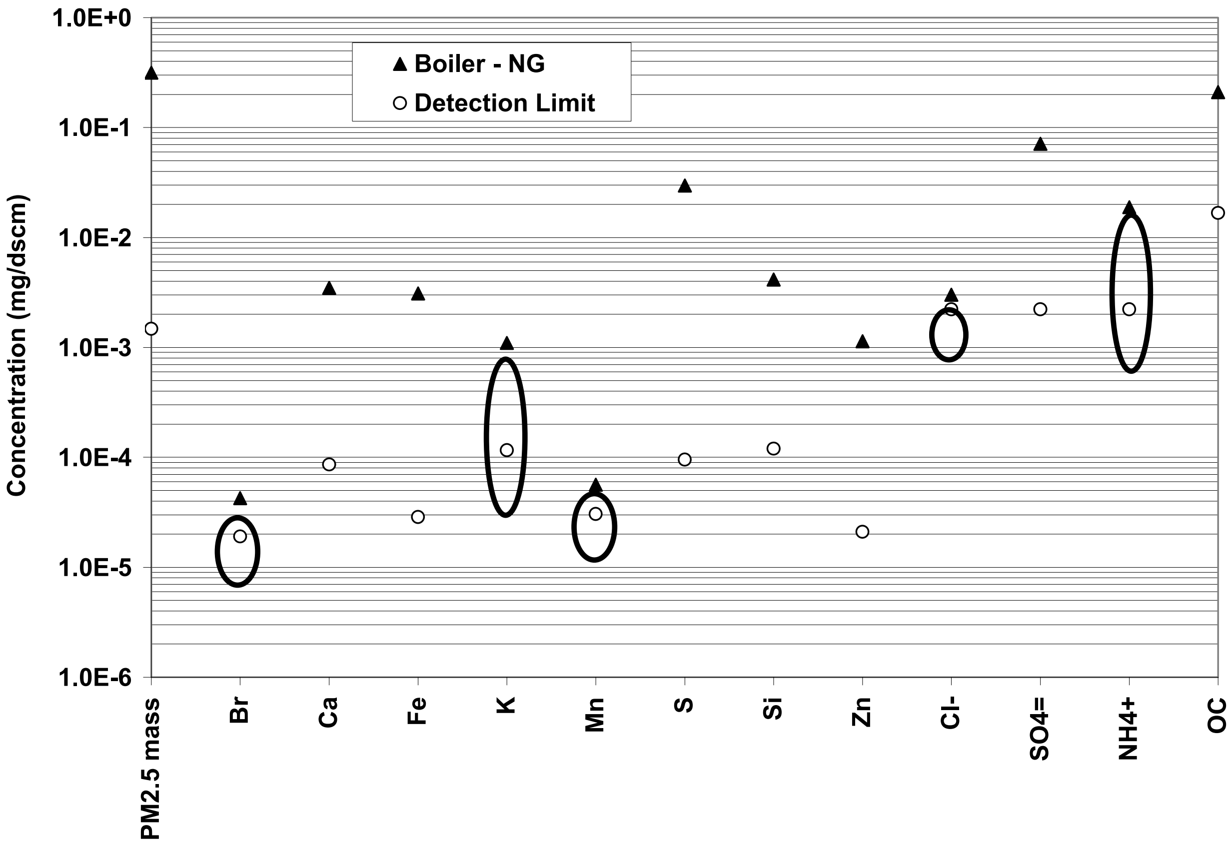

Figure 7-2a. Average Sample Concentration and Detection Limits (Delta – NG).

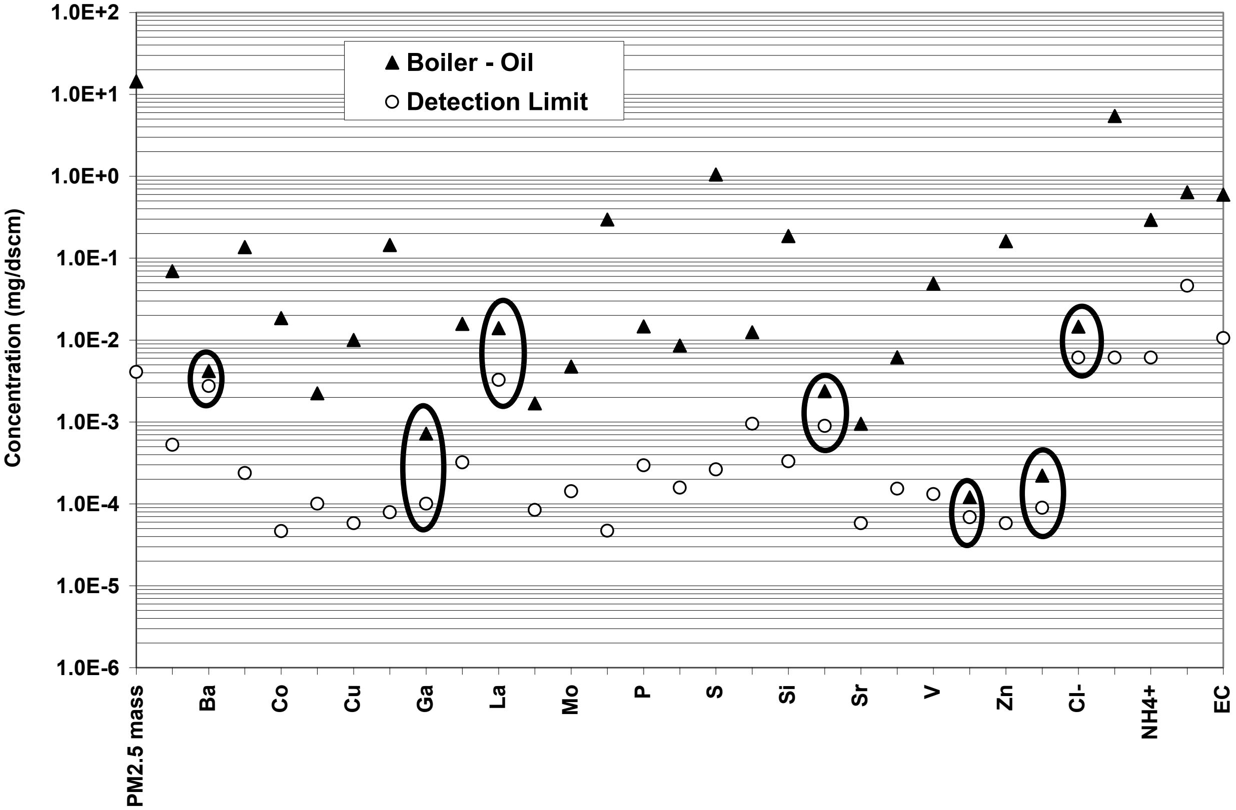

Figure 7-2b. Average Sample Concentration and Detection Limits (Delta – Oil).

The above criteria (Stack average > 10 x Ambient, Stack Average > 10 x MDL) leave Zn and S/$SO_4^=$ as potential marker species for natural gas combustion in commercial boilers. However, S/$SO_4^=$ were detected in the DSB at levels greater than the 95% confidence lower bound (Table 6-2a) indicating stack measurements may have been biased high by dilution sampler residue from the oil-fired tests. It is not clear why Zn should be a marker for natural gas combustion since it should not be present in the gas at significant levels. Although the Zn stack average measurement 95% confidence lower bound (Table 6-3a) was greater than the DSB, the DSB level was about 75% of the stack average, suggesting residue from oil-firing may have contributed to the Zn measurements. Collaborating data from other natural gas tests are recommended prior to using Zn as a natural gas marker. The lack of other metals as marker species for natural gas combustion is consistent with a GTI report that found no significant levels of trace metals in natural gas samples (Chao et al. 1999).

The above criteria (Stack average > 10 x Ambient, Stack Average > 10 x MDL) leave Al, Ca, Co, Cr, Cu, Fe, K, Mn, Mo, Ni, P, Pb, Sb, Si, Sr, Ti, V, Zn, S/$SO_4^=$, NH_4^+, OC, and EC as potential marker species for No. 6 oil combustion in commercial boilers. Stack average measurements 95% confidence lower bounds were greater than the DSB levels for all of these species; however, Cl^-, NH_4^+, OC, and EC all had stack average/DSB ratios less than 10. Collaborating data from other oil-fired tests are recommended prior to using these species as No. 6 oil markers.

Subtraction of the ambient from in-stack concentrations provides further indication of which species can be considered to be emissions markers. Ignoring species found near detection limits, the resulting emissions profiles (Figure 7-3a and 7-3b) suggest that the marker species remain the same as stated above. The dots in the figures show the standard deviation of the runs relative to zero. The low Zn concentration for natural gas combustion supports the use of caution when using Zn as a marker species. The uncertainty of several of these values is large, as reflected in the high standard deviations, casting doubt on those species being definitively used as emissions markers.

Another potentially useful marker for source emissions is the organic species profile. All of the PAHs (SVOCs) detected were present at low concentrations. OC emissions for the Site Delta gas-fired tests were similar to the emissions at the boiler tested at Site C (Table 7-3). The OC emissions from the oil-fired tests were the highest measured so far in this program. Measurable SVOC emissions at Site Delta were also higher than previous gas-fired tests, resulting in a greater percentage of OC being speciated, while measurable SVOC emissions from the oil-fired tests were higher than all but Site A. VOC emissions from gas-fired and oil-fired tests at Site Delta were higher than other sites to date.

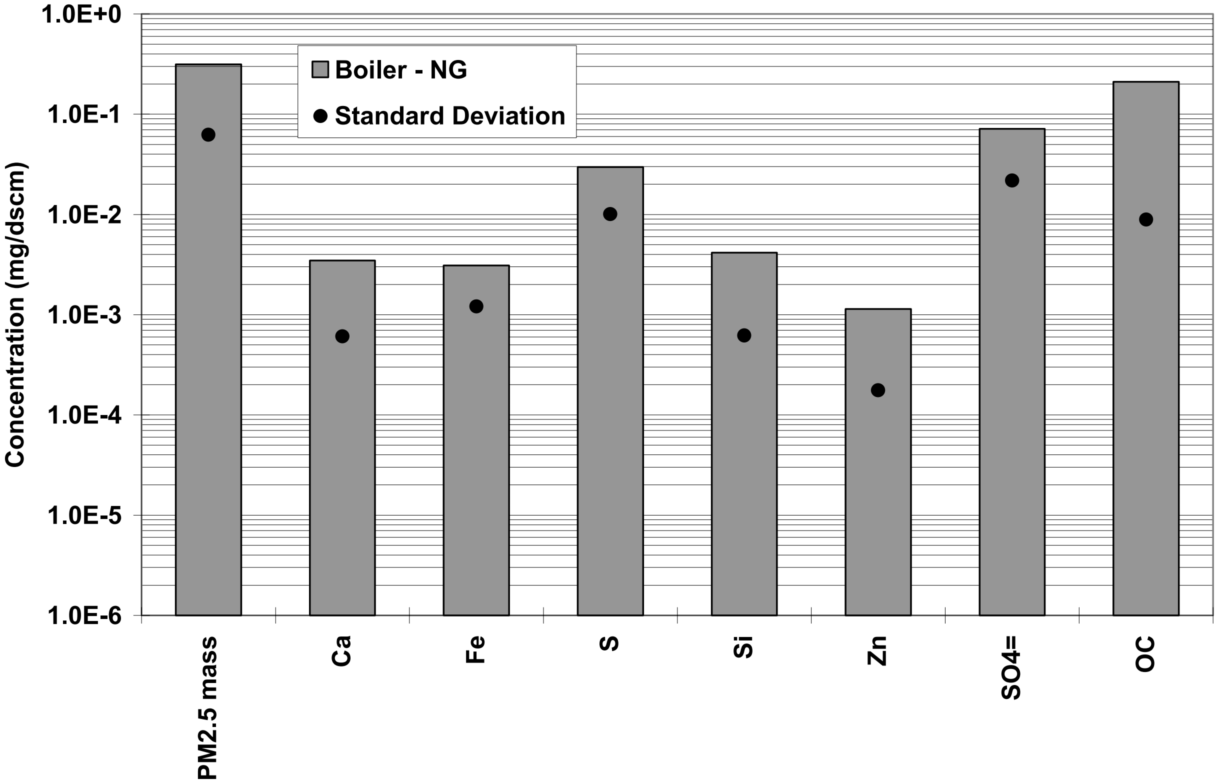

Figure 7-3a. Average Sample Concentration Minus Ambient Concentration (Delta – NG).

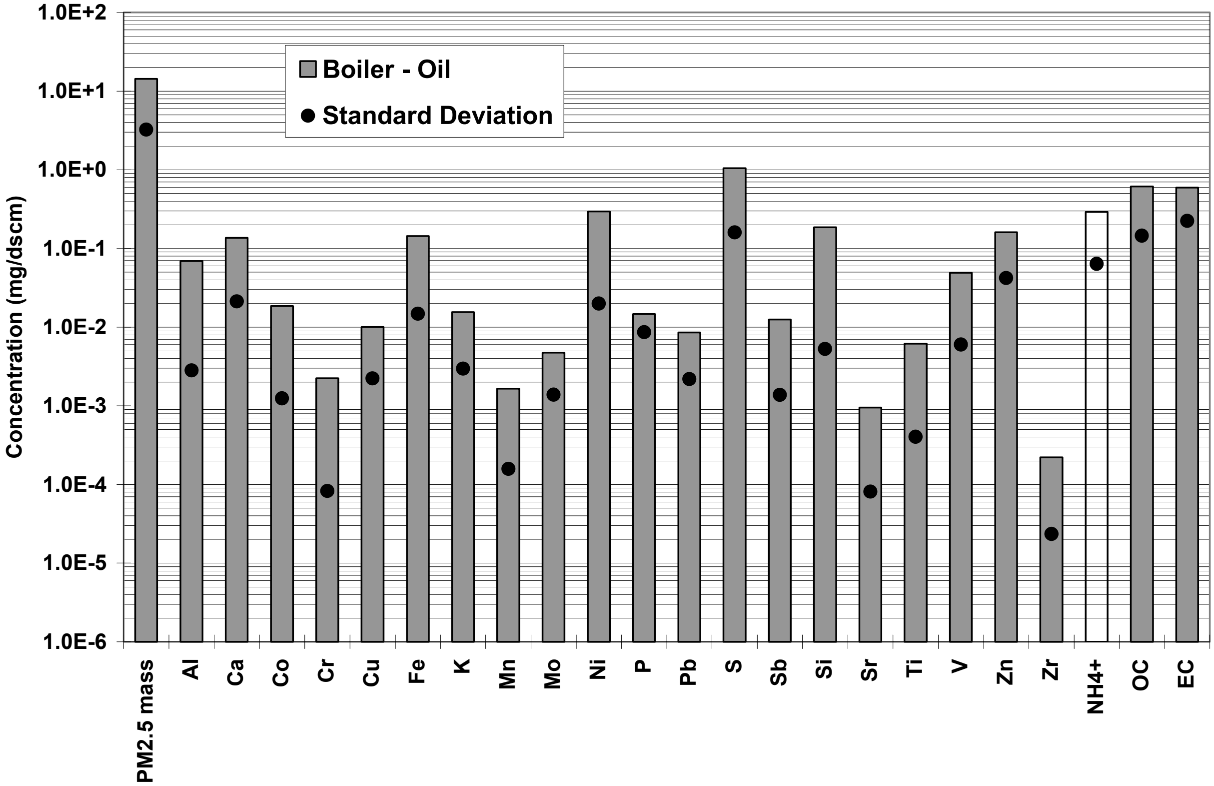

Figure 7-3b. Average Sample Concentration Minus Ambient Concentration (Delta – Oil).

Table 7-3. Average Organic Aerosol Emission Factors Comparison (lb/MMBtu).

Source	Unit Type	Organic Carbon	Elemental Carbon	Total Carbon	Sum of All SVOCs*	Sum of All VOCs**
Site A	Refinery Gas-fired Boiler	1.5E-4	9.4E-5	2.5E-4	4.1E-6	1.6E-4
Site B	Refinery Gas-fired Process Heater	2.8E-5	1.9E-5	3.4E-5	6.6E-7	4.0E-4
Site C	Natural Gas-fired Steam Generator	2.3E-4	9.2E-6	2.4E-4	1.5E-5	4.1E-5
Site Alpha	Refinery Gas-fired Process Heater	9.3E-5	1.0E-5	1.0E-4	5.5E-6	3.6E-5
Site Bravo	Natural Gas-fired Combined Cycle Power Plant with supplementary firing, SCR, and oxidation catalyst.	2.0E-4	1.9E-5	2.2E-4	9.1E-7	NI
Site Charlie	Refinery Gas-fired Heater	1.9E-4	3.6E-5	2.2E-4	3.0E-6	2.4E-4
Site Delta	Dual-fuel Commercial Boiler - NG	3.5E-4	6.5E-5	4.1E-4	5.5E-5	6.8E-4
Site Delta	Dual-fuel Commercial Boiler - No. 6 Oil	7.2E-4	6.7E-4	1.4E-3	1.1E-5	5.3E-4

* Sum of substances included in Table 5-2.

** Sum of substances measured on Tenax and included in Table 5-3.

NI - None of the measured species emission factors met the Table 5-3 inclusion critieria.

Elevated levels of organic compounds in the stack samples as compared to levels detected in the blank and the ambient air indicate that potential marker species may be found in the semivolatile organic compounds. For the Site Delta gas-fired tests 1,3+1,6+1,7-dimethylnaphthalene, 2-methylnaphthalene, 1-methylnaphthalene, and 2,6+2,7-dimethlynapthalene are present at elevated concentrations relative to the other SVOCs and their respective ambient and blanks concentrations, and might be potential marker species. For the No. 6 oil tests phenanthrene, B-MePy/MeFl, Fluoranthene, and Anthrone might be potential marker species. However, motor vehicles are also predominant sources of dimethylnaphthalenes and methylnaphthalenes, and the sampling location was present within 2 miles of a major highway. Because the ambient air was only sampled on one day, it is possible that elevated levels of these compounds were present in the ambient air during source sampling that were not present when the ambient sample was taken. In addition, the relative concentrations of these compounds may not be unique enough to clearly distinguish this source from other external natural gas combustion sources. Also, for the oil tests, a high dilution sampler blank value may be an indication of contamination, although the dilution sampler blank was taken after stack sampling so it may overestimate contamination. In the future, it is recommended that a dilution sampler blank be taken before and after testing, if the schedule and budget allow, to improve the quality of the test data.

More comparison to existing speciation profiles is necessary to gauge the uniqueness of the profile produced by this test. In addition, further testing of similar sources is recommended to provide a more robust basis for the emission factors and speciation profiles described herein.

PARTICULATE CARBON

Quartz filters were used to collect PM that was then analyzed for OC and EC by TOR using the IMPROVE protocol. Previous studies have shown that OC measurements on quartz filters are susceptible to two artifacts: adsorption of VOCs onto the filter media and collected PM, and devolatilization of organic PM, with the adsorptive artifact dominating and causing a positive bias (Mazurek et al, 1993). In these tests, a quartz fiber filter was placed downstream of a TMF during sample collection and subsequently analyzed for OC and EC to determine the extent of this artifact (Turpin, 1994). The OC collected on this filter may be used to evaluate the potential significance of the artifact relative to the OC collected on the front-loaded quartz fiber filter. This is commonly referred to as "backup OC". In some cases, this approach may overestimate the extent of the artifact because the adsorptive capacity of the filter media itself and the collected particles can affect the amount of VOC adsorbed on the filter (Kirchstetter, 2001). Therefore, it is convention not to correct OC measurements for the backup filter/artifact results, but rather to present both sets of results and discuss the potential impact of the artifact on the measured OC results.

Table 7-4a presents the data from the backup and front quartz filters used for the natural gas-fired tests, as well as the equivalent OC concentration if the results are corrected for backup OC (i.e., the OC mass measured on the backup quartz filter is subtracted from the OC mass measured on the primary quartz filter). The backup OC was about 100 percent of the OC concentration measured on the primary quartz filter for all measurements except the ambient sample. Table 7-4b presents the data from the backup and front quartz filters used for the oil-fired tests, as well as the equivalent OC concentration if the results are corrected for backup OC. The backup OC was 9 to 25 percent of the OC concentration measured on the primary quartz filter for the four test runs. The high blank levels as well as the VOC adsorption artifact associated with the quartz filters used to measure OC indicate a significant positive bias on the OC concentrations. Therefore, the OC results should be considered as an upper bound for the potential OC emissions, with significant uncertainty in the reported values. The natural gas results are qualitatively similar to the results of Hildemann et al. (1991), who determined speciated PM emissions from gas-fired home appliances using methods identical to those used in this program. Hildemann found that OC accounted for 84.9 percent of PM mass and that the backup OC accounts for 73 percent of the measured OC emissions, on average. Hildemann's data are incorporated into EPA's SPECIATE database, and are currently the only PM speciation data available for gas-combustion. Thus, Hildemann's results provide validation of the OC results measured in this study, and also reinforce the need for caution when using the OC results, particularly those from the natural gas tests.

Table 7-4a. OC and Backup Filter OC Results (Delta-NG).

	mg/dscm						
	NG-Run 1	NG-Run 2	NG-Run 3	NG-Run 4	Average	DSB	Ambient
OC	2.2E-1	2.0E-1	2.1E-1	-	2.1E-1	2.5E-01	2.3E-2
Backup Filter OC	2.2E-1	2.0E-1	2.2E-1	-	2.1E-1	2.5E-01	5.1E-3
OC (Corrected for Backup)	0.0E+0	0.0E+0	-1.0E-2	-	0.0E+0	0.0E+0	1.8E-2
Backup OC/OC (%)	100	100	101	-	100	99	22

Table 7-4b. OC and Backup Filter OC Results (Delta-Oil).

	mg/dscm						
	Oil-Run 1	Oil-Run 2	Oil-Run 3	NG-Run 4	Average	DSB	Ambient
OC	7.7E-1	6.0E-1	4.5E-1	7.3E-1	6.4E-1	4.4E-01	2.3E-2
Backup Filter OC	1.5E-1	1.1E-1	1.1E-1	6.5E-2	1.1E-1	2.8E-01	5.1E-3
OC (Corrected for Backup)	6.2E-1	4.9E-1	3.3E-1	6.6E-1	5.3E-1	1.7E-1	1.8E-2
Backup OC/OC (%)	19	19	25	9	17	62	22

FINDINGS

The main findings of these tests are:

- PM mass emissions from the boiler during gas firing were low, consistent with levels expected for gaseous fuel combustion, but still higher than any previously tested gas-fired sources in the current program. The elevated PM mass emissions during gas combustion may be due to shedding of oil ash deposited on the boiler gas-side surfaces during oil-fired operation, because gas-fired testing was performed only a few days after the seasonal switch from oil firing to gas firing. This residue also may have biased other natural gas-fired emissions data. The dilution sampler apparatus was cleaned in the field between tests, but the field conditions were not ideal, creating the possibility for residual contamination in the sampler from the previous oil-fired tests.

- PM2.5 emissions from the boiler when firing No. 6 oil were more than an order of magnitude higher when firing natural gas. This is attributed to the elevated sulfur and ash content of the oil compared to natural gas.

- Two methods for determining the average emission factor for primary PM mass from oil firing gave results that corresponded relatively well: 0.016 lb/MMBtu using the dilution sampler; and 0.033 lb/MMBtu using a controlled condensation train. Both results include filterable and condensable PM. The dilution sampler result is believed to be the best representation of primary PM2.5 emissions to the atmosphere. The difference is attributed mainly to reduced condensation of sulfuric acid in the dilution sampler, which simulates the stack plume conditions driving condensation more accurately than the controlled condensation train.

- Quantified chemical species accounted for 128 percent of the measured PM2.5 mass from gas firing and 64 percent from oil firing (applying an organic carbon scaling factor and assuming common oxide states for other elements).

- Organic and elemental carbon comprise approximately 67 percent of the sum of species (measured by the dilution sampler) from gas firing, but only 15 percent of the sum of species from oil firing. Organic carbon results are probably biased high due to a significant measurement artifact; this artifact is more pronounced for the natural gas-fired tests.

- For oil firing, the predominant component of the PM2.5 (measured by the dilution sampler) is sulfur (60 percent of the sum of species as sulfate), reflecting the higher sulfur content of No. 6 oil compared to natural gas. Calcium, iron, nickel, silica, zinc and vanadium also are elevated in the oil combustion emissions, reflecting the ash content of the fuel.

- Most organic species were not detected at levels significantly above background levels in the ambient air or blanks.

- Particle size distribution measurements using a modified micro-orifice uniform deposit impactor determined that most of the particles were in the condensation mode during natural gas combustion, with an average of 77 percent of the mass in the fraction less than 0.32 micrometers. During oil combustion, an average of 76 percent of PM2.5 was in the size range less than 0.32 micrometers in aerodynamic diameter, very similar to the natural gas results.

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Appendix A
LIST OF ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
$\mu g/cm^2$	micrograms per square centimeter
µg/mL	micrograms per milliliter
µm	microns, or micrometers
acfm	actual cubic feet per minute
ACS	American Chemical Society
Ag	silver
Al	aluminum
API	American Petroleum Institute
As	arsenic
ASME	American Society of Mechanical Engineers
Au	gold
Ba	barium
Br	bromine
Btu/lb	British thermal units per pound
Btu/scf	British thermal units standard cubic feet
Ca	calcium
CCT	controlled condensation train
Cd	cadmium
CEC	California Energy Commission
CEMS	continuous emissions monitoring system
Cl^-	chloride ion
Cl	chlorine
CO	carbon monoxide
Co	cobalt
CO_2	carbon dioxide
CPM	condensible particulate matter
Cr	chromium
Cu	copper
DI	distilled deionized
DNPH	dinitrophenylhydrazine
DOE	United States Department of Energy
DRI	Desert Research Institute
DSB	dilution sampler blank
dscf/MMbtu	dry standard cubic feet per million British thermal units
dscfm	dry standard cubic feet per minute
dscmm	dry standard cubic meters per minute
DS	dilution sampler
EC	elemental carbon
ECD	electron capture detection
ED-XRF	energy dispersive x-ray fluorescence
EPA	Environmental Protection Agency

LIST OF ABBREVIATIONS
(Continued)

ERA	Environmental Research Associates
eV	electron volts
FB	field blank
Fe	iron
FID	flame ionization detection
FPM	filterable particulate matter
FTIR	Fourier transform infrared detection
g	grams
Ga	gallium
GC	gas chromatography
GC/FID/ECD	gas chromatography/flame ionization detection/electron capture detection
GC/IRD/MSD	gas chromatography/infrared detector/mass selective detector
GC/MS	gas chromatography/mass spectrometry
GCMS/FID	gas chromatography/mass spectrometry/flame ionization detection
GE EER	GE Energy and Environmental Research Corporation
GE MP	GE MostardiPlatt
GRI	Gas Research Institute
H	hydrogen
H_2O	water
H_2O_2	hydrogen peroxide
H_2S	hydrogen sulfide
HC	hydrocarbon
HEPA	high efficiency particulate air
Hg	mercury
HPLC	high performance liquid chromatography
IC	ion chromatography
In	indium
K_2CO_3	potassium carbonate
K	potassium
K^+	potassium ion
keV	kilo electron volts
KHP	potassium hydrogen phthalate
La	lanthanum
lb/hr	pounds per hour
lb/MMBtu	pounds of pollutant per million British thermal units of gas fired
Lpm	liters per minute
MDL	method detection limit
MeFl	methylfluorene
MEK	methyl ethyl ketone
MePy	methylpyrene
Mg	magnesium
mg	milligram
mg/dscm	milligrams per dry standard cubic meter

LIST OF ABBREVIATIONS
(Continued)

mL	milliliter
MMBtu/hr	million British thermal units per hour
Mn	manganese
Mo	molybdenum
MOUDI	micro-orifice uniform deposit impactor
MSD	mass selective detector
MSD/FTIR	mass selective detector/Fourier transform infrared detection
n/a	not applicable
Na	sodium
Na^+	sodium ion
NAAQS	National Ambient Air Quality Standards
ND	not detected
NG	natural gas
ng/µl	nanograms per microliter
NH_3	ammonia
NH_4^+	ammonium ion
Ni	nickel
NIST	National Institute of Standards and Technology
NMHC	non-methane hydrocarbons
NO_3^-	nitrate ion
NO_x	oxides of nitrogen
NYSERDA	New York State Energy Research and Development Authority
O	oxygen
O_2	molecular oxygen
OC	organic carbon
P	phosphorus
PAH	polycyclic aromatic hydrocarbon
Pb	lead
Pd	palladium
PM	particulate matter
PM10	particulate with aerodynamic diameter less than 10 micrometers
PM2.5	particulate with aerodynamic diameter less than 2.5 micrometers
ppm	parts per million
ppmv	parts per million (volume)
ppbv	parts per billion (volume)
PTFE	polytetrafluoroethylene
PUF	polyurethane foam
QA	quality assurance
QA/QC	quality assurance/quality control
Rb	rubidium
RE	relative enrichment factor
RH	relative humidity
RPD	relative percent differences

LIST OF ABBREVIATIONS
(Continued)

RSD	relative standard deviation
S	sulfur
Sb	antimony
scfm	standard cubic feet per minute
sLpm	standard liters per minute
Se	selenium
Si	silicon
Sn	tin
SO_2	sulfur dioxide
SO_3	sulfur trioxide
$SO_4^=$	sulfate ion
Sr	strontium
SRM	standard reference material
SS	stainless steel
SVOC	semivolatile organic compound
Ti	titanium
TIGF	Teflon-impregnated glass fiber
Tl	thallium
TMF	Teflon-membrane filter
TOR	thermal/optical reflectance
TSI	Thermo Scientific Incorporated
U	uranium
V	vanadium
VOC	volatile organic compound
XAD-4	Amberlite® sorbent resin (trademark)
XRF	x-ray fluorescence
Y	yttrium
Zn	zinc
Zr	zirconium

Appendix B

SI CONVERSION FACTORS

	English (US) units	X	Factor	=	SI units
Area:	1 ft^2	x	9.29×10^{-2}	=	m^2
	1 in^2	x	6.45	=	cm^2
Flow Rate:	1 gal/min	x	6.31×10^{-5}	=	m^3/s
	1 gal/min	x	6.31×10^{-2}	=	L/s
Length:	1 ft	x	0.3048	=	m
	1 in	x	2.54	=	cm
	1 yd	x	0.9144	=	m
Mass:	1 lb	x	4.54×10^{2}	=	g
	1 lb	x	0.454	=	kg
	1 gr	x	0.0648	=	g
Volume:	1 ft^3	x	28.3	=	L
	1 ft^3	x	0.0283	=	m^3
	1 gal	x	3.785	=	L
	1 gal	x	3.785×10^{-3}	=	m^3
Temperature	°F-32	x	0.556	=	°C
	°R	x	0.556	=	K
Energy	Btu	x	1055.1	=	Joules
Power	Btu/hr	x	0.29307	=	Watts