# CHARACTERIZATION OF FINE PARTICULATE EMISSION FACTORS AND SPECIATION PROFILES FROM STATIONARY PETROLEUM INDUSTRY COMBUSTION SOURCES

## TEST REPORT: NATURAL GAS-FIRED COMBINED-CYCLE GAS TURBINE (SITE E)

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**DRAFT REPORT**
**PRELIMINARY DATA**
**DO NOT QUOTE OR CITE**

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## PROJECT OVERVIEW

In 1997, the United States Environmental Protection Agency (EPA) promulgated new ambient air standards for particulate matter, including for the first time particles with aerodynamic diameter smaller than 2.5 micrometers (PM2.5). There are few existing data regarding emissions and characteristics of fine aerosols from petroleum industry combustion sources, and the information that is available is old. 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. This issue was extensively reviewed by API in a recent report (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 (Hildemann et al., 1994; McDonald et al., 1998) and use clean ambient air to dilute the stack gas sample and provide 80-90 seconds residence time for aerosol formation prior to sample collection for determination of mass and chemical speciation.

As a result of the API review, a test protocol was developed based on the dilution sampling system described in this report. The dilution sampling protocol was used to collect particulate emissions data from petroleum industry combustion sources, along with emissions data obtained from conventional sampling methods. This test program is designed to provide reliable source emissions data for use in assessing the contribution of petroleum industry combustion sources to ambient PM2.5 concentrations. The goals of this test program were to:

- Develop emission factors and speciation profiles for emissions of fine particulate matter, especially organic aerosols; and
- Identify and characterize PM2.5 precursor compound emissions.

This test report describes the results of tests performed on a natural gas-fired combined cycle turbine at Site E on September 6-11, 2001.

## PROJECT OBJECTIVES

The specific objectives of this test were to:

Primary Objectives

- Compare PM2.5 mass measured using an in-stack filter and iced impinger train (EPA Method PRE-4/202) and mass measured using a dilution tunnel;
- Develop emission factors and speciation profiles for organic aerosols and PM2.5 mass;
- Characterize sulfate, nitrate, ammonium, inorganic elements, elemental carbon (EC) and organic carbon (OC) in particulate matter collected on filter media in the dilution sampler;
- Characterize key secondary particle precursors in stack gas samples: volatile organic compounds (VOC) with carbon number of 7 and above; sulfur dioxide ($SO_2$); and oxides of nitrogen ($NO_X$); and
- Compare condensable particulate matter (CPM) results obtained using two different methods: EPA Method 202 and a modified version of EPA Method 8 (the back-half isopropyl alcohol catch is dried and weighed).

## TEST OVERVIEW

The scope of testing is summarized in Table 1-1. The emissions testing included simultaneous collection and analysis of both in-stack and diluted stack gas samples. All emission samples were collected from the stack of the unit. 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.

### Source Level (In-stack) Samples

In-stack sampling and analysis for filterable (total, PM10 and PM2.5) and condensable particulate matter (CPM) was performed using traditional EPA methods. In-stack cyclones and filters were used for filterable particulate matter.

### Dilution Stack 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 approximately 21:1 with purified ambient air. Because PM2.5 behaves aerodynamically like a gas at typical stack conditions, the samples were extracted

Table 1-1. Overview of Sampling Scope.

| | Number of Samples | | |
|---|---|---|---|
| Sampling Location | Fuel Gas Header | Stack | Ambient Air |
| EPA Method PRE-4/202 train | -- | 4 | -- |
| EPA Method 17/8 train | -- | 4 | -- |
| Dilution tunnel<br>Teflon® filter (mass, elements)<br>Quartz filter (ions, OC/EC)<br>$K_2CO_3$-impregnated cellulose fiber filter ($SO_2$)<br>Citric acid-impregnated cellulose fiber filter ($NH_3$)<br>TIGF/PUF/XAD-4 (SVOCs)<br>Tenax (VOCs)<br>Stainless steel canisters (VOCs, C2-C10)<br>DNPH-coated silica gel cartridges (carbonyls) | -- | 4 | 1 |
| $NO_x$, CO, $O_2$ | -- | Continuous (Plant) | -- |
| Process monitoring | -- | Continuous | -- |

TIGF - Teflon®-impregnated glass fiber filter
PUF - polyurethane foam
XAD-4 - Amberlite® sorbent resin
DNPH - dinitrophenylhydrazine

nonisokinetically. A slipstream of the mixed and diluted sample was extracted into a residence time chamber where it resided 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 microns, after which samples were collected on various media: high-purity quartz for ions and carbon speciation, Teflon® membrane (TMF) for PM2.5 mass and elements, potassium carbonate-impregnated cellulose fiber for $SO_2$, citric acid-impregnated cellulose fiber for ammonia and Teflon®-impregnated glass fiber (TIGF) filters for particle phase semivolatile organic compounds (SVOCs); a polyurethane foam (PUF)/Amberlite® sorbent resin (XAD-4)/PUF cartridge to collect gas phase SVOCs; Tenax tubes to capture VOCs with a carbon number greater than

Table 1-2. Summary of Analytical Targets.

| Parameters | In-Stack | | | | Dilution Tunnel | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cyclones | Quartz filter | Imp. | Gases | Quartz filter | TIGF/ PUF/ XAD | TMF | Tenax | SS cans | DNPH cartrid-ges | $K_2CO_3$ filter | Citric acid filter | Gases |
| Total PM mass | X | X | | | | | | | | | | | |
| PM10 mass | X | X | | | | | | | | | | | |
| PM2.5 mass | X | X | | | | | X | | | | | | |
| Condensable particulate mass | | | X | | | | | | | | | | |
| Sulfate | | | X | | X | | | | | | | | |
| Chloride | | | X | | X | | | | | | | | |
| Ammonium | | | X | | | | | | | | | | |
| Nitrate | | | X | | X | | | | | | | | |
| Elements | | | X | | | | X | | | | | | |
| Organic carbon | | X | | | X | | | | | | | | |
| Elemental carbon | | X | | | X | | | | | | | | |
| Semivolatile organic compounds | | X | | | | X | | | | | | | |
| Volatile organic compounds* | | | | | | | | X | | | | | |
| Volatile organic compounds** | | | | | | | | | X | | | | |
| Aldehydes | | | | | | | | | | X | | | |
| Ammonia (gaseous) | | | | | | | | | | | | X | |
| $NO_x$ | | | | X | | | | | | | | | |
| $SO_2$ | | | X | | | | | | | | X | | |
| CO | | | | X | | | | | | | | | |
| $O_2$ | | | | X | | | | | | | | | |
| $CO_2$ | | | | X | | | | | | | | | |
| Moisture or relative humidity | | | X | | | | | | | | | | X |
| Velocity | | | | X | | | | | | | | | |
| Temperature | | | | X | | | | | | | | | 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

seven; a stainless steel canister to capture VOCs with a carbon number greater than two; and dinitrophenylhydrazine (DNPH)-coated silica gel cartridges to capture carbonyls (aldehydes). Four samples were collected on four separate test days.

An ambient air sample was collected to establish background concentrations of measured substances. The same sampling and analysis procedures used for the dilution tunnel were applied for collecting ambient air samples.

Process Samples

A sample of the fuel gas burned in the process heater was collected on each day of source testing and analyzed for specific gravity, heating value and hydrocarbon speciation.

## KEY PERSONNEL

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

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# Section 2
# PROCESS DESCRIPTION

Tests were performed on a combined-cycle generating unit employing a General Electric Frame 7FA gas turbine with steam augmentation. The unit is a single shaft design, with the single generator driven by a shaft common to both the gas and the steam turbine. Hot exhaust gases from the turbine pass through a heat recovery steam generator (HRSG) before venting to the atmosphere via the stack (Figure 2-1). The Vogt HRSG contains supplementary duct burners for additional steam production. The gas turbine's nominal rated base load is approximately 180 MW. The total nominal capacity of the cogeneration facility is 240 MW. The unit will fire natural gas for these tests. The facility is equipped with continuous emissions monitors for CO, $O_2$ and $NO_x$. The unit employs GE Mark V Speedtronic® control systems.

## POLLUTION CONTROL EQUIPMENT DESCRIPTION

The unit was retrofitted with GE's dry low $NO_x$ (DLN) version 2.6 combustion system for $NO_x$ emissions control to 9 ppmv (dry, corrected to 15% $O_2$) or less over the normal operating load range. The DLN combustion system achieves low $NO_x$ emissions by staging the fuel addition to achieve initial combustion under premixed, fuel-lean conditions. The remaining fuel is added downstream of the premix zone. Design CO concentration is less than 9 ppmv during normal operation. Combustion in the full premixed mode is maintained from 50 to 100 percent of base load.

In addition to DLN, the unit has post-combustion air pollution control equipment. The HRSG is equipped with an oxidation catalyst for control of CO emissions followed by ammonia injection and a selective catalytic reduction (SCR) system for control of $NO_x$ emissions.

## SAMPLING LOCATIONS

The turbine and HRSG exhaust through a vertical, cylindrical stack that is 233 feet tall. Emissions sampling will be conducted at this stack, which has an inside diameter of 16.5 feet (198.0 inches) and has numerous ports, some of which are used for the plant CEMS. There are four six-inch diameter flanged ports positioned at 90 degrees to each other and located approximately 6 feet above the sampling platform. There are also four four-inch ports offset

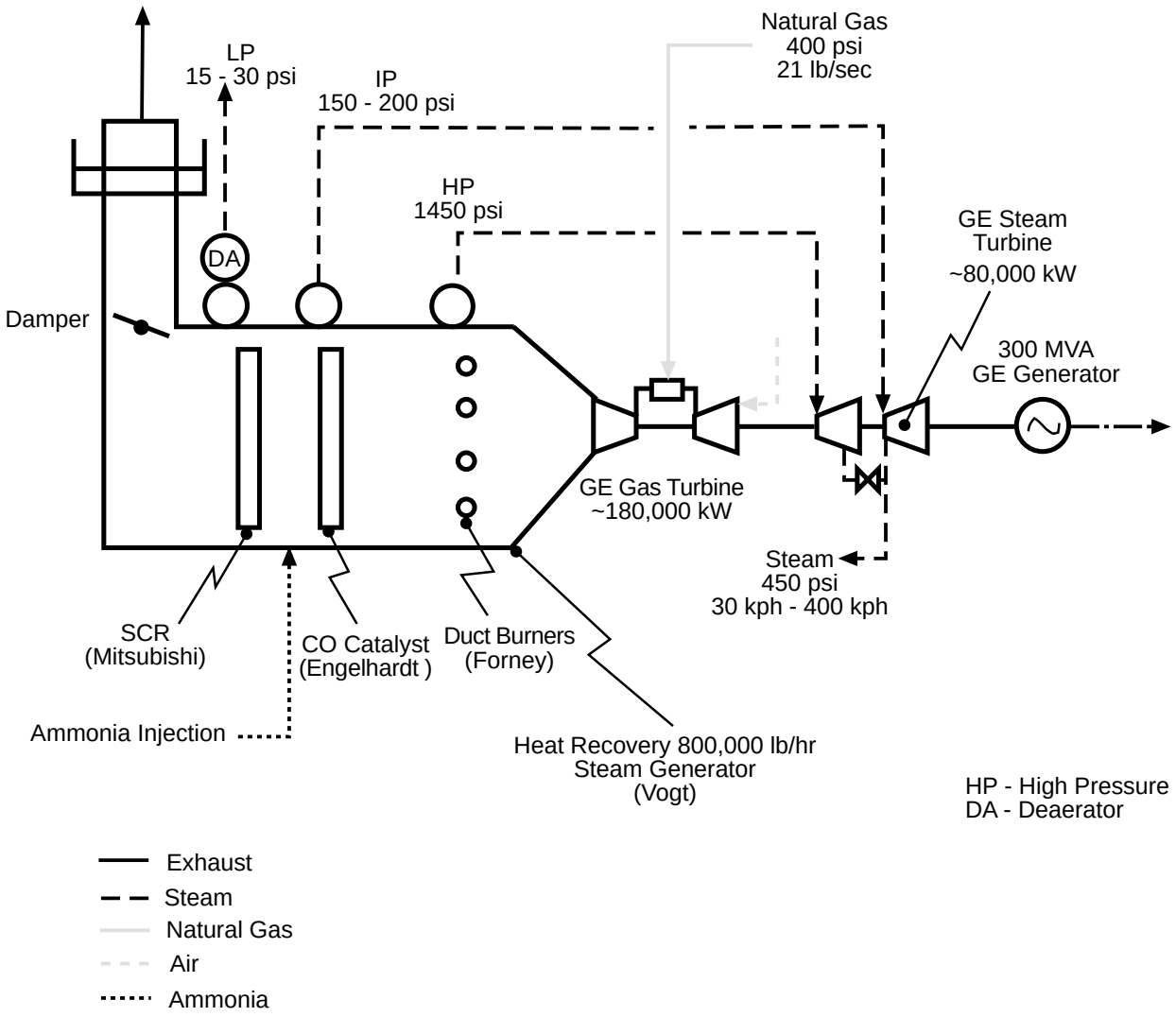



Figure 2-1. Site E Process Overview.

from the six-inch ports and located at 90 degrees to each other; the ports are flanged and located 4 feet above the platform. The ports are at least 60 feet (3.6 diameters) downstream from the last disturbance and 100 feet (6.1 diameters) upstream from the top of the stack. All ports are accessed from a single platform that is approximately 61 inches wide and approximately 128 feet above the ground. The unit is not stratified and there is no cyclonic flow present, based on previous testing at the unit. Preliminary velocity traverses were performed to determine average velocity in the stack. Sampling was performed through three separate ports at points of average flow, as determined by the velocity traverses; the Method 17/8 train and the dilution tunnel probe were sampled through the same port.

A single ambient air samples was collected adjacent to and at the same level as the air inlet for the turbine.

# Section 3
# TEST PROCEDURES

An overview of the sampling and analysis procedures is given in Table 3-1. Figure 3-1 shows the testing chronology for the dilution tunnel and in-stack methods. The time of day for the start and finish of each measurement run is shown on the figure. For example, Method PRE-4/202 Run 1 began at 11:56 hours and finished at 17:56 hours on Thursday, September 6. Dilution tunnel testing and in-stack testing were performed concurrently. All samples were collected at points of average flow 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 Method 201A/202 train 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.

## $O_2$, $CO_2$, CO, AND $NO_x$

Major gases and pollutant concentrations in the stack sample were monitored using the plant's continuous emission monitoring system (CEMS).

## IN-STACK METHOD TESTS

Total particulate, PM10 and PM2.5 filterable at stack temperature were determined using in-stack methods. CPM, defined as the material collected in chilled impingers, also was measured for the in-stack samples. Ammonia and formaldehyde were measured using different sampling trains and methods described below.

### In-Stack Total Filterable PM, PM10 and PM2.5

EPA Preliminary Method PRE-4 was used to measure total PM, PM10 and PM2.5. The method uses two in-stack cyclones (Andersen Model Case-PM10 and Case-PM2.5), the first with a cut

Table 3-1. Summary of Test Procedures.

| Sampling Location | Measurements | Sampling Approach | Sample Analyses | Reference |
|---|---|---|---|---|
| Stack | Total PM, PM10, PM2.5 and composition | In-stack series cyclones and filter | Mass; organic species | U.S. EPA Method PRE-4 (preliminary method) |
| | Condensable PM and composition | Impingers | Mass (organic and inorganic), sulfate, chloride, nitrate, ammonium, elements | U.S. EPA Method 202 |
| | Ammonia | Acid impingers | Ammonia | BAAQMD ST-1B; SCAQMD 207.1 |
| | Formaldehyde | Midget impinger train | Formaldehyde | Celanese Method (Gas Technology Institute) |
| | PM2.5 mass and chemical composition | Dilution tunnel and filters | Mass, organic carbon (OC), elemental carbon (EC), elements, sulfate, nitrate, chloride, ammonium | U.S. EPA, 1999a; Hildemann et al., 1989 |
| | Gaseous PM2.5 precursors | Dilution tunnel and $K_2CO_3$-impregnated cellulose-fiber filter | Ammonia | Chow and Watson, 1998 |
| | Gaseous PM2.5 precursors | Dilution tunnel and citric acid-impregnated cellulose-fiber filter | Sulfur dioxide | Chow and Watson, 1998 |
| | VOC | Dilution tunnel and Tenax | Speciated VOC (C7 and greater | Zielinska et al., 1996; Hildemann et al., 1989 |
| | VOC | Dilution tunnel and stainless steel canisters | Speciated VOC (C2 and greater) | US EPA Method TO-15 |
| | Carbonyls (aldehydes) | Dilution tunnel and DNPH-coated silica gel cartridges | Formaldehyde and other carbonyls | UP EPA Method TO-11A |
| | SVOC | Dilution tunnel and filter/PUF/XAD-4/PUF | Speciated SVOC | U.S. EPA Method TO-13; Hildemann et al., 1989 |
| Turbine air inlet – ambient air | PM2.5 and chemical composition | Filters | Mass, OC, EC, elements, chloride, sulfate, nitrate, ammonium | U.S. EPA, 1999a |
| | Gaseous PM2.5 precursors | Dilution tunnel and potassium carbonate-impregnated cellulose-fiber filter | Ammonia | Chow and Watson, 1998 |
| | Gaseous PM2.5 precursors | Dilution tunnel and citric acid-impregnated cellulose-fiber filter | Sulfur dioxide | Chow and Watson, 1998 |
| | VOC | Dilution tunnel and Tenax | Speciated VOC (C7 and greater | Zielinska et al., 1996; Hildemann et al., 1989 |
| | VOC | Dilution tunnel and stainless steel canisters | Speciated VOC (C2 and greater) | US EPA Method TO-15 |
| | Carbonyls (aldehydes) | Dilution tunnel and DNPH-coated silica gel cartridges | Formaldehyde and other carbonyls | UP EPA Method TO-11A |
| | SVOC | Dilution tunnel and filter/PUF/XAD-4/PUF | Speciated SVOC | U.S. EPA Method TO-13; Hildemann et al., 1989 |

| | Time | Turbine Stack | | | | | | Turbine Air Inlet |
|---|---|---|---|---|---|---|---|---|
| | | Velocity | Method PRE-4/202 | Method 17/8 | Celanese Method | BAAQMD ST-1B | Dilution Tunnel | Ambient Sample |
| 06-Sep-01 Thurs. | 8:00 | | | | | | | |
| | 9:00 | 9:30 | | | | | | |
| | 10:00 | | | | | | | |
| | 11:00 | | Run 1 | Run 1 | Run 1 | Run 1 | Run 1 | |
| | 12:00 | | 11:56 | 11:55 | 11:55 | 11:55 | 11:55 | |
| | 13:00 | | | | | | | |
| | 14:00 | | | | | | | |
| | 15:00 | | | | | | | |
| | 16:00 | | | | | | | |
| | 17:00 | | 17:56 | 17:55 | 17:55 | 17:55 | 17:55 | |
| | 18:00 | 18:15 | | | | | | |
| 07-Sep-01 Fri. | 8:00 | 8:49 | | | | | | |
| | 9:00 | | Run 2 | Run 2 | Run 2 | Run 2 | Run 2 | |
| | 10:00 | | 10:26 | 10:25 | 10:25 | 10:25 | 10:25 | |
| | 11:00 | | | | | | | |
| | 12:00 | | | | | | | |
| | 13:00 | | | | | | | |
| | 14:00 | | | | | | | |
| | 15:00 | | | | | | | |
| | 16:00 | | 16:26 | 16:25 | 16:25 | 16:25 | 16:25 | |
| | 17:00 | | | | | | | |
| 08-Sep-01 Sat. | 8:00 | 8:32 | Run 3 | Run 3 | Run 3 | Run 3 | Run 3 | |
| | 9:00 | | 9:11 | 9:10 | 9:10 | 9:10 | 9:10 | |
| | 10:00 | | | | | | | |
| | 11:00 | | | | | | | |
| | 12:00 | | | | | | | |
| | 13:00 | | | | | | | |
| | 14:00 | | | | | | | |
| | 15:00 | 15:43 | 15:11 | 15:10 | 15:10 | 15:10 | 15:10 | |
| | 16:00 | | | | | | | |
| 09-Sep-01 Sun. | 8:00 | 8:22 | Run 4 | Run 4 | Run 4 | Run 4 | Run 4 | |
| | 9:00 | | 9:01 | 9:00 | 9:00 | 9:00 | 9:00 | |
| | 10:00 | | | | | | | |
| | 11:00 | | | | | | | |
| | 12:00 | | | | | | | |
| | 13:00 | | | | | | | |
| | 14:00 | | 15:01 | 15:00 | 15:00 | 15:00 | 15:00 | |
| | 15:00 | 15:45 | | | | | | |
| | 16:00 | | | | | | | |

Figure 3-1. Chronology for Natural Gas-Fired Turbine Tests (Site E).

| | Time | Turbine Stack | | | | | | Turbine Air Inlet |
|---|---|---|---|---|---|---|---|---|
| | | Velocity | Method PRE-4/202 | Method 17/8 | Celanese Method | BAAQMD ST-1B | Dilution Tunnel | Ambient Sample |
| 10-Sep-01 | 7:00 | | | | | | Tunnel Blank | |
| Mon. | 8:00 | | | | | | 8:50 | |
| | 9:00 | | | | | | | |
| | 10:00 | | | | | | | |
| | 11:00 | | | | | | | |
| | 12:00 | | | | | | | |
| | 13:00 | | | | | | | |
| | 14:00 | | | | | | 14:50 | |
| | 15:00 | | | | | | | |
| 11-Sep-01 | 8:00 | | | | | | | |
| Tues. | 9:00 | | | | | | | 9:58 |
| | 10:00 | | | | | | | |
| | 11:00 | | | | | | | |
| | 12:00 | | | | | | | |
| | 13:00 | | | | | | | |
| | 14:00 | | | | | | | |
| | 15:00 | | | | | | | 15:58 |
| | 16:00 | | | | | | | |

Figure 3-1. Chronology for Natural Gas-Fired Turbine Tests (Site E) (continued).

point of 10 microns and the second with a cut point of 2.5 microns, followed by an in-stack filter in series (Figure 3-2). The sampling time was six hours for each of the four runs. Sampling was performed as published except for the following modifications and clarifications:

- The sample was collected from a single traverse point near a point of average flow to preserve the integrity of the dilution tunnel method comparison. It is assumed that any particulate present is small enough to mix aerodynamically in the same manner as a gas; therefore, the magnitude of the particle concentration profile was assumed to be no greater than the gas concentration profile;

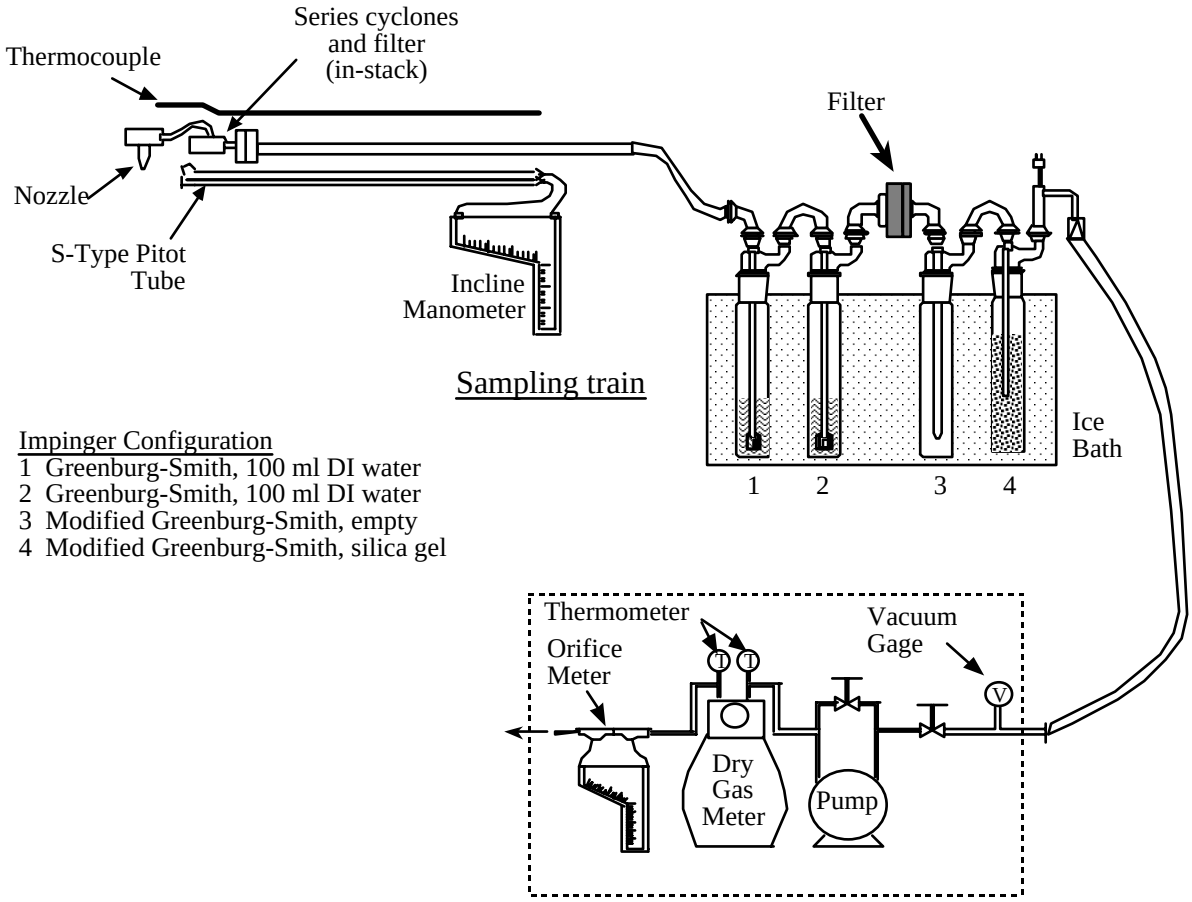
- A modified filter assembly was employed in an effort to improve the precision of the gravimetric analysis for low particulate concentration. An o-ring, a filter and a filter support are all placed together in an aluminum foil pouch and weighed as a unit. All three components are recovered together into the same foil pouch after sampling to prevent negative bias due to filter breakage.

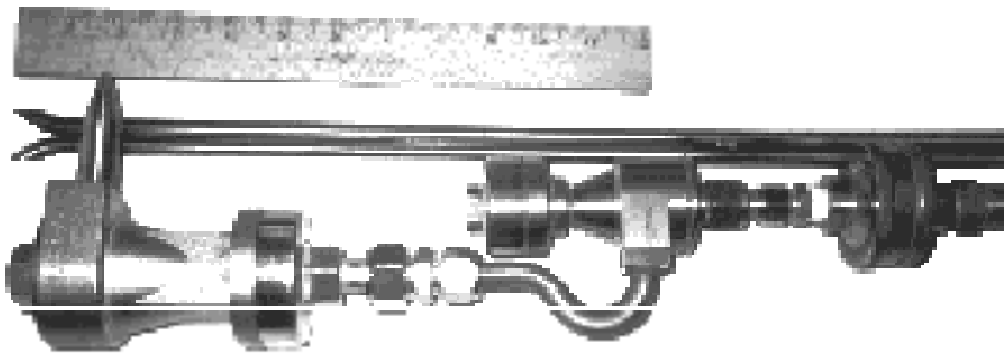
A second particulate train was run in order to compare CPM measured by two different methods: a modified EPA Method 8 train and EPA Method 202. The front half of the second train was performed in accordance with EPA Method 17, which uses an in-stack filter to determine total particulate emissions. The front-half of the second train was not analyzed except for Runs 3 and 4.

The particulate mass collected in the two cyclones and on the filter was determined gravimetrically. The quartz filters (Pallflex No. 51575) were weighed before and after testing on an analytical balance with a sensitivity of 10 micrograms. In an effort to improve the accuracy and precision of the gravimetric results, the filters, filter support and stainless steel O-ring seals were weighed together to minimize post-test loss of filter matter during sample recovery. Pre- and post-test weighing was performed after drying the filters in a dessicator for a minimum of 72 hours, then repeat weighings were performed at a minimum of six-hour intervals until constant weight was achieved. Probe and cyclone acetone rinses were recovered in glass sample jars for storage and shipment, then transferred to tared beakers for evaporation and weighing. Acetone and filter blanks also were collected and analyzed. See Section 4 for discussion of data treatment.

Condensable Particulate Matter Mass and Chemical Analysis

EPA Method 202 CPM was determined using EPA Method 202; total sampling time was six hours for all runs. After the in-stack filter, the sample passed through a heated Teflon line to a series of four impingers placed in the ice bath used for the Method PRE-4 train. Impingers 1 and 2 were standard Greenburg-Smith impingers containing DI water; the third was a modified Greenburg-Smith impinger containing DI water; the fourth was an empty modified Greenburg-Smith impinger; and the fifth contained silica gel. A quartz filter was placed between the third and fourth impingers to improve capture efficiency for any aerosols that may have passed the first three impingers. The impinger train was purged with nitrogen for one hour at the conclusion of each test run. The purge is performed in an attempt to eliminate dissolved $SO_2$. The contents of the impinger train were recovered with distilled deionized (DI) water and dichloromethane.



Series cyclone and filter assembly

Figure 3-2. PM10/PM2.5 Train Configuration for Method PRE-4/202.

Previous tests (England et al., 2000) have found that a majority of the particulate matter emissions from gas-fired sources consisted of condensable matter. To obtain an optimal understanding of the composition of the material collected in the impingers, additional analysis of the inorganic CPM residue was performed to more fully speciate its constituents. The inorganic residue was resuspended in DI water and analyzed for anions and cations (bromide, chloride, fluoride, nitrate, phosphate and sulfate) by ion chromatography, for ammonium by colorimetry, and for metals by digesting the sample in acid and analyzing by ICP/MS. Figure 3-3 illustrates the Method 202 analytical procedure and additional analyses performed.

EPA Method 8 (modified) CPM was also determined by EPA Method 8, which uses a four-impinger train. In the standard form of the method, impinger 1 contains isopropanol (IPA)to capture sulfuric acid mist; impingers 2 and 3 contain hydrogen peroxide to capture sulfur dioxide and impinger 4 contains silica gel. An additional IPA impinger was added between impingers 1 and 2 to account for moisture collection during the long sample run. A filter was placed behind the second IPA impinger and analyzed for sulfate content. Sampling was isokinetic for six hours at 0.4 cfm (to match the sample flow rate of the PRE-4/202 train). A 15 minute purge with ambient air at the average flow rate for the test was performed after sampling was completed. The contents of the IPA impinger and probe rinse were dried and weighed to determine CPM mass. The residue was then resuspended with DI water and analyzed by barium thorin titration to determine sulfate content. The contents of the peroxide impingers were also analyzed using barium thorin titration to perform a sulfur mass balance.

Ammonia

Concentrations of ammonia were measured using Bay Area Air Quality Management District (BAAQMD) Method ST-1B. In this method, a gas sample is withdrawn from the stack through a glass probe and collected in a Greenburg-Smith impinger train. The sampling train consists of four impingers connected in series. The first and second impingers contain 0.1N hydrochloric acid (HCl), the third impinger is empty, and the fourth impinger contains a weighed amount of silica gel. Ammonia in the sampled gas is collected in the impingers and in rinses of the sample probe and connecting glassware. Sampling occurred for six hours at a constant rate of 0.5 cfm.

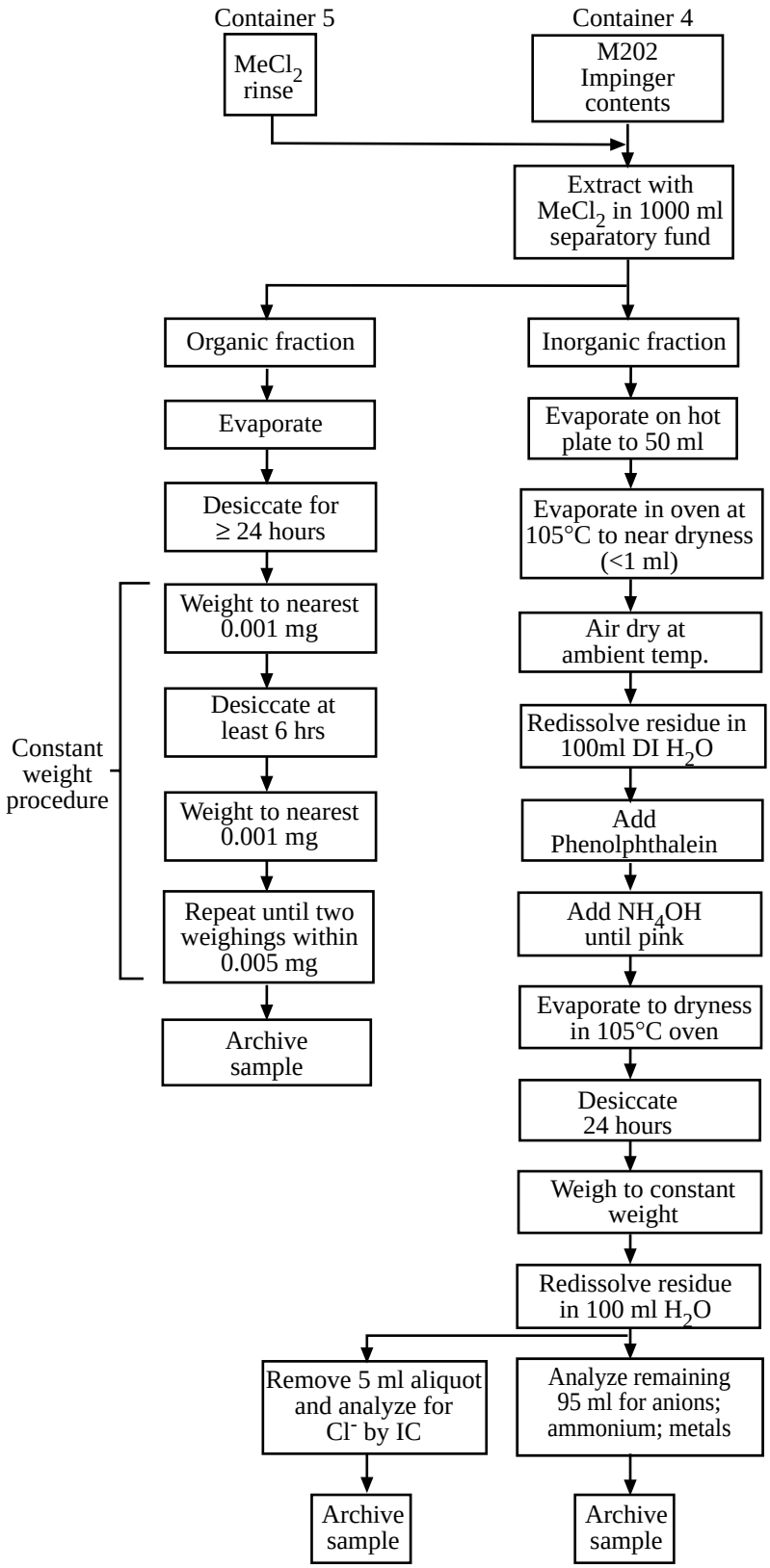



Figure 3-3. Modified Method 202 Sample Analysis Procedure.

After the test, the train was purged for five minutes with ambient air. The recovery of the sampling train was performed on-site to reduce the probability of sample loss during shipment. During this recovery, all the impinger catches and glassware rinses were collected into a single bottle. Ammonia content is determined by ion selective electrode.

Formaldehyde

Formaldehyde in the stack gas was determined by the Celanese method. This method uses a midget impinger train. An empty moisture knockout impinger is followed by an impinger containing organic free water in an ice bath, and a silica gel impinger to remove moisture. Sample runs were six hours long at a constant sample rate of 0.2 to 0.4 L/min. Samples were analyzed by acetylacetone derivitization and spectrophotometry, with an additional analysis by HPLC to achieve lower detection limits.

DILUTION TUNNEL TESTS

PM2.5 mass and chemical speciation in the stack gas was determined using a dilution tunnel (Figure 3-4). 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. The sample was transported through a heated copper line into the dilution tunnel. The sample was mixed in the tunnel 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 particulate matter and an activated carbon bed to remove gaseous organic compounds. After passing through a tunnel length equal to 10 tunnel 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 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 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 and TIGF/PUF/XAD-4/PUF cartridge). 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

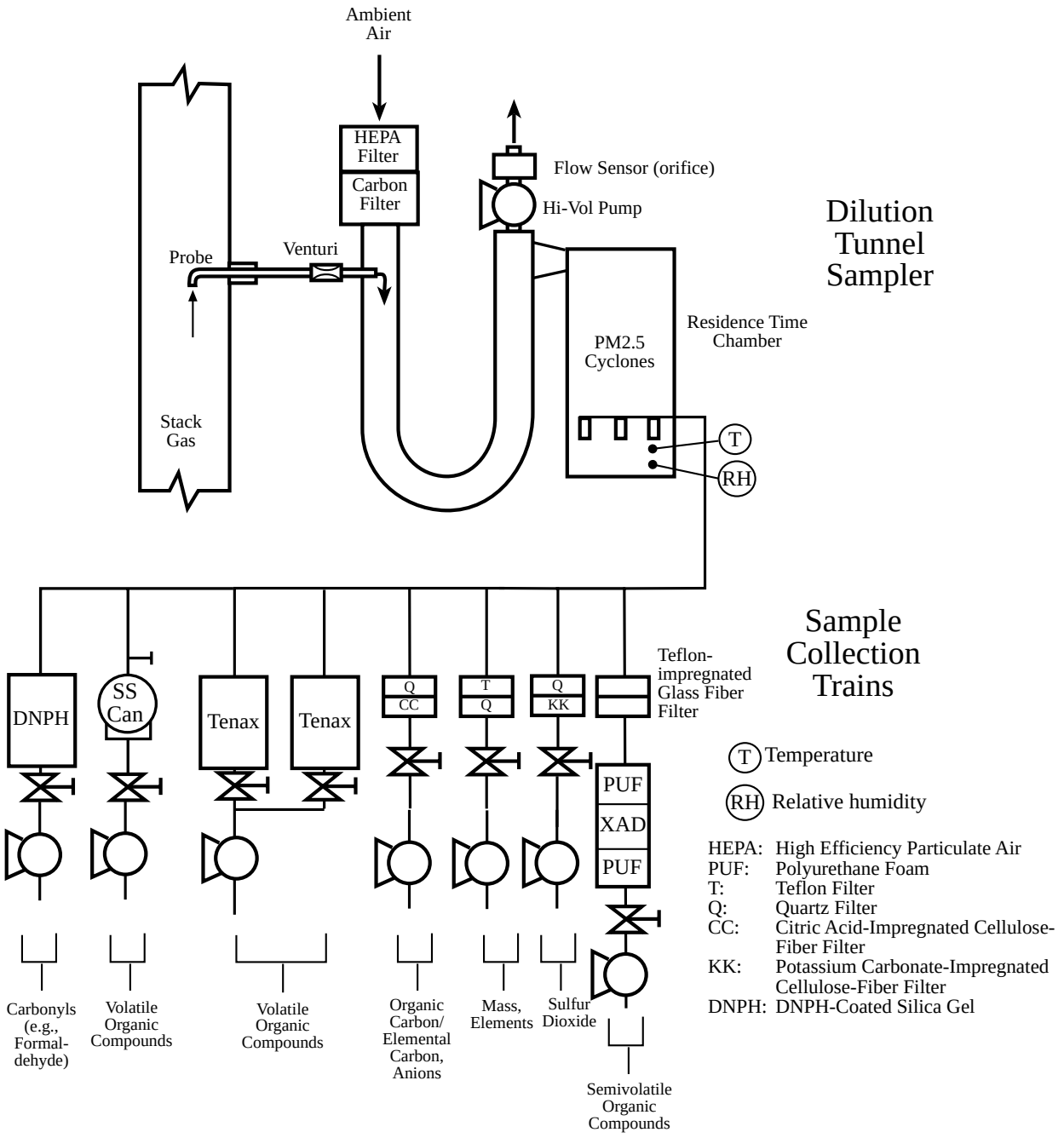



Figure 3-4. Dilution Tunnel Sampling System.

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 test run was six hours.

For these tests, flow rates were set in the field to achieve a target dilution ratio of approximately 20:1 to improve minimum detection limits since very low concentrations of the target substances were anticipated. The prior work of Hildemann et al. (1989) suggests that mixing between the sample and the dilution air begins to degrade at a dilution ratio of approximately 10:1.

A single ambient air sample was collected using the dilution tunnel. The dilution tunnel setup was modified by attaching a three-cyclone manifold (similar to the one inside the residence time chamber) directly to the sampling module. The ambient air sample was drawn into the module without dilution for a sampling period of six hours. The same sampling media were used as described below and in Figure 3-4.

PM2.5 Mass

Samples for PM2.5 mass measurements were collected on a 47-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 TSI mass flow meter (Model 4043). Weighing was performed on a Cahn 31 electro-microbalance with ± 1 microgram sensitivity.

Elements

Energy dispersive x-ray fluorescence (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, and Chloride

Samples for determining water-soluble $Cl^-$, nitrate ($NO_3^-$), and $SO_4^{=}$ were collected on quartz fiber filters. 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 TSI mass flow meter (Model 4043).

For analysis, each quartz-fiber filter was cut in half, and one filter half was placed in a polystyrene extraction vial with 15 ml of DI water. The remaining 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. The unanalyzed filter half was archived in the original petri slide.

$Cl^-$, $NO_3^-$, and $SO_4^=$ were measured with a Dionex 2020i ion chromatograph (IC). Approximately 2 ml of the filter extract was injected into the ion chromatograph.

Organic and Elemental Carbon

Quartz fiber filters 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°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 and 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.

Volatile Organic Compounds

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 liters per minute 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 spectrometric/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 tunnel 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 milliliters 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 (GC) 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 ECD, and the resultant peaks are quantified and recorded by an electronic integrator and by the chromatographic data system

Semivolatile Organic Compounds

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 liters per minute (lpm).

The samples were isotopically spiked, extracted in dichloromethane, and concentrated prior to analysis. Sample extracts were analyzed by the electron impact (EI) gas chromatography/mass spectrometric (GC/MS) technique, using a Hewlett-Packard 5890 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. Quantification of polycyclic aromatic hydrocarbons (PAH), and other compounds of interest, was obtained by multiple ion detection (MID).

Carbonyls (Aldehydes and Ketones)

Carbonyls in the sample gas were collected by drawing sample through a cartridge impregnated with acidified 2,4-dinitrophenylhydrazine (DNPH), which is very reactive with carbonyls. 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 air. Typically $C_1$-$C_6$ carbonyl compounds, including benzaldehyde, are measured effectively by this technique. The target flow rate used for this sample was 0.4 lpm.

Sulfur dioxide

Filter packs containing a quartz filter followed by a potassium carbonate impregnated cellulose-fiber filters were used to collect $SO_2$ gas downstream of the dilution tunnel. 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 ammonia gas downstream of the dilution tunnel. These filters were extracted with DI water and then analyzed using automated colorimetry.

# Section 4
# TEST RESULTS

All 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 and a standard pressure of 29.92 inches 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. The approximate minimum in-stack detection limits achieved for all measured substances are given in Table 4-1.

## PROCESS OPERATING CONDITIONS

Turbine operating conditions during testing are summarized in Table 4-2. The turbine operated at close to its normal firing rate corresponding to approximately 100 percent of full generator output (240 MW) for Runs 1 and 2. Runs 3 and 4 were performed on weekend days when power and steam demand were lower, and the unit operated at approximately 82-85 percent of capacity.

The average heat input to the turbine during the tests was obtained from the plant process data. The average heat input was used to convert in-stack emission rates (lb/hr) to emission factors (lb/MMBtu), which are presented in Section 5. Previous analyses of the natural gas indicate that there is no sulfur above detectable levels.

## PRELIMINARY TEST RESULTS

Preliminary tests were conducted to establish a single point in the stack for sample collection. A velocity profile was developed by traversing the stack with the pitot probe before and after each test run. The resulting average velocity profile was used to correct the velocities measured at the center during sampling to the overall stack average velocity.

Table 4-1. Approximate In-Stack Detection Limits Achieved for Gas Turbine Tests (Site E).

| 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 |
|---|---|---|---|---|---|---|---|---|
| Total PM mass | -- | 2.5E-03 | Sr | 1.1E-05 | J-trimethylnaphthalene | 4.3E-07 | 1-MeFl+C-MePy/Fl | 8.5E-07 |
| PM10 mass | -- | 2.5E-03 | Ti | 3.0E-05 | 1,4,5-trimethylnaphthalene | 5.0E-06 | B-MePy/MeFl | 5.3E-08 |
| PM2.5 mass | 8.1E-04 | 2.5E-03 | Tl | 2.6E-05 | Acenaphthylene | 5.5E-06 | C-MePy/MeFl | 5.3E-08 |
| Ag | 1.3E-04 | -- | U | 2.4E-05 | Acenaphthene | 1.4E-06 | D-MePy/MeFl | 5.3E-08 |
| Al | 1.0E-04 | -- | V | 2.6E-05 | Fluorene | 6.4E-06 | 4-methylpyrene | 1.1E-07 |
| As | 1.7E-05 | -- | Y | 1.4E-05 | Phenanthrene | 4.2E-07 | 1-methylpyrene | 4.2E-07 |
| Au | 3.2E-05 | -- | Zn | 1.1E-05 | A-methylfluorene | 5.6E-06 | Benzo(c)phenanthrene | 5.8E-07 |
| Ba | 5.4E-04 | -- | Zr | 1.8E-05 | 1-methylfluorene | 3.5E-06 | Benz(a)anthracene | 3.2E-07 |
| Br | 1.0E-05 | -- | SO4= | 1.2E-03 | B-methylfluorene | 3.5E-06 | 7-methylbenz(a)anthracene | 3.3E-07 |
| Ca | 4.7E-05 | -- | NO3- | 1.2E-03 | 9-fluorenone | 7.1E-06 | Chrysene | 1.1E-07 |
| Cd | 1.3E-04 | -- | NH4+ | 1.2E-03 | Xanthone | 2.1E-07 | Benzanthrone | 4.8E-07 |
| Cl | 1.0E-04 | -- | Cl- | 1.2E-03 | Acenaphthenequinone | 3.2E-07 | Benz(a)anthracene-7,12-dionene | 2.0E-06 |
| Co | 9.2E-06 | -- | OC | 9.3E-03 | Perinaphthenone | 5.2E-05 | 5+6-methylchrysene | 0.0E+00 |
| Cr | 2.0E-05 | -- | EC | 2.1E-03 | A-methylphenanthrene | 2.5E-06 | chryq14 | 0.0E+00 |
| Cu | 1.1E-05 | -- | Naphthalene | 5.1E-05 | 2-methylphenanthrene | 1.1E-07 | Benzo(b+j+k)fluoranthene | 5.3E-08 |
| Fe | 1.6E-05 | -- | 2-methylnaphthalene | 3.3E-06 | B-methylphenanthrene | 5.8E-07 | 7-methylbenzo(a)pyrene | 3.7E-07 |
| Ga | 2.0E-05 | -- | 1-methylnaphthalene | 2.0E-06 | C-methylphenanthrene | 1.5E-06 | Benzo(e)pyrene | 3.3E-07 |
| Hg | 2.7E-05 | -- | Biphenyl | 3.6E-06 | 1-methylphenanthrene | 1.2E-06 | Perylene | 1.1E-07 |
| In | 1.4E-04 | -- | 1+2-ethylnaphthalene | 6.8E-06 | Anthrone | 5.3E-08 | Benzo(a)pyrene | 3.2E-07 |
| K | 6.4E-05 | -- | 2,6+2,7-dimethylnaphthalene | 5.7E-06 | Anthraquinone | 2.9E-06 | Indeno[123-cd]pyrene | 3.2E-07 |
| La | 6.5E-04 | -- | 1,3+1,6+1,7-dimethylnaphthalene | 1.2E-05 | 2,3-Benzofluorene | 0.0E+00 | Benzo(ghi)perylene | 3.2E-07 |
| Mg | 8.1E-14 | -- | 1,4+1,5+2,3-dimethylnaphthalene | 5.4E-06 | 3,6-dimethylphenanthrene | 2.5E-06 | Dibenzo(ah+ac)anthracene | 3.2E-07 |
| Mn | 1.7E-05 | -- | 1,2-dimethylnaphthalene | 3.7E-06 | A-dimethylphenanthrene | 2.5E-06 | Coronene | 3.2E-07 |
| Mo | 2.8E-05 | -- | 2-Methylbiphenyl | 8.4E-06 | B-dimethylphenanthrene | 1.8E-06 | Dibenzo(ah+ac)anthracene | 3.2E-07 |
| Na | 8.1E-14 | -- | 3-Methylbiphenyl | 1.2E-05 | C-dimethylphenanthrene | 1.8E-06 | Coronene | 3.2E-07 |
| Ni | 9.3E-06 | -- | 4-Methylbiphenyl | 1.0E-06 | 1,7-dimethylphenanthrene | 1.8E-06 | Volatile Organic Compounds | 3.0E-02 |
| P | 5.8E-05 | -- | Dibenzofuran | 3.3E-06 | D-dimethylphenanthrene | 1.6E-06 | | |
| Pb | 3.1E-05 | -- | Bibenzyl | 1.3E-04 | E-dimethylphenanthrene | 8.0E-07 | | |
| Pd | 1.1E-04 | -- | A-trimethylnaphthalene | 1.0E-07 | Anthracene | 0.0E+00 | | |
| Rb | 1.0E-05 | -- | B-trimethylnaphthalene | 5.3E-08 | 9-methylanthracene | 2.4E-06 | | |
| S | 5.2E-05 | -- | C-trimethylnaphthalene | 4.2E-07 | Fluoranthene | 1.1E-07 | | |
| Sb | 1.9E-04 | -- | E-trimethylnaphthalene | 5.3E-08 | Pyrene | 2.1E-07 | | |
| Se | 1.3E-05 | -- | F-trimethylnaphthalene | 5.0E-08 | 9-Anthraldehyde | 1.4E-06 | | |
| Si | 6.6E-05 | -- | 2,3,5+I-trimethylnaphthalene | 1.6E-07 | Retene | 3.2E-06 | | |
| Sn | 1.8E-04 | -- | 2,4,5-trimethylnaphthalene | 4.2E-07 | Benzonaphthothiophene | 1.1E-07 | | |

Table 4-2. Process Operating Conditions (Site E).

| Parameter | Units | Run 1 | Run 2 | Run 3 | Run 4 |
|---|---|---|---|---|---|
| Date | dd-mmm-yy | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 |
| Start time | hh:mm | 11:55 | 10:25 | 9:10 | 9:00 |
| End time | hh:mm | 17:55 | 16:25 | 15:10 | 15:00 |
| Turbine fuel flow rate | lb/hr | 72.9 | 73.0 | 68.0 | 62.3 |
| Duct burner fuel flow rate* | lb/hr | 8.1 | 8.7 | 0.12 | 0.00 |
| Total fuel flow rate | lb/hr | 81.0 | 81.7 | 68.1 | 62.3 |
| Total fuel flow rate | scfm | 30,948 | 30,107 | 22,340 | 20,438 |
| Ambient temperature | °F | 73.9 | 71.1 | 62.8 | 62.6 |
| Gas turbine exit temperature | °F | 1,139 | 1,139 | 1,131 | 1,126 |
| Compressor inlet pressure | in. H2O | 3.55 | 3.56 | 3.24 | 2.96 |
| Compressor inlet temperature | °F | 63.0 | 62.2 | 63.0 | 63.1 |
| Barometric pressure | in. Hg | 29.8 | 29.8 | 29.8 | 29.8 |
| Compressor discharge pressure | psig | 212.7 | 213.6 | 196.3 | 185.5 |
| Humidity | lb H2O/lb air | 0.0128 | 0.0128 | 0.0128 | 0.0128 |
| Oxidation catalyst temperature | °F | 688 | 691 | 638 | 627 |
| Ammonia feed rate | lb/hr | 167 | 163 | 106 | 80 |
| Generator electrical output | MW | 244.3 | 245.5 | 206.1 | 196.6 |
| Stack $NO_x$ Concentration (dry, 15% $O_2$) | ppmv | 5.7 | 5.8 | 3.1 | 1.8 |
| Stack CO Concentration (dry, 15% $O_2$) | ppmv | 2.4 | 2.8 | 0.7 | 0.8 |
| Stack $O_2$ Concentration (dry, as measured) | %v | 12.5 | 12.4 | 13.8 | 13.9 |
| Gross heat input | MMBtu/hr | 1,906 | 1,921 | 1,602 | 1,465 |
| Process steam output flow | klb/hr | 295 | 261 | 85.2 | 7.84 |

* Duct burners were on for Runs 1 and 2, intermittent for Run 3 (total of approx. 30 minutes) and off for Run 4

## STACK GAS CONDITIONS AND FLOW RATE

A summary of the stack conditions during testing is presented in Table 4-3. Stack gas temperature during the tests averaged 206-236°F.

Table 4-3. Average Stack Conditions (Site E).

| Parameter | Units | Run 1 | Run 2 | Run 3 | Run 4 |
|---|---|---|---|---|---|
| Date | | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 |
| Stack Temperature | °F | 225 | 206 | 231 | 236 |
| Moisture | %v | 12.5 | 13.6 | 8.5 | 8.5 |
| Velocity | ft/s | 84 | 83 | 75 | 72 |
| | m/s | 25.6 | 25.3 | 22.9 | 21.9 |
| Flow Rate | acfm | 1,081,600 | 1,060,300 | 962,000 | 921,900 |
| | dscfm | 723,600 | 721,000 | 667,600 | 634,500 |
| | dscmm | 20,490 | 20,420 | 18,910 | 17,970 |

IN-STACK AND IMPINGER METHOD RESULTS

Particulate Mass

Filterable particulate matter (FPM). Filterable particulate matter (FPM) results as measured by Method PRE-4 and Method 17 are presented in Table 4-4. The rinse data have been blank corrected for the acetone reagent blank, which in some cases caused the net weight to become negative. These results are treated as non detects.

Table 4-4. Filterable Particulate Matter Results (Site E).

| Parameter | Units | Results | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | | 2 | | 3 | | 4 | | Average | | | RSD |
| Date | - | 6-Sep-01 | | 7-Sep-01 | | 8-Sep-01 | | 9-Sep-01 | | | | | |
| Total FPM | mg/dscm | < | 1.18 | < | 0.39 | < | 0.06 | < | 0.06 | < | 0.42 | | 126% |
| (by Method PRE-4) | lb/hr | < | 3.2 | < | 1.0 | < | 0.15 | < | 0.13 | < | 1.13 | | 128% |
| Total FPM | mg/dscm | NA | | NA | | | 0.48 | | 0.26 | | 0.37 | | 42% |
| (by Method 17) | lb/hr | | | | | | 1.2 | | 0.67 | | 0.95 | | 42% |
| FPM <10 µm | mg/dscm | < | 0.47 | < | 0.07 | < | 0.06 | ND | | < | 0.20 | | 117% |
| (by Method PRE-4) | lb/hr | < | 1.3 | < | 0.19 | < | 0.15 | ND | | < | 0.54 | | 119% |
| FPM <2.5 µm | mg/dscm | ND | | ND | | < | 0.06 | ND | | < | 0.06 | | n/a |
| (by Method PRE-4) | lb/hr | ND | | ND | | < | 0.15 | ND | | < | 0.15 | | n/a |

<-one or more, but not all, constituents are less than the detection limit
n/a - not applicable
ND - not detected
NA - not analyzed
RSD - relative standard deviation

Method PRE-4. Total FPM, which includes all particulate collected in the in-stack nozzle/cyclone assembly and on the in-stack filter, ranged from 0.06 to 1.18 mg/dscm. FPM < 10 micrometers, which includes the portion of total FPM collected downstream of the PM10 cyclone, was 0.06 to 0.47 mg/dscm. FPM < 2.5 micrometers, which includes the portion of FPM collected downstream of the PM2.5 cyclone and on the in-stack filter, was only present at levels above detection limits for one run after blank correction, at a level of 0.06 mg/dscm. These in-stack concentrations correspond to total weight gains in the sampling train of 0.2 to 4 milligrams (mg), with uncorrected net weights in each fraction of -0.8 to 4.8 mg. If negative weights were not set to zero after blank correction, total PM weight gains would range from –1.4 to 2.8 mg. This result reflects the

extremely low particulate loading in the stack and suggest that the particulate mass loading at the stack in these tests may be near or below the practical limits of the overall method.

Method 17. On average, the total FPM result obtained from Method 17 agrees well with the result from Method PRE-4 (0.37 mg/dscm versus 0.42 mg/dscm). However, Method 17 was only analyzed for two of the four runs, and the run-to-run agreement is poor, with the Method 17 result being four to eight times higher than the Method PRE-4 result. The agreement between the averages is most likely due to the high concentration obtained by Method PRE-4 for Run 1, when Method 17 was not analyzed.

Condensible Particulate Matter (CPM). Since there has been much comment on the most effective method of measuring CPM at the low levels encountered with gas-fired units, such as gas turbine, two separate trains were sampled simultaneously, as described in Section 3, with one being run according to Method 202 and the other according to Method 8. The results are summarized in Table 4-5.

Table 4-5. Condensible Particulate Matter (Method 202) Results (Site E).

| Parameter | Units | Value | | | | | |
|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | 2 | 3 | 4 | Average | RSD |
| Date | - | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | |
| Inorganic CPM (Method 202) | mg/dscm | 1.2 | 2.4 | 1.3 | 2.4 | 1.8 | 36% |
| | lb/hr | 3.2 | 6.4 | 3.3 | 5.7 | 4.6 | 35% |
| Organic CPM (Method 202) | mg/dscm | 0.39 | ND | ND | ND | < 0.39 | n/a |
| | lb/hr | 1.0 | ND | ND | ND | < 1.0 | n/a |
| Total CPM (Method 202) | mg/dscm | 1.7 | < 2.4 | < 1.3 | < 2.4 | < 2.0 | 28% |
| (corrected for $NH_4^+$ and $H_2O$) | lb/hr | 4.6 | < 6.5 | < 3.3 | < 5.8 | < 5.1 | 28% |
| Total CPM (Method 8) | mg/dscm | 1.7 | 1.7 | 0.87 | 1.7 | 1.5 | 26% |
| | lb/hr | 4.7 | 4.4 | 2.3 | 4.2 | 3.9 | 27% |
| Sulfate (as $SO_4^=$) in Impingers (Method 202) | mg/dscm | 1.1 | 1.1 | 0.76 | 0.99 | 0.99 | 16% |
| | lb/hr | 3.0 | 3.0 | 1.9 | 2.3 | 2.5 | 21% |
| Sulfate (as $SO_4^=$) in Impingers (Method 8) | mg/dscm | 1.2 | 1.1 | 0.79 | 1.1 | 1.0 | 17% |
| | lb/hr | 3.2 | 3.1 | 2.0 | 2.7 | 2.8 | 20% |

RSD-relative standard deviation
CPM-condensable particulate matter
<-one or more, but not all, constituents are less than the detection limit
n/a - not applicable

Method 202. The average total CPM, which is the sum of the evaporated organic extract (corrected for dichloromethane reagent blank), the inorganic residue (corrected for addition of $NH_4OH$ and water reagent blank) and the back-half filter, is 2.0 mg/dscm. The total inorganic CPM is 1.8 mg/dscm, 55 percent of which is accounted for by sulfate, with a concentration of 0.99 mg/dscm. This sulfate concentration is determined from the aliquot taken from the impinger catch and rinse before it is extracted with the organic solvent. The average organic CPM concentration is 0.39 mg/dscm, with three of the four runs being below detection limits. This result is lower than previous tests on a gas-fired boiler and gas-fired steam generator that had organic CPM concentrations of 0.6 and 0.8 mg/dscm, respectively.

CPM concentration was approximately 33 times greater than FPM2.5 on average. On average, approximately 91 percent of the CPM was found in the inorganic fraction, while 6 percent was found in the organic fraction; the remaining mass is accounted for in the impinger filter that is not speciated. The inorganic CPM results are somewhat variable from run to run, with a standard deviation equal to 36 percent of the average result; organic CPM was only found at detectable levels in one run. CPM results have been corrected for dichloromethane and water recovery blank results. The inorganic CPM data are also corrected for ammonium ion retained and combined water released in the acid base titration, as described in Method 202. Further discussion of the data is provided in Section 7.

Method 8. This method does not differentiate between organic and inorganic CPM. The average total CPM concentration is 1.5 mg/dscm, approximately equal to that determined from the Method 202 Train. The concentration of sulfate is comparable between the two different methods. However, a larger percentage of the CPM in the Method 8 train is accounted for by the sulfate number, indicating that the Method 202 train is capturing something that the Method 8 train does not. This result indicates that the methods, when performed as indicated in this report, may give equivalent results.

Additionally, the resuspended inorganic residues of the Method 202 train was analyzed for a broader range of elements and ions in order to more fully speciate the inorganic CPM. These results are presented in Table 4-6; the results have been corrected by subtracting the reagent blank, adjusted for relative volume. Sulfate, chloride, ammonium, sodium, and calcium are the five most abundant compounds in the inorganic CPM fraction. $SO_4^{=}$, Na, $Cl^-$, $NH_4^+$, and Ca account for an average of 1.3 mg/dscm, or 74 percent, of the inorganic CPM mass as presented in Table 4-5. The remaining elements that were detected account for an average of 0.004 mg/dscm, or 0.2 percent, of the average inorganic CPM mass. Agreement between the speciated mass and the gravimetric number is good; the sum of species accounts for approximately 75 percent of the inorganic CPM mass, on average. The high percentages of Na and Cl are indicative of the coastal location of the turbine. The additional analysis also confirms that $SO_4^{=}$ is the dominant compound in the inorganic residue; it is believed the majority of $SO_4^{=}$ found in the impinger contents is an artifact resulting from gaseous $SO_2$ in the stack gas. These results and issues are discussed in more detail in Section 7.

Table 4-6. Speciation (mg/dscm) of Method 202 Back-Half Impinger Catch (Site E).

| | Run 1 | Run 2 | Run 3 | Run 4 | Average | RSD |
|---|---|---|---|---|---|---|
| Cl- | ND | 4.52E-1 | ND | 2.46E-1 | < 3.49E-1 | 42% |
| SO4= | 1.07E+0 | 1.08E+0 | 7.38E-1 | 9.69E-1 | 9.65E-1 | 16% |
| NH4+ | 7.42E-2 | 4.07E-1 | 3.10E-2 | 1.92E-1 | 1.76E-1 | 96% |
| Ba | 6.58E-5 | 4.50E-5 | 3.19E-5 | 4.62E-5 | 4.72E-5 | 30% |
| Ca | ND | ND | ND | 5.03E-3 | < 5.03E-3 | n/a |
| Mn | 7.30E-4 | 1.23E-4 | 3.43E-4 | 5.26E-5 | 3.12E-4 | 98% |
| Na | ND | ND | ND | 2.88E-2 | < 2.88E-2 | n/a |
| Sr | ND | ND | 2.44E-4 | 3.20E-4 | < 2.82E-4 | 19% |
| Zn | 2.13E-4 | 3.50E-3 | 3.44E-3 | 4.88E-3 | 3.01E-3 | 66% |

< - one or more blank corrected values less than zero
n/a-not applicable; two or more runs not detected
ND - blank corrected value less than zero

## DILUTION TUNNEL RESULTS

### Particulate Mass

PM2.5 mass measurements using the dilution tunnel include both solid aerosols that are directly emitted and those that condense under simulated stack plume conditions in the residence chamber. The dilution tunnel determines only the PM2.5 fraction of particulate emissions.

Results from these measurements show that PM2.5 concentrations and emission rates average 0.12 mg/dscm and 0.32 lb/hr, respectively, with a relative standard deviation of 104 percent, based on Teflon filter weight (Table 4-7). The filter weight for Run 4 was negative and is flagged as not detected. These results are approximately 17 times lower than the sum of FPM2.5 and CPM measured by EPA Methods PRE-4 and 202. PM2.5 concentration measured in the turbine stack gas was approximately five times higher than the concentration measured in the ambient air.

Table 4-7. Dilution Tunnel PM2.5 Results (Site E).

| | Units | Results | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | - | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| PM2.5 | mg/dscm | 0.074 | 0.26 | 0.023 | ND | 0.12 | 104% | 0.025 |
| | lb/hr | 0.20 | 0.70 | 0.058 | ND | 0.32 | 105% | n/a |

n/a-not applicable
RSD- Relative standard deviation

The concentration of PM2.5 using the dilution tunnel is an two times higher than FPM <2.5 micrometers measured using Method PRE-4 and almost 33 times lower than CPM measured using Method 202. CPM is normally included in regulatory definitions of PM10. These emission measurements are strongly method dependent because the dilution tunnel replicates conditions experienced by the stack emissions as they mix with the atmosphere more accurately than Method 202. Due to suspected artifacts associated with Method 202, it is believed the dilution tunnel results are more representative of the true primary PM2.5 emissions.

Sulfate, Nitrate, Chloride, Ammonium and Soluble Sodium

Quartz filters were analyzed for $SO_4^{=}$, $Cl^-$, $NO_3^-$, $NH_4^+$ and $Na^+$ ion. Of these, $NO_3^-$ had the highest average concentration at 0.01 mg/dscm, followed by $SO_4^{=}$ at 0.008 mg/dscm (Table 4-8). The Teflon filter for PM2.5 mass had a negative net weight, therefore the results from the chemical speciation of the PM2.5 are invalidated and flagged “NV” in the table. All ions in the field blank were present below detectable levels (see Section 6 for additional discussion of blanks).

Table 4-8. Dilution Tunnel Sulfate, Nitrate, and Chloride Results (Site E).

| Parameter | Units | Value | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | - | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| Sulfate | mg/dscm | 3.2E-3 | 2.0E-2 | 1.9E-3 | NV | 8.4E-3 | 122% | 2.1E-3 |
| | lb/hr | 8.6E-3 | 5.5E-2 | 4.6E-3 | NV | 2.3E-2 | 123% | n/a |
| Nitrate | mg/dscm | 3.6E-3 | 2.6E-2 | 1.7E-3 | NV | 1.0E-2 | 129% | 2.1E-3 |
| | lb/hr | 9.8E-3 | 7.0E-2 | 4.2E-3 | NV | 2.8E-2 | 130% | n/a |
| Chloride | mg/dscm | 4.3E-3 | 1.5E-2 | 1.7E-3 | NV | 6.9E-3 | 100% | 8.1E-4 |
| | lb/hr | 1.2E-2 | 4.0E-2 | 4.3E-3 | NV | 1.9E-2 | 101% | n/a |
| Ammonium | mg/dscm | ND | 5.2E-3 | ND | NV | 5.2E-3 | n/a | 4.9E-4 |
| | lb/hr | ND | 4.1E-2 | ND | NV | 4.1E-2 | n/a | n/a |
| Soluble Na | mg/dscm | 2.3E-4 | 1.0E-3 | 2.3E-4 | NV | 4.9E-4 | n/a | 8.3E-5 |
| | lb/hr | 6.4E-4 | 2.8E-3 | 5.7E-4 | NV | 1.3E-3 | n/a | n/a |

n/a - not applicable
ND - not detected
RSD- Relative standard deviation
NV - not valid; the filter weight was negative, invalidating the other analyses

The quartz filters used for these measurements have the potential for a positive $SO_4^=$ bias. The average $SO_4^=$ concentration from the dilution tunnel is more than two orders of magnitude lower than the average concentration reported above for Method 202. This difference lends further support to the possibility of a significant sampling artifact in Method 202 due to gaseous $SO_2$ in the stack gas. Concentrations of nitrate, sulfate, soluble sodium and chloride measured in the stack gas are within an order of magnitude of the concentrations measured in the ambient air.

OC, EC and Organic Species

OC and EC were measured on quartz filters from the dilution tunnel. OC concentration ranged from 0.055 to 0.13 mg/dscm. EC was detected at concentrations of 0.0064 and 0.011 mg/dscm (Table 4-9). The Teflon filter for PM2.5 mass had a negative net weight, therefore the results from the chemical speciation of the PM2.5 are invalidated and flagged "NV" in the table. OC accounts for approximately 95 percent of the total carbon mass. Average elemental carbon concentrations measured in the stack gas are an order of magnitude greater than the ambient sample concentration; the average OC concentration is slightly more than an order of magnitude greater than the ambient concentration. Organic and elemental carbon were below detection limits in the field blank (see Section 6 for additional discussion of blank results).

Table 4-9. OC/EC as Measured by the Dilution Tunnel (Site E).

| Parameter | Units | Value | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | - | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| Organic Carbon | mg/dscm | 0.13 | 0.10 | 0.055 | NV | 0.095 | 39% | 0.0086 |
| | lb/hr | 0.35 | 0.28 | 0.14 | NV | 0.25 | 42% | n/a |
| Elemental Carbon | mg/dscm | 0.0064 | 0.011 | ND | NV | 0.0088 | 39% | 0.00088 |
| | lb/hr | 0.017 | 0.030 | ND | NV | 0.024 | 38% | n/a |
| Total Carbon | mg/dscm | 0.13 | 0.11 | 0.055 | NV | 0.10 | 40% | 0.010 |
| | lb/hr | 0.36 | 0.31 | 0.14 | NV | 0.27 | 43% | n/a |

SVOCs. SVOCs were determined on the combined TIGF/PUF/XAD-4/PUF cartridge used with the dilution tunnel. This method determines both particulate and vapor phase SVOCs together. Results of the stack emissions and ambient air sample are presented in Table 4-10. 1,4+1,5+2,3-dimethylnaphthalene is the most abundant SVOC in the dilution tunnel samples with an average concentration of 0.0012 mg/dscm. Approximately fifty percent of the SVOC compounds at detectable levels in the stack gas are within a factor of ten of their concentration in the ambient air. Anthracene is present at detectable levels in only one run at a concentration less than the ambient air.

VOCs - Tenax. Tenax sorbent was used to collect VOCs. The analysis of Tenax focused only on VOCs with a carbon number greater than seven since these are believed to be the most significant precursors for secondary organic aerosols. The wrong channel was sampled during Run 1, causing the samples to be invalid for Run 1. A backup sample was used for Run 2 and the ambient sample, so the results in the table for those samples are the sum of the concentration in the front and backup tubes. Hexadecanoic acid was the most abundant VOC detected during sampling, with an average concentration of 0.15 mg/dscm (Table 4-11). Benzaldehyde was the second most abundant, but can come from the Tenax sorbent if there is something in the sample which causes the Tenax material to disintegrate (for example, ozone or some acids). In general, the average VOC concentration in the stack gas was within a factor of approximately three to thirty times the ambient air concentration. Concentrations of ethylbenzene, m & p xylenes and nonane in the field samples were all approximately equal to concentrations in the ambient sample.

Table 4-10. Semi-Volatile Organic Compound (SVOC) Results (mg/dscm) (Site E).

| Parameter | Value | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run Number | 1 | 2 | 3 | 4 | Average | RSD | Ambient | MDL |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | (%) | 11-Sep-01 | |
| 1,4+1,5+2,3-dimethylnaphthalene | 1.9E-3 | 4.1E-4 | ND | ND | 1.2E-3 | 91 | 1.9E-5 | 1.2E-4 |
| 2-methylnaphthalene | 2.0E-4 | 8.0E-4 | ND | ND | 5.0E-4 | 86 | 1.9E-4 | 7.4E-5 |
| Acenaphthene | 6.8E-4 | 1.9E-4 | ND | ND | 4.3E-4 | 81 | 7.7E-5 | 3.0E-5 |
| 1,3+1,6+1,7-dimethylnaphthalene | ND | 3.7E-4 | ND | ND | 3.7E-4 | n/a | 6.5E-5 | 2.7E-4 |
| 1+2-ethylnaphthalene | 3.4E-4 | 3.8E-4 | 2.7E-4 | 3.0E-4 | 3.2E-4 | 14 | 2.9E-5 | 1.5E-4 |
| Phenanthrene | 4.8E-4 | 6.2E-4 | 4.7E-5 | 5.6E-5 | 3.0E-4 | 98 | 1.3E-4 | 9.3E-6 |
| Dibenzofuran | ND | 2.8E-4 | ND | ND | 2.8E-4 | n/a | 6.1E-5 | 7.2E-5 |
| 1-methylnaphthalene | 1.2E-4 | 4.3E-4 | ND | ND | 2.7E-4 | 81 | 8.8E-5 | 4.4E-5 |
| 2,6+2,7-dimethylnaphthalene | ND | 2.1E-4 | ND | ND | 2.1E-4 | n/a | 3.9E-5 | 1.2E-4 |
| Fluorene | ND | 1.7E-4 | ND | ND | 1.7E-4 | n/a | 4.3E-5 | 1.4E-4 |
| E-dimethylphenanthrene | ND | ND | ND | 1.6E-4 | 1.6E-4 | n/a | ND | 1.8E-5 |
| Biphenyl | ND | 1.6E-4 | ND | ND | 1.6E-4 | n/a | 3.6E-5 | 7.8E-5 |
| 2,3,5+I-trimethylnaphthalene | ND | ND | ND | 1.2E-4 | 1.2E-4 | n/a | 6.6E-6 | 3.5E-6 |
| Xanthone | 1.5E-5 | 2.2E-4 | ND | ND | 1.2E-4 | 124 | 1.9E-6 | 4.7E-6 |
| C-methylphenanthrene | 1.1E-4 | ND | ND | ND | 1.1E-4 | n/a | 3.6E-6 | 3.3E-5 |
| C-dimethylphenanthrene | 9.8E-5 | ND | ND | ND | 9.8E-5 | n/a | 3.9E-6 | 3.9E-5 |
| Pyrene | 1.4E-4 | 3.1E-5 | ND | ND | 8.3E-5 | 88 | 6.7E-6 | 4.7E-6 |
| 7-methylbenzo(a)pyrene | 9.1E-5 | 5.4E-5 | 6.2E-5 | 1.0E-4 | 7.8E-5 | 31 | ND | 8.2E-6 |
| Fluoranthene | 7.6E-5 | 6.0E-5 | ND | ND | 6.8E-5 | 16 | 1.2E-5 | 2.3E-6 |
| A-trimethylnaphthalene | 7.1E-5 | 5.5E-5 | ND | ND | 6.3E-5 | 19 | 1.0E-5 | 2.2E-6 |
| C-trimethylnaphthalene | 5.8E-5 | 5.5E-5 | ND | ND | 5.7E-5 | 5 | 7.3E-6 | 9.3E-6 |
| 1-methylphenanthrene | 5.3E-5 | ND | ND | ND | 5.3E-5 | n/a | 3.0E-6 | 2.6E-5 |
| 2-methylphenanthrene | 1.6E-4 | 3.2E-5 | 4.8E-6 | 2.4E-6 | 4.9E-5 | 149 | 1.1E-5 | 2.3E-6 |
| 7-methylbenz(a)anthracene | 1.5E-5 | 5.7E-5 | ND | ND | 3.6E-5 | 84 | ND | 7.2E-6 |
| B-trimethylnaphthalene | 3.6E-5 | 3.5E-5 | ND | ND | 3.6E-5 | 2 | 8.0E-6 | 1.2E-6 |
| 4-methylpyrene | 2.9E-5 | ND | ND | ND | 2.9E-5 | n/a | ND | 2.3E-6 |
| E-trimethylnaphthalene | 2.7E-5 | 1.8E-5 | ND | ND | 2.3E-5 | 28 | 4.7E-6 | 1.2E-6 |
| F-trimethylnaphthalene | 2.2E-5 | 2.0E-5 | ND | ND | 2.1E-5 | 7 | 4.8E-6 | 1.1E-6 |
| D-MePy/MeFl | 5.6E-5 | 1.5E-5 | 4.8E-6 | 6.3E-6 | 2.1E-5 | 117 | 8.1E-7 | 1.2E-6 |
| Anthrone | 3.1E-5 | 1.2E-5 | 1.7E-5 | 1.2E-5 | 1.8E-5 | 51 | 3.0E-7 | 1.2E-6 |
| C-MePy/MeFl | ND | 2.3E-6 | ND | ND | 2.3E-6 | n/a | ND | 1.2E-6 |
| Anthracene | 5.6E-7 | ND | ND | ND | 5.6E-7 | n/a | 6.4E-6 | 0.0E+0 |
| Naphthalene | ND | ND | ND | ND | ND | n/a | 2.1E-4 | 1.1E-3 |
| 1,2-dimethylnaphthalene | ND | ND | ND | ND | ND | n/a | 6.3E-6 | 8.1E-5 |
| A-methylfluorene | ND | ND | ND | ND | ND | n/a | 5.9E-6 | 1.2E-4 |
| 1,4,5-trimethylnaphthalene | ND | ND | ND | ND | ND | n/a | 5.6E-6 | 1.1E-4 |
| A-methylphenanthrene | ND | ND | ND | ND | ND | n/a | 5.5E-6 | 5.6E-5 |
| 2,4,5-trimethylnaphthalene | ND | ND | ND | ND | ND | n/a | 1.8E-6 | 9.3E-6 |
| J-trimethylnaphthalene | ND | ND | ND | ND | ND | n/a | 1.5E-6 | 9.4E-6 |
| B-methylphenanthrene | ND | ND | ND | ND | ND | n/a | 6.4E-7 | 1.3E-5 |
| Acenaphthenequinone | ND | ND | ND | ND | ND | n/a | 5.4E-7 | 7.0E-6 |
| 7-methylbenzo(a)pyrene | ND | ND | ND | ND | ND | n/a | 1.6E-6 | 8.2E-6 |
| Benzo(c)phenanthrene | ND | ND | ND | ND | ND | n/a | 8.1E-7 | 1.3E-5 |
| Xanthone | ND | ND | ND | ND | ND | n/a | 7.6E-7 | 4.7E-6 |

n/a- not applicable; only one run within detectable limits.
ND- Not detected
MDL- Method detection limit
RSD- Relative standard deviation

Table 4-11. Volatile Organic Compound (VOC) Results from Tenax (Site E).

| Parameter | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| Units | mg/dscm | | | | | % | mg/dscm |
| Run Number | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| Hexadecanoic acid | NV | 3.1E-1 | 1.3E-1 | 2.0E-2 | 1.5E-1 | 94 | 1.1E-2 |
| Benzaldehyde | NV | 1.3E-1 | 4.3E-2 | 2.8E-2 | 6.8E-2 | 83 | 3.9E-3 |
| Nonanal | NV | ND | 2.3E-2 | 2.6E-2 | 2.4E-2 | 10 | ND |
| Acetophenone | NV | 3.9E-2 | 1.6E-2 | 1.3E-2 | 2.3E-2 | 63 | 1.1E-3 |
| Decanal | NV | < 2.8E-2 | 1.7E-2 | ND | 2.3E-2 | 34 | 6.1E-4 |
| Styrene | NV | 4.5E-2 | 1.4E-2 | 7.4E-3 | 2.2E-2 | 91 | 6.7E-4 |
| Pentadecane | NV | 3.6E-2 | 1.2E-2 | 9.1E-3 | 1.9E-2 | 77 | 1.3E-3 |
| Heptadecane | NV | < 3.9E-2 | 2.7E-3 | 1.5E-3 | 1.4E-2 | 148 | 1.6E-4 |
| Dodecane | NV | 3.0E-2 | 7.3E-3 | 5.5E-3 | 1.4E-2 | 96 | 9.1E-4 |
| Tetradecane | NV | 2.5E-2 | 8.3E-3 | 5.4E-3 | 1.3E-2 | 82 | 6.7E-4 |
| Phenol | NV | 2.3E-2 | 8.8E-3 | 6.6E-3 | 1.3E-2 | 68 | 5.2E-4 |
| Cyclohexanone | NV | < 1.2E-2 | ND | ND | 1.2E-2 | n/a | 7.7E-4 |
| Hexadecane | NV | < 2.6E-2 | 4.3E-3 | 2.9E-3 | 1.1E-2 | 117 | 2.5E-4 |
| Decane | NV | 2.2E-2 | 6.0E-3 | 4.3E-3 | 1.1E-2 | 92 | 1.8E-3 |
| m&p-xylene | NV | 1.7E-2 | 4.5E-3 | 2.3E-3 | 8.0E-3 | 101 | 6.0E-3 |
| Butyl acetate | NV | < 7.8E-3 | ND | ND | 7.8E-3 | n/a | ND |
| Octadecane | NV | < 2.0E-2 | 1.7E-3 | 6.1E-4 | 7.3E-3 | 146 | 6.8E-5 |
| p-isopropyltoluene | NV | < 1.5E-2 | 3.3E-3 | 2.2E-3 | 6.9E-3 | 105 | 3.4E-4 |
| Octanal | NV | < 8.2E-3 | 3.2E-3 | 7.2E-3 | 6.2E-3 | 43 | 3.7E-4 |
| 1-undecene | NV | < 6.7E-3 | 4.8E-3 | ND | 5.8E-3 | 23 | 2.3E-4 |
| Undecane | NV | 1.2E-2 | 1.9E-3 | 1.7E-3 | 5.2E-3 | 112 | 6.3E-4 |
| Nonane | NV | 1.1E-2 | 2.4E-3 | 2.0E-3 | 5.2E-3 | 99 | 3.1E-3 |
| 1-nonene | NV | 4.8E-3 | ND | ND | 4.8E-3 | n/a | 5.3E-5 |
| 1-decene | NV | < 4.8E-3 | ND | ND | 4.8E-3 | n/a | ND |
| Biphenyl | NV | 7.2E-3 | 1.8E-3 | 2.6E-3 | 3.9E-3 | 75 | 1.9E-4 |
| Tridecane | NV | 7.3E-3 | 1.7E-3 | 1.0E-3 | 3.3E-3 | 103 | 3.6E-4 |
| Ethylbenzene | NV | 6.4E-3 | 1.8E-3 | 1.2E-3 | 3.1E-3 | 91 | 2.9E-3 |
| o-xylene | NV | 6.3E-3 | 1.6E-3 | 6.7E-4 | 2.8E-3 | 106 | 2.1E-3 |
| Dodecene | NV | ND | 1.9E-3 | 3.7E-3 | 2.8E-3 | 46 | ND |
| Nonadecane | NV | ND | 2.4E-3 | ND | 2.4E-3 | n/a | 2.9E-4 |
| 2-heptanone | NV | < 2.3E-3 | ND | ND | 2.3E-3 | n/a | 1.3E-4 |
| 1,2,4-trimethylbenzene | NV | < 4.9E-3 | 1.3E-3 | 6.9E-4 | 2.3E-3 | 99 | 5.5E-4 |
| 3-methyloctane | NV | < 3.1E-3 | 1.2E-3 | ND | 2.1E-3 | 60 | 4.8E-4 |
| Eicosane | NV | ND | 2.9E-3 | 1.3E-3 | 2.1E-3 | 55 | ND |
| Dimethyloctane | NV | 2.0E-3 | ND | ND | 2.0E-3 | n/a | 2.8E-4 |
| 1,3-dichlorobenzene | NV | < 1.9E-3 | ND | ND | 1.9E-3 | n/a | 6.5E-5 |
| 2,3-benzofuran | NV | < 1.9E-3 | ND | ND | 1.9E-3 | n/a | ND |
| Naphthalene | NV | 3.6E-3 | 1.1E-3 | 8.1E-4 | 1.8E-3 | 84 | 4.6E-4 |
| m-ethyltoluene | NV | < 3.6E-3 | 1.1E-3 | 6.3E-4 | 1.8E-3 | 88 | 4.7E-4 |
| (+/-)-limonene | NV | < 1.1E-3 | ND | ND | 1.1E-3 | n/a | 1.3E-4 |
| Propylbenzene | NV | 1.8E-3 | 3.5E-4 | ND | 1.1E-3 | 95 | 1.6E-4 |
| 2-methylnaphthalene | NV | < 1.6E-3 | 3.2E-4 | ND | 9.8E-4 | 95 | 2.0E-4 |
| 4-ethyl-o-xylene | NV | 9.9E-4 | 6.9E-4 | ND | 8.4E-4 | 25 | 1.3E-4 |
| 1,3,5-trimethylbenzene | NV | < 1.2E-3 | 3.9E-4 | ND | 8.2E-4 | 74 | 2.1E-4 |
| o-ethyltoluene | NV | < 1.3E-3 | 1.1E-4 | ND | 7.1E-4 | 120 | 1.5E-4 |
| 2-methyloctane | NV | < 9.7E-4 | 3.7E-4 | ND | 6.7E-4 | 64 | 2.6E-4 |
| Propylcyclohexane | NV | < 6.5E-4 | ND | ND | 6.5E-4 | n/a | 2.1E-4 |
| p-ethyltoluene | NV | < 9.0E-4 | 4.7E-4 | 3.0E-4 | 5.6E-4 | 56 | 1.7E-4 |
| 2,6+2,7-dimethylnaphthalene | NV | < 4.8E-4 | ND | ND | 4.8E-4 | n/a | ND |
| 2-n-propyltoluene | NV | < 4.4E-4 | ND | ND | 4.4E-4 | n/a | ND |
| 5-ethyl-m-xylene | NV | < 4.2E-4 | ND | ND | 4.2E-4 | n/a | 5.9E-5 |
| 1,2,3,5-tetramethylbenzene | NV | < 4.2E-4 | ND | ND | 4.2E-4 | n/a | 3.4E-5 |
| Indan | NV | < 3.9E-4 | ND | ND | 3.9E-4 | n/a | 7.8E-5 |
| 1-methylnaphthalene | NV | < 3.9E-4 | ND | ND | 3.9E-4 | n/a | 6.7E-5 |
| 4-tert-butyltoluene | NV | ND | 3.9E-4 | ND | 3.9E-4 | n/a | 4.4E-5 |
| Butylbenzene | NV | < 6.0E-4 | 6.5E-5 | ND | 3.3E-4 | 114 | 5.4E-5 |
| 1,2,3,4-tetramethylbenzene | NV | < 3.0E-4 | ND | ND | 3.0E-4 | n/a | ND |
| 1,3-diethylbenzene | NV | ND | 2.6E-4 | ND | 2.6E-4 | n/a | ND |
| 2-ethyl-p-xylene | NV | < 2.5E-4 | ND | ND | 2.5E-4 | n/a | ND |
| 1,2-diethylbenzene | NV | < 2.5E-4 | ND | ND | 2.5E-4 | n/a | 3.4E-5 |
| 1,2,4,5-tetramethylbenzene | NV | < 2.3E-4 | ND | ND | 2.3E-4 | n/a | ND |
| m-isopropyltoluene | NV | < 3.7E-4 | ND | 3.9E-5 | 2.0E-4 | 114 | 4.5E-5 |
| 1+2-ethylnaphthalene | NV | < 1.6E-4 | ND | ND | 1.6E-4 | n/a | ND |
| Isopropylbenzene | NV | < 1.6E-4 | ND | ND | 1.6E-4 | n/a | 5.5E-5 |
| 4-methylstyrene | NV | ND | ND | ND | ND | n/a | 5.7E-5 |
| 1-methylindan | NV | ND | ND | ND | ND | n/a | 4.7E-5 |
| Acenaphthylene | NV | ND | ND | ND | ND | n/a | 3.5E-5 |
| 1,2,3-trimethylbenzene | NV | ND | ND | ND | ND | n/a | 3.1E-5 |
| 1,6+1,3+1,7-dimethylnaphthalene | NV | ND | ND | ND | ND | n/a | 3.0E-5 |

n/a-not applicable. Less than two runs within detectable limits.
RSD-relative standard deviation.
ND-not detected.
< - one fraction less than detection limits

VOCs - Canisters. Stainless steel canisters were used to collect VOCs and the analysis of the sample obtained from the canisters allows for detection of organic species with carbon numbers as low as two. Results from the canister samples are presented in Table 4-12. Toluene and nonanal were the two highest detected compounds with concentrations of 0.53 mg/dscm and 0.22 mg/dscm respectively. All concentrations at detectable levels in the stack samples are at least three times larger than concentrations in the ambient sample, with most being at least an order of magnitude larger.

Elements

Element concentrations were determined by XRF analysis of the Teflon membrane filters used in the dilution tunnel. On average, Cl, Ag, Fe, Si, and S are the most abundant elements in the stack gas (Table 4-13). The Teflon filter for PM2.5 mass had a negative net weight, therefore the results from the chemical speciation of the PM2.5 are invalidated and flagged "NV" in the table. The S results are approximately a factor of three less than the dilution tunnel $SO_4^{=}$ results presented earlier, as expected based on relative molecular weights. Mg results are considered semi-quantitative because of analytical limitations. As, Au, Ba, Cd, Ga, Hg, In, La, Pd, Rb, Sb, Se, Sn, Tl, U and Y were below detectable levels for all sample runs. Most in-stack concentrations are between 5 and 35 times the concentrations in the ambient sample.

Carbonyls (Aldehydes and Ketones)

Dilution Tunnel. Aldehydes were captured in a DNPH-impregnated silica gel cartridge. Backup cartridges were in place during all runs to check for breakthrough, and the results presented in Table 4-14 are the sum of the front and backup samples. Formaldehyde, acetaldehyde MEK and valeraldehyde were present at detectable levels in the stack samples. The data have been blank corrected based on an average of the field blank values. Formaldehyde was not detected in any of the field blanks. A tunnel blank was also performed, where the sample inlet was capped and an ambient sample was taken through the inlet filters and the dilution tunnel. If the data were also corrected for this tunnel blank, the levels of formaldehyde for Runs 3 and 4 would be below detectable limits (the duct burners were off for Runs 3 and 4). The concentrations detected in the backup range from 20 to 52 percent of the total, indicating that there may be significant breakthrough.

Table 4-12. Volatile Organic Compound (VOC) Results from Canisters (Site E).

| Parameter | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| Units | mg/dscm | | | | | % | mg/dscm |
| Run Number | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| Toluene | 8.39E-1 | 5.87E-1 | 3.95E-1 | 3.02E-1 | 5.31E-1 | 45 | 2.83E-2 |
| Nonanal | 5.22E-1 | 7.25E-2 | 1.38E-1 | 1.35E-1 | 2.17E-1 | 95 | 3.40E-2 |
| Octanal | 2.46E-1 | 3.20E-1 | 1.32E-1 | 1.39E-1 | 2.09E-1 | 43 | 2.03E-2 |
| Isopentane | 2.58E-1 | 3.51E-1 | 1.31E-1 | 3.66E-2 | 1.94E-1 | 71 | 1.26E-2 |
| Acetone | 6.16E-1 | 2.85E-2 | 1.54E-2 | 1.68E-2 | 1.69E-1 | 176 | 9.74E-4 |
| styrene + heptanal | 1.30E-1 | 3.03E-1 | 1.06E-1 | 1.36E-1 | 1.69E-1 | 54 | 1.02E-2 |
| Propane | 1.94E-1 | 2.03E-1 | 1.51E-1 | 1.03E-1 | 1.63E-1 | 28 | 1.3E-02 |
| n-hexane | 1.36E-1 | 1.72E-1 | 3.10E-1 | 2.71E-2 | 1.61E-1 | 72 | 3.28E-3 |
| m- & p-xylene | 2.69E-1 | 1.99E-1 | 1.00E-1 | 5.82E-2 | 1.57E-1 | 61 | 2.92E-2 |
| alpha-pinene | 3.94E-1 | 1.41E-2 | 1.13E-1 | 6.59E-3 | 1.32E-1 | 137 | 2.79E-4 |
| Methanol | 3.76E-1 | 1.15E-2 | 6.22E-3 | ND | 1.31E-1 | 162 | ND |
| Hexanal | 1.65E-1 | 1.71E-1 | 7.78E-2 | 9.60E-2 | 1.28E-1 | 37 | 5.04E-3 |
| o-xylene | 1.95E-1 | 9.21E-2 | 5.34E-2 | 8.72E-2 | 1.07E-1 | 57 | 1.38E-2 |
| Ethane | 1.1E-01 | 1.38E-1 | 9.80E-2 | 6.83E-2 | 1.05E-1 | 28 | 1.8E-02 |
| n-pentane | 1.13E-1 | 1.76E-1 | 7.33E-2 | 2.27E-2 | 9.63E-2 | 67 | 6.67E-3 |
| n-butane | 7.85E-2 | 1.45E-1 | 1.12E-1 | 2.53E-2 | 9.04E-2 | 57 | 8.4E-03 |
| n-dodecane | 1.56E-1 | 8.20E-2 | 1.65E-2 | 3.98E-2 | 7.35E-2 | 83 | 1.95E-3 |
| 2-methylpentane | 1.18E-1 | 1.11E-1 | 4.64E-2 | 1.11E-2 | 7.15E-2 | 72 | 1.56E-3 |
| n-decane | 8.62E-2 | 1.10E-1 | 2.64E-2 | 2.18E-2 | 6.11E-2 | 72 | 6.75E-3 |
| Ethene | 8.00E-2 | 1.05E-1 | 4.04E-2 | 1.67E-2 | 6.05E-2 | 65 | 1.3E-03 |
| Benzene | 1.00E-1 | 6.41E-2 | 4.14E-2 | 3.02E-2 | 5.90E-2 | 53 | 3.80E-3 |
| Methylcyclopentane | 7.84E-2 | 7.94E-2 | 5.05E-2 | 8.14E-3 | 5.41E-2 | 62 | 2.44E-3 |
| 2,2,4-trimethylpentane | 9.47E-2 | 7.33E-2 | 3.83E-2 | 4.60E-3 | 5.27E-2 | 75 | 2.66E-3 |
| m-ethyltoluene | 9.07E-2 | 5.90E-2 | 2.87E-2 | 1.65E-2 | 4.87E-2 | 68 | 3.83E-3 |
| Isobutane | 4.49E-2 | 7.62E-2 | 5.23E-2 | 1.73E-2 | 4.77E-2 | 51 | 4.5E-03 |
| Ethylbenzene | 8.71E-2 | 5.11E-2 | 3.09E-2 | 1.37E-2 | 4.57E-2 | 69 | 1.45E-2 |
| n-undecane | 7.14E-2 | 6.93E-2 | 1.66E-2 | 2.27E-2 | 4.50E-2 | 65 | 2.62E-3 |
| 3-methylpentane | 7.63E-2 | 6.34E-2 | 2.81E-2 | 3.47E-3 | 4.28E-2 | 78 | 2.29E-3 |
| 1,4-diethylbenzene | 8.50E-2 | 3.55E-2 | 2.25E-2 | 2.81E-2 | 4.28E-2 | 67 | 3.51E-3 |
| 1,2,3-trimethylbenzene | 8.51E-2 | 4.31E-2 | 2.33E-2 | 1.74E-2 | 4.22E-2 | 72 | 2.16E-3 |
| C10 paraffin | 9.28E-2 | ND | 2.76E-2 | 4.59E-3 | 4.17E-2 | 110 | 1.51E-3 |
| Acetylene | 5.94E-2 | 5.28E-2 | 3.08E-2 | 1.30E-2 | 3.90E-2 | 54 | 1.1E-03 |
| 3-methylhexane + pentanal | 6.16E-2 | 5.01E-2 | 3.01E-2 | 6.46E-3 | 3.71E-2 | 65 | 2.21E-3 |
| 1,2,4-trimethylbenzene | 6.61E-2 | 6.24E-2 | 9.55E-3 | 4.84E-3 | 3.57E-2 | 92 | 6.88E-4 |
| C10 olefin | 6.40E-2 | 6.62E-3 | ND | ND | 3.53E-2 | 115 | 6.31E-4 |
| Propene | 3.96E-2 | 4.17E-2 | 3.19E-2 | 2.03E-2 | 3.34E-2 | 29 | 9.6E-04 |
| n-octane | 3.09E-2 | 6.90E-2 | 7.06E-3 | 2.21E-2 | 3.22E-2 | 82 | 1.78E-3 |
| n-heptane | 4.95E-2 | 4.54E-2 | 2.21E-2 | 5.65E-3 | 3.07E-2 | 67 | 2.42E-3 |
| n-nonane | 5.38E-2 | 4.23E-2 | 1.59E-2 | 9.30E-3 | 3.03E-2 | 70 | 5.51E-3 |
| Cyclohexane | 5.41E-2 | 3.57E-2 | 1.86E-2 | 6.78E-3 | 2.88E-2 | 72 | 1.24E-3 |
| p-ethyltoluene | 5.07E-2 | 3.19E-2 | 1.69E-2 | 9.47E-3 | 2.72E-2 | 67 | 2.04E-3 |
| 2-methylhexane | 4.76E-2 | 3.52E-2 | 1.65E-2 | 3.96E-3 | 2.58E-2 | 75 | 1.69E-3 |
| Methylcyclohexane | 3.66E-2 | 4.26E-2 | 1.82E-2 | 5.54E-3 | 2.57E-2 | 66 | 2.13E-3 |
| 1,3,5-trimethylbenzene | 4.48E-2 | 3.40E-2 | 1.27E-2 | 7.75E-3 | 2.48E-2 | 71 | 2.85E-3 |
| 2,3,4-trimethylpentane | 4.36E-2 | 3.02E-2 | 1.61E-2 | 4.60E-3 | 2.36E-2 | 72 | ND |

Table 4-12. Volatile Organic Compound (VOC) Results from Canisters (Site E) (Continued).

| Parameter | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| Units | mg/dscm | | | | | % | mg/dscm |
| Run Number | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| 2,2,5-trimethylhexane | 1.91E-2 | 2.54E-2 | 2.49E-2 | 2.07E-2 | 2.25E-2 | 14 | 5.77E-4 |
| 1,2,3,5-tetramethylbenzene | 5.50E-2 | 1.52E-2 | 8.29E-3 | 9.73E-3 | 2.21E-2 | 101 | 5.49E-4 |
| 2,2-dimethylbutane | 2.81E-2 | 2.60E-2 | 1.07E-2 | ND | 2.16E-2 | 44 | 9.52E-4 |
| 2,3-dimethylbutane | 3.21E-2 | 3.33E-2 | 1.52E-2 | 4.86E-3 | 2.14E-2 | 64 | 1.08E-4 |
| n-propylbenzene | 3.36E-2 | 2.15E-2 | 1.17E-2 | 1.65E-2 | 2.08E-2 | 45 | 1.52E-3 |
| 2,3-dimethylpentane | 3.64E-2 | 2.84E-2 | 1.42E-2 | 3.23E-3 | 2.05E-2 | 72 | 1.43E-3 |
| Isopropyltoluene | 4.13E-2 | 1.77E-2 | 9.48E-3 | 6.49E-3 | 1.87E-2 | 84 | 8.23E-4 |
| iso-butene | 2.41E-2 | 2.49E-2 | 1.29E-2 | 1.31E-2 | 1.87E-2 | 35 | 8.3E-04 |
| 1,2,3,4-trimethylbenzene | 2.25E-2 | 1.52E-2 | 1.66E-2 | 1.95E-2 | 1.84E-2 | 18 | 1.87E-3 |
| MTBE | 3.45E-2 | ND | ND | 2.13E-3 | 1.83E-2 | 125 | 4.33E-3 |
| o-ethyltoluene | 3.25E-2 | 2.04E-2 | 8.49E-3 | 6.78E-3 | 1.70E-2 | 70 | 1.23E-3 |
| Naphthalene | 3.70E-2 | 9.67E-3 | 7.92E-3 | 1.24E-2 | 1.68E-2 | 81 | 2.78E-3 |
| limonene | 2.03E-2 | 1.29E-2 | 1.80E-2 | 1.54E-2 | 1.66E-2 | 19 | 2.40E-3 |
| 1,3-dimethylcyclopentane | 2.65E-2 | 1.57E-2 | 6.93E-3 | ND | 1.64E-2 | 60 | 8.03E-4 |
| 2-methylheptane | 2.15E-2 | 2.30E-2 | 4.53E-3 | ND | 1.63E-2 | 63 | 1.36E-3 |
| 3-ethylpentane | 2.45E-2 | 1.51E-2 | 7.06E-3 | ND | 1.55E-2 | 56 | 9.34E-4 |
| Isoprene | 2.79E-2 | 2.18E-2 | 7.22E-3 | 3.29E-3 | 1.51E-2 | 78 | 8.91E-4 |
| 2,4-dimethylpentane | 2.89E-2 | 1.89E-2 | 9.73E-3 | 2.42E-3 | 1.50E-2 | 77 | 7.79E-4 |
| Ethanol | 1.37E-2 | ND | 1.59E-2 | ND | 1.48E-2 | 10 | ND |
| 1,3-diethylbenzene | 2.00E-2 | 2.03E-2 | 8.29E-3 | 9.73E-3 | 1.46E-2 | 44 | 4.39E-4 |
| 2,6-dimethyloctane | 9.28E-3 | 1.75E-2 | 1.76E-2 | 1.38E-2 | 1.45E-2 | 27 | 1.05E-3 |
| 1,2,4,5-tetramethylbenzene | 3.50E-2 | 1.14E-2 | 4.74E-3 | 6.49E-3 | 1.44E-2 | 97 | 2.74E-4 |
| octene-1 | 2.30E-2 | 1.06E-2 | 7.93E-3 | 1.36E-2 | 1.38E-2 | 48 | 8.72E-4 |
| 3-methylheptane | 1.49E-2 | 1.72E-2 | 7.06E-3 | ND | 1.31E-2 | 41 | 8.88E-4 |
| C11 paraffin | 1.60E-2 | 1.03E-2 | ND | 1.26E-2 | 1.30E-2 | 22 | 3.84E-4 |
| C10 paraffin | 9.28E-3 | 1.75E-2 | ND | 1.15E-2 | 1.27E-2 | 33 | 2.33E-4 |
| Isobutylbenzene | 1.63E-2 | 1.90E-2 | 8.29E-3 | 6.49E-3 | 1.25E-2 | 48 | 1.04E-3 |
| C10 aromatic | 1.25E-2 | ND | ND | ND | 1.25E-2 | n/a | 4.94E-4 |
| Isopropylcyclohexane | 2.35E-2 | 2.02E-2 | 2.23E-3 | 3.05E-3 | 1.23E-2 | 91 | 2.48E-3 |
| 2,3-dimethylhexane | 1.92E-2 | 1.19E-2 | 3.03E-3 | ND | 1.13E-2 | 71 | 6.54E-4 |
| 3,6-dimethyloctane | 1.33E-2 | 6.71E-3 | 1.38E-2 | ND | 1.13E-2 | 35 | 1.75E-4 |
| 2,5-diemthylhexane | 1.70E-2 | 1.08E-2 | 5.04E-3 | ND | 1.09E-2 | 55 | 5.61E-4 |
| 4,4-dimethylheptane | 1.08E-2 | ND | ND | ND | 1.08E-2 | n/a | 3.15E-4 |
| Cyclopentane | 1.50E-2 | 1.65E-2 | 6.19E-3 | 4.52E-3 | 1.06E-2 | 58 | 1.23E-3 |
| 2-propyl toluene | 1.83E-2 | 1.18E-2 | 7.87E-3 | 4.31E-3 | 1.06E-2 | 57 | 2.92E-4 |
| C10 aromatic | 2.00E-2 | 1.14E-2 | 4.74E-3 | 4.33E-3 | 1.01E-2 | 73 | 8.78E-4 |
| C10 aromatic | 2.00E-2 | 8.86E-3 | 5.92E-3 | 4.33E-3 | 9.78E-3 | 72 | 3.84E-4 |
| 2,4,4-trimethyl-1-pentene | 1.05E-2 | 1.06E-2 | 7.93E-3 | 9.94E-3 | 9.73E-3 | 13 | 2.29E-4 |
| Chlorobenzene | 1.26E-2 | 9.56E-3 | 6.96E-3 | ND | 9.70E-3 | 29 | 9.21E-4 |
| Isopropylbenzene | 1.57E-2 | 1.13E-2 | 6.37E-3 | 4.84E-3 | 9.56E-3 | 52 | 1.13E-3 |
| indan | 1.54E-2 | 1.45E-2 | 4.17E-3 | 3.81E-3 | 9.47E-3 | 67 | 1.01E-3 |
| C10 aromatic | 1.75E-2 | 5.06E-3 | 4.74E-3 | ND | 9.10E-3 | 80 | 3.29E-4 |
| c-2-hexene | 1.18E-2 | 7.94E-3 | 8.92E-3 | 6.78E-3 | 8.85E-3 | 24 | 6.20E-4 |
| beta-pinene | 3.81E-3 | 1.80E-2 | 9.62E-3 | 3.29E-3 | 8.68E-3 | 79 | ND |
| Benzaldehyde | 7.91E-3 | 5.00E-3 | 9.37E-3 | 1.20E-2 | 8.56E-3 | 34 | 4.34E-4 |
| 2,6-dimethylheptane | 8.37E-3 | ND | ND | ND | 8.37E-3 | n/a | 4.20E-4 |

Table 4-12. Volatile Organic Compound (VOC) Results from Canisters (Site E) (Continued).

| Parameter | Value | | | | | | |
|---|---|---|---|---|---|---|---|
| Units | mg/dscm | | | | | % | mg/dscm |
| Run Number | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| 2,2,3-trimethylbutane | 1.40E-2 | 7.56E-3 | 7.08E-3 | 2.42E-3 | 7.77E-3 | 61 | 4.51E-4 |
| C8 paraffin | 1.17E-2 | 7.54E-3 | 4.03E-3 | ND | 7.76E-3 | 49 | 4.20E-4 |
| 1,2-diethylbenzene | 1.38E-2 | 8.86E-3 | 3.55E-3 | 4.33E-3 | 7.63E-3 | 62 | 1.65E-4 |
| t-2-pentene | 7.19E-3 | ND | ND | ND | 7.19E-3 | n/a | ND |
| nonene-1 | ND | 7.15E-3 | ND | ND | 7.15E-3 | n/a | 2.07E-4 |
| indene | 1.08E-3 | 1.31E-2 | ND | ND | 7.12E-3 | 120 | 1.43E-4 |
| 1-methylindan | ND | 7.48E-3 | ND | 5.33E-3 | 6.40E-3 | 24 | 2.16E-4 |
| 4-methylheptane | 8.37E-3 | 9.68E-3 | 1.13E-3 | ND | 6.39E-3 | 72 | 5.25E-5 |
| C8 paraffin | 1.06E-2 | 6.47E-3 | 2.02E-3 | ND | 6.38E-3 | 68 | 1.87E-4 |
| dodecene-1 | 1.27E-2 | 1.61E-3 | ND | 4.12E-3 | 6.14E-3 | 95 | 3.48E-4 |
| 1-hexene | ND | ND | ND | 6.10E-3 | 6.10E-3 | n/a | ND |
| C11 aromatic | ND | 4.19E-3 | 7.85E-3 | ND | 6.02E-3 | 43 | ND |
| c-3-hexene | 1.10E-2 | 8.73E-3 | 2.23E-3 | 2.03E-3 | 5.99E-3 | 76 | 6.20E-4 |
| 3,3-dimethylheptane | 5.98E-3 | ND | ND | ND | 5.98E-3 | n/a | 4.20E-4 |
| c-2-butene | ND | ND | 6.44E-3 | 5.42E-3 | 5.93E-3 | 12 | 2.52E-4 |
| C11 aromatic | 6.91E-3 | ND | ND | 4.78E-3 | 5.84E-3 | 26 | 6.06E-5 |
| 1-butene | 6.80E-3 | 6.88E-3 | 5.94E-3 | 3.16E-3 | 5.70E-3 | 31 | 2.8E-04 |
| C9 olefin | 5.88E-3 | 5.95E-3 | 3.34E-3 | ND | 5.06E-3 | 29 | ND |
| 2-methylpropanal | 6.04E-3 | ND | ND | 4.06E-3 | 5.05E-3 | 28 | 1.18E-4 |
| C9 paraffin | ND | ND | 5.66E-3 | 4.13E-3 | 4.90E-3 | 22 | ND |
| 2,4-diemthylhexane | 4.26E-3 | 4.31E-3 | ND | ND | 4.28E-3 | 1 | 4.67E-5 |
| C9 paraffin | 2.39E-3 | 4.84E-3 | 4.53E-3 | ND | 3.92E-3 | 34 | 2.10E-4 |
| C9 olefin | 2.35E-3 | 4.76E-3 | ND | ND | 3.56E-3 | 48 | ND |
| 2-methyl-1-butene | 3.27E-3 | 5.95E-3 | 1.24E-3 | ND | 3.49E-3 | 68 | 1.15E-4 |
| 1,3-butadiene | 5.04E-3 | 4.59E-3 | 2.39E-3 | 1.74E-3 | 3.44E-3 | 47 | 1.1E-04 |
| 3,3-dimethylpentane | 4.67E-3 | 3.78E-3 | 1.77E-3 | ND | 3.41E-3 | 44 | 8.20E-5 |
| Cyclopentene | 3.17E-3 | 3.86E-3 | 1.20E-3 | 4.39E-3 | 3.16E-3 | 44 | 5.16E-4 |
| 1,1-dimethylcyclohexane | 4.18E-3 | 2.12E-3 | ND | ND | 3.15E-3 | 46 | 9.18E-5 |
| Cyclohexene | 3.06E-3 | 3.10E-3 | 2.90E-3 | ND | 3.02E-3 | 3 | 6.72E-5 |
| C7 olefin | 2.74E-3 | 3.71E-3 | 2.60E-3 | ND | 3.02E-3 | 20 | 1.20E-4 |
| C9 paraffin | 2.39E-3 | 3.63E-3 | ND | ND | 3.01E-3 | 29 | 3.15E-4 |
| 2-methyl-1-pentene | 1.57E-3 | 3.97E-3 | ND | ND | 2.77E-3 | 61 | ND |
| C8 olefin | 2.09E-3 | 3.18E-3 | ND | ND | 2.63E-3 | 29 | 3.21E-4 |
| sec-butylbenzene | ND | 2.53E-3 | ND | ND | 2.53E-3 | n/a | 2.74E-4 |
| t-2-butene | 2.61E-3 | 3.18E-3 | 2.97E-3 | 1.36E-3 | 2.53E-3 | 32 | 1.1E-04 |
| t-2-hexene | 2.35E-3 | ND | ND | ND | 2.35E-3 | n/a | 2.07E-4 |
| C10 aromatic | 1.25E-3 | 2.53E-3 | ND | 3.24E-3 | 2.34E-3 | 43 | ND |
| 2-methyl-2-pentene | 2.35E-3 | 2.38E-3 | 1.49E-3 | ND | 2.07E-3 | 25 | 1.38E-4 |
| 2-methyl-2-butene | 1.96E-3 | 1.98E-3 | 3.10E-3 | 1.13E-3 | 2.04E-3 | 39 | 2.29E-4 |
| c-2-pentene | ND | 1.98E-3 | ND | ND | 1.98E-3 | n/a | 8.60E-5 |
| C8 olefin | 3.14E-3 | ND | 9.91E-4 | 1.81E-3 | 1.98E-3 | 55 | 9.18E-5 |
| 4-methylhexene | 1.83E-3 | ND | ND | ND | 1.83E-3 | n/a | 4.02E-5 |
| C6 olefin | 1.57E-3 | ND | ND | ND | 1.57E-3 | n/a | 2.07E-4 |
| t-3-heptene | 9.15E-4 | 1.85E-3 | ND | ND | 1.38E-3 | 48 | 1.20E-4 |
| Total Identified NMHC | 1.14E+0 | 9.75E-1 | 6.87E-1 | 4.57E-1 | 8.14E-1 | 37 | 6.15E-2 |
| Unidentified | 3.39E-1 | 1.22E-1 | 1.35E-1 | 8.81E-2 | 1.71E-1 | 67 | 9.63E-3 |

n/a-not applicable. Less than two runs within detectable limits
RSD-relative standard deviation
ND-not detected.

Table 4-13. Elements, as Measured by the Dilution Tunnel (Site E).

| Parameter | Value | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Units | mg/dscm | | | | | % | mg/dscm | |
| Run | 1 | 2 | 3 | 4 | Average | RSD | Ambient | MDL |
| Date | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 | (2) |
| Ag | 5.4E-3 | ND | ND | NV | 5.4E-3 | n/a | ND | 1.3E-4 |
| Al | 4.4E-4 | 2.3E-3 | ND | NV | 1.4E-3 | 97% | 1.0E-4 | 1.0E-4 |
| Br | 1.2E-5 | 5.4E-5 | ND | NV | 3.3E-5 | 89% | 5.2E-6 | 1.0E-5 |
| Ca | 5.9E-4 | 3.3E-3 | ND | NV | 1.9E-3 | 98% | 1.5E-4 | 4.7E-5 |
| Cl | 5.4E-3 | 1.4E-2 | 5.7E-4 | NV | 6.7E-3 | 103% | 8.2E-4 | 1.0E-4 |
| Co | 2.9E-5 | ND | 1.4E-5 | NV | 2.2E-5 | 50% | ND | 9.2E-6 |
| Cr | 4.3E-4 | ND | ND | NV | 4.3E-4 | n/a | 3.9E-6 | 2.0E-5 |
| Cu | 1.1E-4 | 8.0E-4 | 2.6E-5 | NV | 3.1E-4 | 136% | 7.1E-6 | 1.1E-5 |
| Fe | 2.5E-3 | 9.5E-3 | 1.4E-4 | NV | 4.0E-3 | 120% | 2.2E-4 | 1.6E-5 |
| K | 2.3E-4 | 1.5E-3 | ND | NV | 8.4E-4 | 102% | 1.1E-4 | 6.4E-5 |
| Mg | 7.4E-4 | 1.6E-3 | 5.1E-5 | NV | 8.0E-4 | 98% | 1.2E-4 | (1) |
| Mn | 7.1E-5 | 1.6E-4 | ND | NV | 1.1E-4 | 53% | 3.5E-6 | 1.7E-5 |
| Mo | 4.7E-5 | ND | ND | NV | 4.7E-5 | n/a | ND | 2.8E-5 |
| Ni | 2.6E-4 | 6.5E-5 | 2.4E-5 | NV | 1.2E-4 | 108% | 3.4E-6 | 9.3E-6 |
| P | ND | 2.3E-4 | ND | NV | 2.3E-4 | n/a | ND | 5.8E-5 |
| Pb | 4.5E-5 | 1.0E-4 | ND | NV | 7.3E-5 | 54% | 1.6E-5 | 3.1E-5 |
| S | 1.3E-3 | 6.7E-3 | 6.8E-4 | NV | 2.9E-3 | 114% | 7.2E-4 | 5.2E-5 |
| Si | 1.2E-3 | 9.3E-3 | 2.3E-4 | NV | 3.6E-3 | 140% | 3.5E-4 | 6.6E-5 |
| Sr | ND | 4.3E-5 | ND | NV | 4.3E-5 | n/a | 2.4E-6 | 1.1E-5 |
| Ti | 1.3E-4 | 4.0E-4 | ND | NV | 2.6E-4 | 71% | 1.5E-5 | 3.0E-5 |
| V | 4.9E-5 | 1.7E-4 | ND | NV | 1.1E-4 | 77% | 8.7E-6 | 2.6E-5 |
| Zn | 1.6E-4 | 9.3E-4 | 3.8E-5 | NV | 3.8E-4 | 128% | 1.2E-5 | 1.1E-5 |
| Zr | ND | 2.7E-5 | ND | NV | 2.7E-5 | n/a | ND | 1.8E-5 |

(1) No detection limits given. Zeroes treated as non-detect. Data is semi-quantitative.
(2) Average method detection limit for dilution ratio 22:1. Ambient sample MDLs are smaller due to 1:1 dilution ratio.
MDL- Method Detection Limit
ND- Not detected
n/a- not applicable; only one run within detectable limits.
RSD- Relative standard deviation

Table 4-14. Carbonyl (Aldehyde) Results (mg/dscm) (Site E).

| Run | | 1 | 2 | 3 | 4 | Average | RSD (%) | Tunnel Blank | Ambient |
|---|---|---|---|---|---|---|---|---|---|
| Date | Units | 06-Sep-01 | 07-Sep-01 | 08-Sep-01 | 09-Sep-01 | | | 10-Sep-01 | 11-Sep-01 |
| Formaldehyde | mg/dscm | 8.8E-2 | 9.3E-2 | 3.3E-2 | 3.5E-2 | 6.2E-2 | 53 | 2.0E-3 | 3.6E-3 |
| | ppb | 70.8 | 74.4 | 26.2 | 28.0 | 49.9 | 53 | 1.6 | 2.9 |
| Acetaldehyde | mg/dscm | 1.1E-1 | 6.6E-2 | 3.2E-2 | 3.2E-2 | 5.9E-2 | 60 | 2.6E-3 | 5.2E-3 |
| MEK | mg/dscm | ND | ND | ND | 3.2E-3 | 3.2E-3 | n/a | ND | 5.5E-4 |
| Valeraldehyde | mg/dscm | 1.3E-2 | 2.3E-2 | 1.5E-2 | 1.5E-2 | 1.6E-2 | 28 | ND | 1.9E-3 |

ND - not detected
RSD - relative standard deviation

Celanese Method. Analysis of the samples collected using the Celanese Method using the acetylacetone derivatization for formaldehyde yielded all runs below detection limits (approximately 35 ppb). An additional analysis of the sample by HPLC yielded little additional information; levels in the field blanks and reagent blank were on the order of levels in the samples, indicating that stack levels of formaldehyde are below the capability of this method

Gaseous Precursors

Gaseous ammonia was captured on a citric acid-impregnated cellulose-fiber filter downstream of the quartz filter used for ions and OC/EC analysis. Sulfur dioxide was captured on a potassium carbonate impregnated cellulose-fiber filter downstream of a quartz filter. Results are presented in Table 4-15.

Table 4-15. Secondary PM Gaseous Precursor Results (Site E).

| Parameter | Units | Value | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run Number | - | 1 | 2 | 3 | 4 | Average | RSD | Ambient |
| Date | - | 6-Sep-01 | 7-Sep-01 | 8-Sep-01 | 9-Sep-01 | | | 11-Sep-01 |
| Ammonia | mg/dscm | 0.71 | 0.71 | 0.80 | 0.60 | 0.71 | 12% | 2.4E-3 |
| (Dilution tunnel) | ppm | 1.01 | 1.00 | 1.13 | 0.85 | 1.00 | 12% | 3.4E-3 |
| | lb/hr | 1.93 | 1.91 | 2.00 | 1.42 | 1.82 | 15% | n/a |
| Sulfur Dioxide | mg/dscm | 0.46 | 0.57 | 0.32 | 0.040 | 0.35 | 66% | 8.6E-4 |
| (Dilution tunnel) | ppm | 0.17 | 0.22 | 0.12 | 0.015 | 0.13 | 66% | 4.4E-3 |
| | lb/hr | 1.24 | 1.55 | 0.81 | 0.095 | 0.92 | 68% | n/a |
| Ammonia | mg/m3 | 1.13 | 1.17 | 1.12 | 0.92 | 1.08 | 11% | -- |
| (BAAQMD ST-1B) | ppm | 1.60 | 1.66 | 1.58 | 1.30 | 1.53 | 11% | -- |
| | lb/hr | 3.12 | 3.22 | 2.83 | 2.21 | 2.85 | 16% | -- |

Ammonia was also measured using BAAQMD Method ST-1B. The results from this method are also presented in Table 4-15. These results are consistent with previous tests on this unit. Ammonia concentrations measured using the wet chemistry method are approximately 1.5 times higher than those measured by the dilution tunnel filter.

# Section 5
# EMISSION FACTORS AND SPECIATION PROFILES

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 unit (lb/MMBtu). Heat input is the product of the measured fuel flow rate and the average fuel heating value (based on fuel grab sample analysis). Average emission factors were determined by averaging detected data. Undetected data were excluded.

## 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, 1990). In the tables that follow, the reported results, the total uncertainty, and a 95 percent confidence upper bound are given for each of the substances of interest. The total 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.

## EMISSION FACTORS

Table 5-1 presents emission factors for primary emissions, including filterable and condensable particulate mass as measured with in-stack methods, and PM2.5, elements and ions as measured on the dilution tunnel filters. FPM includes all particulate captured in the in-stack cyclones, probe and filter with Method PRE-4 and all particulate captured in the nozzle and filter with Method 17. Inorganic, organic and total CPM have been corrected in accordance with Method 202 guidelines. The average emission factor for total PM2.5 (including CPM) measured using in-stack methods and a purged back-half train is 18 times higher than the emission factor for PM2.5 by the dilution tunnel. As discussed previously in Section 4, this difference is believed to be due to sampling and analytical artifacts associated with the CPM measurement method, however the higher CPM data for the purged train is inconsistent with the hypothesis that sulfate is causing an artifact. Therefore, the emission factor derived from the dilution tunnel results is considered the most reliable.

Table 5-1. Primary Emissions- Particulate Mass and Elements (Site E).

| Substance | | Emission Factor (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|---|
| Particulate Mass | Organic CPM (Method 202) | 5.5E-4 | n/a | n/a |
| | Inorganic CPM (Method 202) | 2.7E-3 | 60 | 4.0E-3 |
| | Total CPM (Method 202) | 3.0E-3 | 48 | 4.1E-3 |
| | Total CPM (Method 8) | 2.3E-3 | 45 | 3.1E-3 |
| | Total Filterable PM (Method 17/8 train) | 6.1E-4 | 383 | 1.8E-3 |
| | Total Filterable PM (Method PRE-4/202 train) | 6.0E-4 | 201 | 1.5E-3 |
| | Filterable PM10 (Method PRE-4/202 train) | 2.9E-4 | 291 | 8.6E-4 |
| | Filterable PM2.5 (Method PRE-4/202 train) | 9.6E-5 | n/a | n/a |
| | PM2.5 (dilution tunnel) | 1.7E-4 | 259 | 4.6E-4 |
| Elements (dilution tunnel) | Ag | 7.6E-7 | n/a | n/a |
| | Al | 2.0E-6 | 872 | 1.0E-5 |
| | Br | 4.7E-8 | 805 | 2.3E-7 |
| | Ca | 2.7E-6 | 885 | 1.5E-5 |
| | Cl | 9.5E-6 | 257 | 2.6E-5 |
| | Co | 3.2E-8 | 448 | 1.0E-7 |
| | Cr | 6.1E-7 | n/a | n/a |
| | Cu | 4.4E-7 | 339 | 1.5E-6 |
| | Fe | 5.7E-6 | 298 | 1.7E-5 |
| | K | 1.2E-6 | 918 | 6.6E-6 |
| | Mg | 1.1E-6 | 244 | 3.0E-6 |
| | Mn | 1.6E-7 | 484 | 5.5E-7 |
| | Mo | 6.7E-8 | n/a | n/a |
| | Ni | 1.7E-7 | 269 | 4.7E-7 |
| | P | 3.2E-7 | n/a | n/a |
| | Pb | 1.0E-7 | 491 | 3.5E-7 |
| | S | 4.1E-6 | 284 | 1.2E-5 |
| | Si | 5.0E-6 | 349 | 1.7E-5 |
| | Sr | 6.0E-8 | n/a | n/a |
| | Ti | 3.7E-7 | 637 | 1.5E-6 |
| | V | 1.5E-7 | 694 | 6.8E-7 |
| | Zn | 5.3E-7 | 318 | 1.7E-6 |
| | Zr | 3.9E-8 | n/a | n/a |
| Ions (dilution tunnel) | Chloride | 9.8E-6 | 249 | 2.7E-5 |
| | Nitrate | 1.5E-5 | 322 | 4.7E-5 |
| | Sulfate | 1.2E-5 | 303 | 3.7E-5 |
| | Ammonium | 7.3E-6 | n/a | n/a |
| | Soluble Na | 7.1E-7 | 229 | 1.8E-6 |

n/a- not applicable; only one run was within detectable limits.

Table 5-2 presents emission factors for OC, EC, total carbon, and SVOCs as measured by the dilution tunnel. SVOC emission factors are low. The average sum of all SVOCs equals $7.7x10^{-6}$ lb/MMBtu, comprising approximately 3 percent of the total organic carbon. 1,4+1,5+2,3-dimethylnaphthalene has the highest value, with an emission factor of $1.6x10^{-6}$ lb/MMBtu. Since the dilution tunnel samples are expected to collect SVOCs which condense in the plume, these results are useful for receptor modeling purposes.

Emission factors for VOCs obtained from the Tenax samples with carbon number greater than seven are presented in Table 5-3. All VOCs are present at low levels, with hexadecanoic acid being the most abundant ($1.6x10^{-4}$ lb/MMBtu).

Emission factors for VOCs obtained from the canister samples with carbon number greater than two are presented in Table 5-4. All VOCs are present at low levels, with toluene being the most abundant ($7.8x10^{-4}$ lb/MMBtu).

Carbonyl emission factors are presented in Table 5-5. Formaldehyde and acetaldehyde are present at approximately the same levels. The emission factor for formaldehyde ($8.8x10^{-5}$ lb/MMBtu) is lower than that found in the EPA FIRE 6.23 database ($7.1x10^{-4}$ lb/MMBtu) for a natural gas-fired turbine used for electric generation with no emission controls but higher than the emission factor for a turbine with catalytic reduction (SCONOX) at $2.0x10^{-5}$ lb/MMBtu.

Emission factors for $SO_2$ and $NH_3$ as measured by the dilution tunnel and $NH_3$ as measured by BAAQMD ST-1B are presented in Table 5-6.

## PM2.5 SPECIATION PROFILES

### Dilution Tunnel

The speciation profile for PM2.5, based on dilution tunnel results, is given in Table 5-7. This table includes all results from the ED-XRF analysis of the dilution tunnel Teflon® filters, the ion analysis of the dilution tunnel quartz filters and the OC/EC analysis of the dilution tunnel quartz filters. The mass fractions presented are the ratio of the emission factor of the emitted compound over the sum of the species emission factors.

Table 5-2. Primary Emissions- Carbon and SVOCs (Site E).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| Organic Carbon | 1.4E-4 | 98 | 2.3E-4 |
| Elemental Carbon | 1.2E-5 | 351 | 3.4E-5 |
| Total Carbon | 1.5E-4 | 103 | 2.5E-4 |
| **Semi-Volatile Organic Compounds (dilution tunnel)** | | | |
| 2-methylnaphthalene | 7.0E-7 | 774 | 3.4E-6 |
| 1-methylnaphthalene | 3.8E-7 | 731 | 1.8E-6 |
| Biphenyl | 2.2E-7 | n/a | n/a |
| 1+2-ethylnaphthalene | 4.8E-7 | 35 | 6.3E-7 |
| 2,6+2,7-dimethylnaphthalene | 2.9E-7 | n/a | n/a |
| 1,3+1,6+1,7-dimethylnaphthalene | 5.2E-7 | n/a | n/a |
| 1,4+1,5+2,3-dimethylnaphthalene | 1.6E-6 | 817 | 8.3E-6 |
| Dibenzofuran | 3.9E-7 | n/a | n/a |
| A-trimethylnaphthalene | 8.9E-8 | 180 | 1.7E-7 |
| B-trimethylnaphthalene | 5.0E-8 | 60 | 6.9E-8 |
| C-trimethylnaphthalene | 8.0E-8 | 73 | 1.1E-7 |
| E-trimethylnaphthalene | 3.2E-8 | 255 | 7.3E-8 |
| F-trimethylnaphthalene | 3.0E-8 | 85 | 4.4E-8 |
| 2,3,5+I-trimethylnaphthalene | 2.0E-7 | n/a | n/a |
| Acenaphthene | 6.1E-7 | 726 | 2.8E-6 |
| Fluorene | 2.4E-7 | n/a | n/a |
| Phenanthrene | 4.3E-7 | 158 | 9.3E-7 |
| Xanthone | 1.6E-7 | 1113 | 1.1E-6 |
| 2-methylphenanthrene | 7.0E-8 | 239 | 1.9E-7 |
| C-methylphenanthrene | 1.6E-7 | n/a | n/a |
| 1-methylphenanthrene | 7.6E-8 | n/a | n/a |
| Anthrone | 2.7E-8 | 85 | 4.4E-8 |
| C-dimethylphenanthrene | 1.4E-7 | n/a | n/a |
| E-dimethylphenanthrene | 2.7E-7 | n/a | n/a |
| Anthracene | 8.0E-10 | n/a | n/a |
| Fluoranthene | 9.6E-8 | 158 | 1.7E-7 |
| Pyrene | 1.2E-7 | 797 | 5.9E-7 |
| C-MePy/MeFl | 3.2E-9 | n/a | n/a |
| D-MePy/MeFl | 3.0E-8 | 188 | 7.1E-8 |
| 4-methylpyrene | 4.2E-8 | n/a | n/a |
| 7-methylbenz(a)anthracene | 5.0E-8 | 753 | 2.4E-7 |
| 7-methylbenzo(a)pyrene | 1.2E-7 | 55 | 1.7E-7 |
| Sum of All SVOCs | 7.7E-6 | | |

n/a- not applicable; only one run was within detection limits.

Table 5-3. Secondary Organic Aerosol Precursors (VOCs) from Tenax Samples (Site E).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| Ethylbenzene | 3.3E-6 | 227 | 8.4E-6 |
| m&p-xylene | 8.4E-6 | 251 | 2.3E-5 |
| Cyclohexanone | 1.1E-5 | n/a | n/a |
| 2-methyloctane | 7.0E-7 | 575 | 2.7E-6 |
| 2-heptanone | 2.2E-6 | n/a | n/a |
| 3-methyloctane | 2.2E-6 | 546 | 8.4E-6 |
| Styrene | 2.3E-5 | 228 | 5.9E-5 |
| o-xylene | 3.0E-6 | 264 | 8.3E-6 |
| 1-nonene | 4.6E-6 | n/a | n/a |
| Nonane | 5.4E-6 | 247 | 1.4E-5 |
| Isopropylbenzene | 1.6E-7 | n/a | n/a |
| Propylcyclohexane | 6.2E-7 | n/a | n/a |
| Benzaldehyde | 7.2E-5 | 208 | 1.7E-4 |
| Dimethyloctane | 2.0E-6 | n/a | n/a |
| Propylbenzene | 1.1E-6 | 859 | 5.7E-6 |
| m-ethyltoluene | 1.9E-6 | 220 | 4.7E-6 |
| p-ethyltoluene | 6.1E-7 | 140 | 1.2E-6 |
| 1,3,5-trimethylbenzene | 8.4E-7 | 669 | 3.7E-6 |
| Phenol | 1.4E-5 | 171 | 3.0E-5 |
| o-ethyltoluene | 7.0E-7 | 1079 | 4.5E-6 |
| 2,3-benzofuran | 1.8E-6 | n/a | n/a |
| Octanal | 7.0E-6 | 109 | 1.2E-5 |
| 1,2,4-trimethylbenzene | 2.4E-6 | 248 | 6.5E-6 |
| 1,3-dichlorobenzene | 1.8E-6 | n/a | n/a |
| 1-decene | 4.6E-6 | n/a | n/a |
| Decane | 1.1E-5 | 229 | 2.9E-5 |
| m-isopropyltoluene | 2.0E-7 | 1027 | 1.2E-6 |
| p-isopropyltoluene | 7.2E-6 | 261 | 2.0E-5 |
| Indan | 3.8E-7 | n/a | n/a |
| (+/-)-limonene | 1.1E-6 | n/a | n/a |
| 1,3-diethylbenzene | 3.2E-7 | n/a | n/a |
| Acetophenone | 2.5E-5 | 157 | 5.1E-5 |
| Butylbenzene | 3.3E-7 | 1024 | 2.0E-6 |
| 5-ethyl-m-xylene | 4.0E-7 | n/a | n/a |
| 1,2-diethylbenzene | 2.4E-7 | n/a | n/a |
| 2-n-propyltoluene | 4.2E-7 | n/a | n/a |
| 2-ethyl-p-xylene | 2.4E-7 | n/a | n/a |
| 4-ethyl-o-xylene | 9.1E-7 | 234 | 2.0E-6 |
| 4-tert-butyltoluene | 4.9E-7 | n/a | n/a |
| Nonanal | 3.1E-5 | 102 | 4.7E-5 |
| 1-undecene | 6.2E-6 | 216 | 1.3E-5 |
| Undecane | 5.4E-6 | 280 | 1.6E-5 |
| 1,2,4,5-tetramethylbenzene | 2.2E-7 | n/a | n/a |
| 1,2,3,5-tetramethylbenzene | 4.0E-7 | n/a | n/a |
| 1,2,3,4-tetramethylbenzene | 2.9E-7 | n/a | n/a |

Table 5-3. Secondary Organic Aerosol Precursors (VOCs) from Tenax Samples (Site E) (Continued).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| Naphthalene | 2.0E-6 | 209 | 4.7E-6 |
| Decanal | 2.4E-5 | 314 | 6.2E-5 |
| Dodecene | 3.5E-6 | 419 | 1.1E-5 |
| Dodecane | 1.5E-5 | 239 | 4.0E-5 |
| 2-methylnaphthalene | 9.9E-7 | 853 | 5.2E-6 |
| 1-methylnaphthalene | 3.8E-7 | n/a | n/a |
| Tridecane | 3.5E-6 | 257 | 9.5E-6 |
| Biphenyl | 4.2E-6 | 188 | 9.5E-6 |
| 1+2-ethylnaphthalene | 1.6E-7 | n/a | n/a |
| 2,6+2,7-dimethylnaphthalene | 4.7E-7 | n/a | n/a |
| Tetradecane | 1.4E-5 | 204 | 3.3E-5 |
| Pentadecane | 2.0E-5 | 194 | 4.7E-5 |
| Hexadecane | 1.1E-5 | 291 | 3.4E-5 |
| Heptadecane | 1.4E-5 | 369 | 5.0E-5 |
| Octadecane | 7.3E-6 | 364 | 2.5E-5 |
| Nonadecane | 3.0E-6 | n/a | n/a |
| Eicosane | 2.6E-6 | 498 | 9.1E-6 |
| butyl acetate | 7.5E-6 | n/a | n/a |
| Hexadecanoic acid | 1.6E-4 | 235 | 4.2E-4 |

n/a- Not applicable. Only one run within detectable limits.

The average emission factor for the sum of species ($2.0x10^{-4}$ lb/MMBtu) is within two times the average emission factor for total PM2.5 mass ($1.7x10^{-4}$ lb/MMBtu, measured gravimetrically), and the two show good agreement with one another. Any difference is most likely due to the bias associated with the different analytical methods used to determine the speciation of the mass versus the gravimetric analysis used to measure total PM2.5 mass. In addition, two different types of filters were used: Teflon® filters were used for the elemental analysis and particulate mass, while quartz filters were used for OC/EC analysis and ionic analysis. It is possible that variations in particle deposition occurred between the different filters, resulting in a bias. Inhomogeneous deposition on the filter could also cause a bias. The OC/EC analysis and ion analysis each take only part of the filter for analysis, and the total mass on the filter is normalized assuming that this mass is evenly distributed over the collection area.

Figure 5-4. Secondary Organic Aerosol Precursors (VOCs) from Canister Samples (Site E).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| Ethane | 1.6E-4 | 52 | 2.2E-4 |
| Ethene | 8.8E-5 | 107 | 1.6E-4 |
| Acetylene | 5.7E-5 | 91 | 9.6E-5 |
| 1-butene | 8.4E-6 | 56 | 1.2E-5 |
| iso-butene | 2.8E-5 | 63 | 4.1E-5 |
| Propene | 4.9E-5 | 54 | 7.1E-5 |
| Propane | 2.4E-4 | 53 | 3.4E-4 |
| Isobutane | 7.0E-5 | 85 | 1.2E-4 |
| 1,3-butadiene | 5.0E-6 | 80 | 8.1E-6 |
| n-butane | 1.3E-4 | 94 | 2.3E-4 |
| Methanol | 1.9E-4 | 402 | 7.0E-4 |
| t-2-butene | 3.8E-6 | 58 | 5.5E-6 |
| c-2-butene | 9.4E-6 | 121 | 1.5E-5 |
| Ethanol | 2.2E-5 | 105 | 3.5E-5 |
| Isopentane | 2.8E-4 | 117 | 5.3E-4 |
| Acetone | 2.4E-4 | 282 | 7.5E-4 |
| 2-methyl-1-butene | 5.0E-6 | 171 | 1.1E-5 |
| n-pentane | 1.4E-4 | 111 | 2.6E-4 |
| Isoprene | 2.2E-5 | 127 | 4.2E-5 |
| t-2-pentene | 1.0E-5 | n/a | n/a |
| c-2-pentene | 2.8E-6 | n/a | n/a |
| 2-methyl-2-butene | 3.1E-6 | 69 | 4.7E-6 |
| 2,2-dimethylbutane | 3.1E-5 | 113 | 5.6E-5 |
| 2-methylpropanal | 7.6E-6 | 254 | 1.7E-5 |
| Cyclopentene | 4.7E-6 | 75 | 7.5E-6 |
| Cyclopentane | 1.5E-5 | 96 | 2.7E-5 |
| 2,3-dimethylbutane | 3.1E-5 | 106 | 5.6E-5 |
| MTBE | 2.6E-5 | 1124 | 1.7E-4 |
| 2-methylpentane | 1.0E-4 | 118 | 2.0E-4 |
| 3-methylpentane | 6.2E-5 | 126 | 1.2E-4 |
| 2-methyl-1-pentene | 3.9E-6 | 553 | 1.5E-5 |
| 1-hexene | 9.9E-6 | n/a | n/a |
| C6 olefin | 2.2E-6 | n/a | n/a |
| n-hexane | 2.4E-4 | 118 | 4.5E-4 |
| t-2-hexene | 3.3E-6 | n/a | n/a |
| 2-methyl-2-pentene | 3.0E-6 | 68 | 4.5E-6 |
| c-3-hexene | 8.7E-6 | 124 | 1.7E-5 |
| c-2-hexene | 1.3E-5 | 47 | 1.8E-5 |
| Methylcyclopentane | 7.9E-5 | 102 | 1.4E-4 |
| 2,4-dimethylpentane | 2.2E-5 | 125 | 4.2E-5 |
| 2,2,3-trimethylbutane | 1.1E-5 | 101 | 2.0E-5 |
| Benzene | 8.7E-5 | 88 | 1.4E-4 |
| 3,3-dimethylpentane | 4.9E-6 | 112 | 8.8E-6 |
| Cyclohexane | 4.2E-5 | 117 | 7.9E-5 |
| 4-methylhexene | 2.6E-6 | n/a | n/a |
| 2-methylhexane | 3.7E-5 | 123 | 7.2E-5 |
| 2,3-dimethylpentane | 3.0E-5 | 118 | 5.6E-5 |
| Cyclohexene | 4.4E-6 | 30 | 5.7E-6 |
| 3-methylhexane + pentanal | 5.4E-5 | 108 | 9.8E-5 |

Figure 5-4. Secondary Organic Aerosol Precursors (VOCs) from Canister Samples (Site E) (Continued).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| 1,3-dimethylcyclopentane | 2.4E-5 | 151 | 4.8E-5 |
| 3-ethylpentane | 2.2E-5 | 142 | 4.4E-5 |
| 2,2,4-trimethylpentane | 7.6E-5 | 123 | 1.5E-4 |
| C7 olefin 2 | 4.4E-6 | 57 | 6.3E-6 |
| t-3-heptene | 2.0E-6 | 434 | 6.2E-6 |
| n-heptane | 4.4E-5 | 110 | 8.1E-5 |
| C8 olefin 1 | 3.7E-6 | 267 | 8.7E-6 |
| C8 olefin 3 | 3.0E-6 | 139 | 5.8E-6 |
| 2,4,4-trimethyl-1-pentene | 1.5E-5 | 34 | 1.9E-5 |
| Methylcyclohexane | 3.7E-5 | 109 | 6.8E-5 |
| 2,5-diemthylhexane | 1.6E-5 | 139 | 3.1E-5 |
| 2,4-diemthylhexane | 6.1E-6 | 53 | 8.2E-6 |
| C8 paraffin 2 | 1.1E-5 | 126 | 2.1E-5 |
| 2,3,4-trimethylpentane | 3.4E-5 | 117 | 6.5E-5 |
| Toluene | 7.8E-4 | 76 | 1.2E-3 |
| 2,3-dimethylhexane | 1.6E-5 | 179 | 3.6E-5 |
| 2-methylheptane | 2.3E-5 | 159 | 4.9E-5 |
| 4-methylheptane | 9.1E-6 | 181 | 2.0E-5 |
| C8 paraffin 3 | 9.1E-6 | 171 | 2.0E-5 |
| 3-methylheptane | 1.9E-5 | 105 | 3.3E-5 |
| Hexanal | 1.9E-4 | 65 | 2.8E-4 |
| 2,2,5-trimethylhexane | 3.4E-5 | 35 | 4.4E-5 |
| Octene-1 | 2.0E-5 | 81 | 3.3E-5 |
| 1,1-dimethylcyclohexane | 4.5E-6 | 420 | 1.4E-5 |
| n-octane | 4.7E-5 | 133 | 9.4E-5 |
| 4,4-dimethylheptane | 1.5E-5 | n/a | n/a |
| 2,6-dimethylheptane | 1.2E-5 | n/a | n/a |
| Chlorobenzene | 1.4E-5 | 78 | 2.2E-5 |
| 3,3-dimethylheptane | 8.5E-6 | n/a | n/a |
| C9 olefin 1 | 7.3E-6 | 79 | 1.1E-5 |
| Ethylbenzene | 6.6E-5 | 113 | 1.2E-4 |
| m- & p-xylene | 2.3E-4 | 101 | 4.0E-4 |
| C9 paraffin 1 | 7.8E-6 | 205 | 1.6E-5 |
| Styrene + heptanal | 2.5E-4 | 90 | 4.2E-4 |
| o-xylene | 1.6E-4 | 95 | 2.7E-4 |
| Nonene-1 | 1.0E-5 | n/a | n/a |
| C9 paraffin 2 | 4.2E-6 | 267 | 1.0E-5 |
| n-nonane | 4.4E-5 | 115 | 8.2E-5 |
| C9 paraffin 3 | 5.8E-6 | 89 | 9.4E-6 |
| C9 olefin 4 | 5.0E-6 | 434 | 1.6E-5 |
| Isopropylbenzene | 1.4E-5 | 87 | 2.3E-5 |
| Isopropylcyclohexane | 1.8E-5 | 148 | 3.7E-5 |
| Benzaldehyde | 1.3E-5 | 61 | 1.9E-5 |
| 2,6-dimethyloctane | 2.2E-5 | 51 | 3.1E-5 |
| alpha-pinene | 1.9E-4 | 220 | 5.1E-4 |
| 3,6-dimethyloctane | 1.7E-5 | 92 | 2.7E-5 |
| n-propylbenzene | 3.1E-5 | 77 | 4.9E-5 |
| m-ethyltoluene | 7.1E-5 | 112 | 1.3E-4 |

Figure 5-4. Secondary Organic Aerosol Precursors (VOCs) from Canister Samples (Site E) (Continued).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| p-ethyltoluene | 4.0E-5 | 110 | 7.3E-5 |
| 1,3,5-trimethylbenzene | 3.6E-5 | 116 | 6.7E-5 |
| C10 paraffin a | 6.1E-5 | 274 | 1.7E-4 |
| o-ethyltoluene | 2.5E-5 | 115 | 4.6E-5 |
| Octanal | 3.1E-4 | 74 | 4.8E-4 |
| beta-pinene | 1.3E-5 | 128 | 2.5E-5 |
| 1,2,4-trimethylbenzene | 5.1E-5 | 150 | 1.1E-4 |
| n-decane | 8.8E-5 | 118 | 1.7E-4 |
| C10 aromatic 1 | 3.5E-6 | 111 | 6.3E-6 |
| Isobutylbenzene | 1.8E-5 | 82 | 3.0E-5 |
| sec-butylbenzene | 3.6E-6 | n/a | n/a |
| C10 olefin 2 | 5.0E-5 | 1034 | 3.1E-4 |
| 1,2,3-trimethylbenzene | 6.2E-5 | 119 | 1.2E-4 |
| C10 paraffin c | 1.9E-5 | 88 | 3.0E-5 |
| Limonene | 2.5E-5 | 41 | 3.4E-5 |
| Indan | 1.4E-5 | 110 | 2.5E-5 |
| Indene | 1.0E-5 | 1079 | 6.4E-5 |
| 1,3-diethylbenzene | 2.1E-5 | 76 | 3.4E-5 |
| C10 aromatic 2 | 1.5E-5 | 119 | 2.8E-5 |
| 1,4-diethylbenzene | 6.3E-5 | 110 | 1.2E-4 |
| 1,2-diethylbenzene | 1.1E-5 | 102 | 2.0E-5 |
| 2-propyl toluene | 1.5E-5 | 94 | 2.7E-5 |
| C10 aromatic 4 | 1.4E-5 | 118 | 2.7E-5 |
| C10 aromatic 5 | 1.3E-5 | 201 | 3.1E-5 |
| isopropyltoluene | 2.7E-5 | 137 | 5.5E-5 |
| Nonanal | 3.2E-4 | 153 | 6.9E-4 |
| n-undecane | 6.5E-5 | 108 | 1.2E-4 |
| C10 aromatic 6 | 1.8E-5 | n/a | n/a |
| 1,2,4,5-tetramethylbenzene | 2.1E-5 | 157 | 4.6E-5 |
| 1,2,3,5-tetramethylbenzene | 3.2E-5 | 162 | 7.1E-5 |
| C11 paraffin b | 1.9E-5 | 62 | 2.8E-5 |
| 1,2,3,4-trimethylbenzene | 2.8E-5 | 39 | 3.7E-5 |
| 1-methylindan | 9.6E-6 | 220 | 2.0E-5 |
| C11 aromatic 1 | 8.8E-6 | 237 | 1.9E-5 |
| C11 aromatic 3 | 9.1E-6 | 389 | 2.7E-5 |
| Dodecene-1 | 9.0E-6 | 237 | 2.4E-5 |
| Naphthalene | 2.5E-5 | 132 | 4.9E-5 |
| n-dodecane | 1.1E-4 | 135 | 2.1E-4 |
| Total Identified NMHC | 1.2E-3 | 65 | 1.8E-3 |
| Unidentified | 2.5E-4 | 109 | 4.6E-4 |

n/a- Not applicable. Only one run within detectable limits.

Table 5-5. Carbonyl (Aldehyde) Emission Factors (Site E).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| Formaldehyde | 8.8E-5 | 88 | 1.5E-4 |
| Acetaldehyde | 8.4E-5 | 100 | 1.5E-4 |
| MEK | 4.5E-6 | n/a | n/a |
| Valeraldehyde | 2.3E-5 | 52 | 3.3E-5 |

n/a- Not applicable. Only one run within detectable limits.

Table 5-6. Secondary Particulate Precursors- $NH_3$ and $SO_2$ (Site E).

| Substance | Average (lb/MMBtu) | Uncertainty (%) | 95% Confidence Upper Bound (lb/MMBtu) |
|---|---|---|---|
| $NH_3$ (dilution tunnel) | 1.1E-3 | 26 | 1.3E-3 |
| $NH_3$ (BAAQMD ST-1B) | 1.6E-3 | 25 | 2.0E-3 |
| $SO_2$ | 5.1E-4 | 107 | 9.1E-4 |

Figure 5-1 shows the data presented in Table 5-7. The majority of the mass (75 percent) is composed of organic carbon, with nitrate being the next most abundant constituent (6 percent). Compounds with all runs below detectable levels are not included in the figure. Sulfur, chloride, sodium and magnesium were all measured at detectable levels, but are not included in the sum of species, and are therefore not included in the figure.

Table 5-7. Speciation Profile for Primary Emissions- Dilution Tunnel Results (Site E).

| Substance | Average Mass Fraction (1) (%) | Uncertainty (%) | 95% Confidence Upper Bound (%) |
|---|---|---|---|
| Organic Carbon | 74.8 | 162 | 158 |
| Nitrate | 5.83 | 347 | 19.6 |
| Sulfate | 4.95 | 329 | 16.0 |
| Elemental Carbon | 4.79 | 580 | 18.6 |
| Cl | 3.76 | 287 | 11.1 |
| Ammonium | 2.49 | n/a | n/a |
| Fe | 2.14 | 324 | 6.85 |
| Si | 1.86 | 372 | 6.56 |
| Ca | 0.97 | 998 | 5.8 |
| Al | 0.70 | 987 | 4 |
| K | 0.42 | 1027 | 2.58 |
| Ag | 0.35 | n/a | n/a |
| Soluble Na | 0.34 | 263 | 0.95 |
| Cr | 0.28 | n/a | n/a |
| Zn | 0.20 | 343 | 0.68 |
| Cu | 0.17 | 363 | 0.6 |
| Ti | 0.14 | 787 | 0.68 |
| P | 0.11 | n/a | n/a |
| Ni | 0.08 | 298 | 0.24 |
| Mn | 0.06 | 669 | 0.26 |
| V | 0.06 | 833 | 0.29 |
| Pb | 0.04 | 674 | 0.17 |
| Mo | 0.03 | n/a | n/a |
| Co | 0.02 | 644 | 0.1 |
| Sr | 0.02 | n/a | n/a |
| Br | 0.02 | 929 | 0.1 |
| Zr | 0.01 | n/a | n/a |

n/a- Not applicable. Only one run within detectable limits.
1- Mass fraction is emission factor of species divided by emission factor of sum of species. Average speciated mass was greater than average total PM2.5 mass measured on the dilution tunnel filter for Runs 1 and 3.

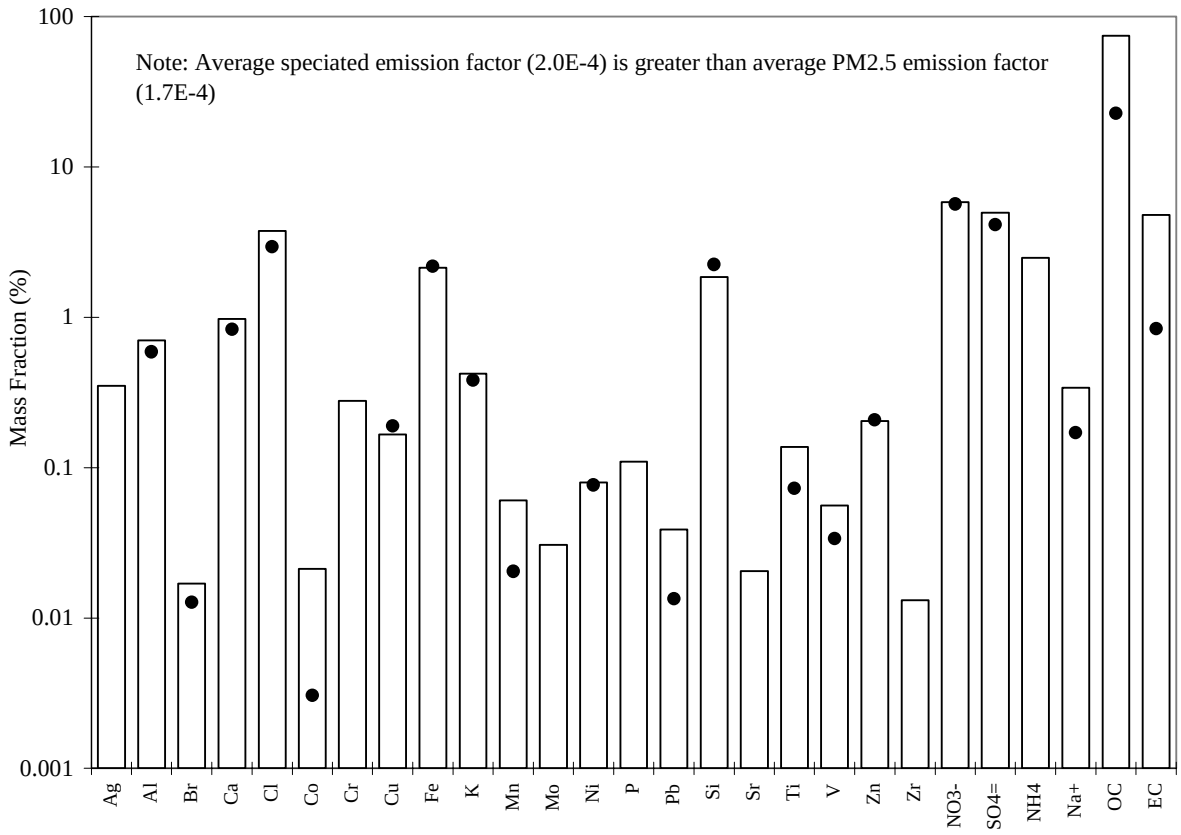



Figure 5-1. PM2.5 Speciation, as Measured by the Dilution Tunnel (Site E).

Organic Aerosols

Table 5-8 shows the organic aerosol speciation profile, expressed as a mass fraction. This mass fraction is determined by dividing the average emission factor of the emitted quantity by the average emission factor of total organic carbon, both in units of lb/MMBtu. The speciated organic carbon, measured as SVOCs, accounts for approximately 5 percent of the total organic carbon. The data from Table 5-8 are shown in Figure 5-2. As can be seen on the figure, the most abundant fraction of the speciated organic aerosol is 1,4+1,5+2,3-dimethylnaphthalene (0.9 percent), followed by 2-methylnaphthalene (0.5 percent).

Table 5-8. Organic Aerosol Speciation Profile (Site E).

| Substance | Average Mass Fraction (1) (%) | Uncertainty (%) | 95% Confidence Upper Bound (%) |
|---|---|---|---|
| 1,4+1,5+2,3-dimethylnaphthalene | 0.94 | 829 | 4.8 |
| 2-methylnaphthalene | 0.47 | 787 | 2.3 |
| 1+2-ethylnaphthalene | 0.38 | 47 | 0.53 |
| 1,3+1,6+1,7-dimethylnaphthalene | 0.36 | n/a | n/a |
| Acenaphthene | 0.36 | 741 | 1.7 |
| Phenanthrene | 0.36 | 161 | 0.78 |
| Dibenzofuran | 0.27 | n/a | n/a |
| 1-methylnaphthalene | 0.26 | 745 | 1.2 |
| 2,6+2,7-dimethylnaphthalene | 0.20 | n/a | n/a |
| Fluorene | 0.17 | n/a | n/a |
| Biphenyl | 0.15 | n/a | n/a |
| Xanthone | 0.11 | 1123 | 0.74 |
| C-methylphenanthrene | 0.089 | n/a | n/a |
| 7-methylbenzo(a)pyrene | 0.078 | 64 | 0.12 |
| C-dimethylphenanthrene | 0.077 | n/a | n/a |
| Pyrene | 0.068 | 810 | 0.34 |
| Fluoranthene | 0.059 | 214 | 0.12 |
| A-trimethylnaphthalene | 0.055 | 231 | 0.12 |
| 2-methylphenanthrene | 0.055 | 241 | 0.15 |
| C-trimethylnaphthalene | 0.050 | 162 | 0.092 |
| 1-methylphenanthrene | 0.042 | n/a | n/a |
| 7-methylbenz(a)anthracene | 0.033 | 767 | 0.16 |
| B-trimethylnaphthalene | 0.031 | 157 | 0.057 |
| 4-methylpyrene | 0.023 | n/a | n/a |
| D-MePy/MeFl | 0.023 | 191 | 0.055 |
| Anthrone | 0.022 | 91 | 0.038 |
| E-trimethylnaphthalene | 0.019 | 293 | 0.048 |
| F-trimethylnaphthalene | 0.018 | 168 | 0.034 |
| C-MePy/MeFl | 0.002 | n/a | n/a |
| Anthracene | 0.0004 | n/a | n/a |

n/a- Not applicable. Only one run was within detectable limits.

1- Mass fraction expressed as a percent of total organic carbon.

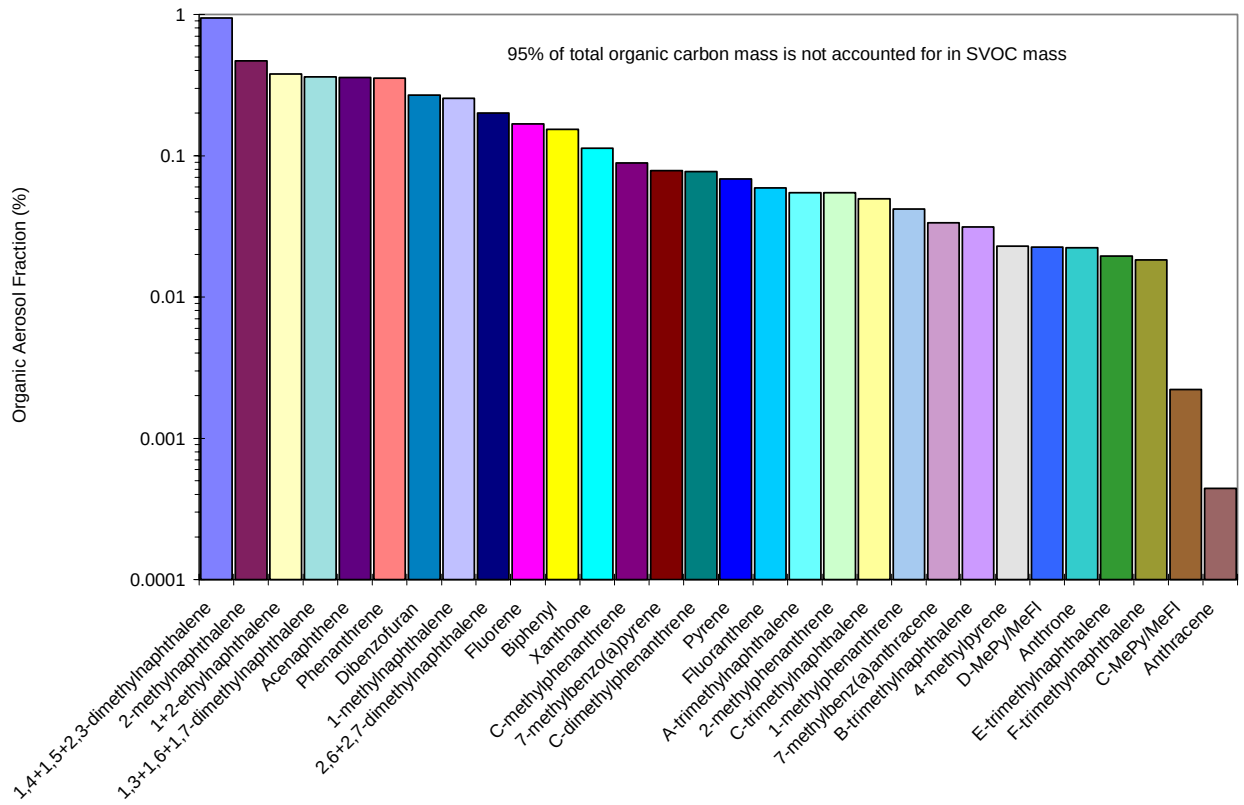



Figure 5-2. Organic aerosol speciation (Site E).

Method PRE-4/202

Table 5-9 shows the speciation profile of the PM2.5 mass as measured by Method PRE-4/202. Mass fraction is the ratio of the measured quantity to the total PM2.5 mass (filterable and condensable particulate). In this table, total condensable particulate has been subdivided into its respective organic and inorganic fractions for illustrative purposes. Inorganic condensable particulate has been further subdivided to show the amount of PM2.5 mass accounted for by sulfate.

The data from Table 5-9 are shown in Figure 5-3. As can be seen from the figure, nearly all of the PM2.5 mass comes from CPM (99 percent). The large majority of CPM is contained in the inorganic fraction, which accounts for 90 percent of the total PM2.5 mass.

Table 5-9. Speciation Profile for PM2.5 Measured by Method PRE-4/202 (Site E).

| Substance | Average Mass Fraction (1) (%) | Uncertainty (%) | 95% Confidence Upper Bound (%) |
|---|---|---|---|
| Filterable PM2.5 | 1.1 | n/a | n/a |
| Total Condensable PM | 98.9 | 66 | 149 |
| Organic CPM | 5.7 | n/a | n/a |
| Inorganic CPM | 90.3 | 75 | 142 |
| Sulfate (as $SO_4^=$) | 51 | 56 | 74 |
| Total | 100 | | |

(1) Mass fraction is percent of total PM2.5 (filterable and condensible).

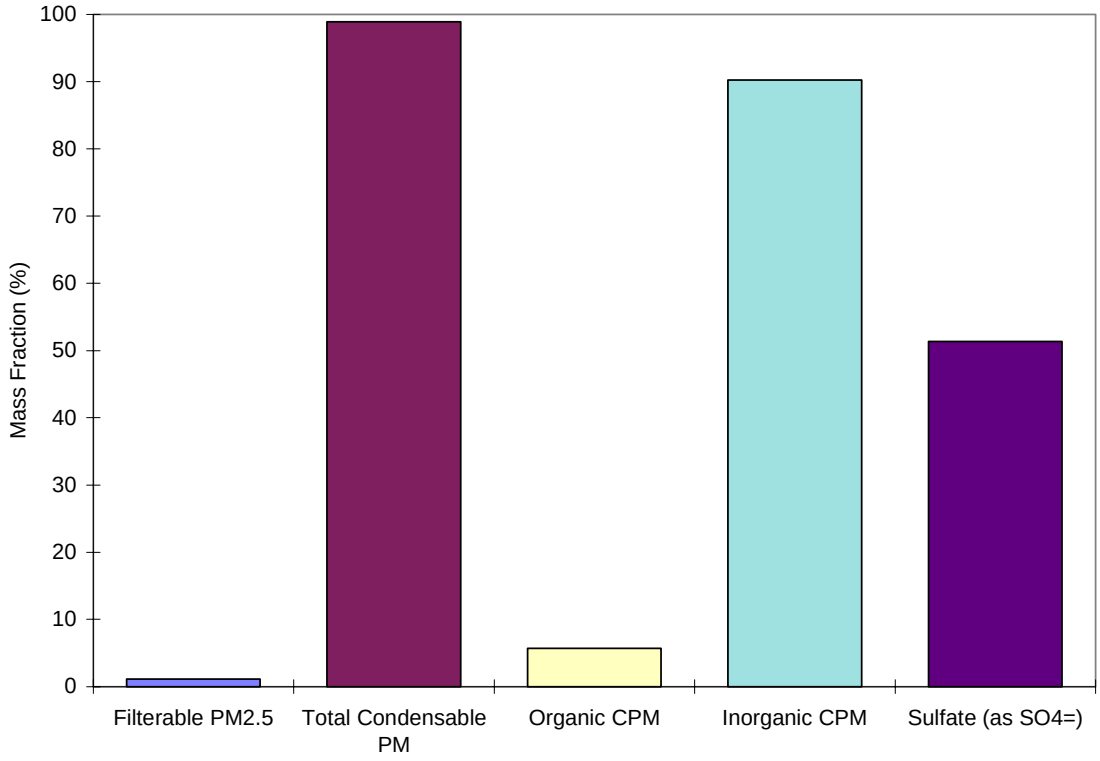



Figure 5-3. Method PRE-4/202 PM2.5 mass speciation profile (Site E).

# 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. In-stack (Method PRE-4 and Method 17) and impinger filters (Method 202) were stored in a desiccator at ambient conditions prior to shipment. 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.

## GRAVIMETRIC ANALYSIS

### Dilution Tunnel Filters

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.

In-Stack Filters

The balance was calibrated daily with two "S" type weights in the range of the media being weighed and the tare was set prior to weighing each batch of filters. If the results of these performance tests had deviated by more than ±1 mg, the balance would have been recalibrated. A recalibration was not required. If consecutive sample weights deviated by more than ±0.5 mg, the sample was returned to the desiccator for at least 6 hours before reweighing. Pre- and post-weights, check weights and reweights (if required) were recorded on data sheets.

Table 6-1 presents the results of the methylene chloride, water and acetone rinse blanks. The acetone blank values were used to correct the EPA Method PRE-4 particulate data. Results of the filter blank weights are also presented in Table 6-2. All negative filter weights were treated as a zero in calculations.

Table 6-1. Filter and Reagent Blank Results.

| Sample | Mass (mg) |
|---|---|
| Method 202 Water Reagent Blank | 0.3 |
| Method 202 Dichloromethane Reagent Blank | ND (1) |
| Acetone Recovery Blank | 2.71 |
| Method 8 IPA Reagent Blank | 0.05 |
| Method 202 Impinger Filter Blank | 0.3 |
| Method PRE-4 Filter Blank | -0.2 |
| Dilution Tunnel Filter Field Blank | -0.6 (2) |
| Dilution Tunnel Filter Trip Blank | -0.01 |

1- Detection limit = 1 mg
2- Teflon membrane separated from support ring causing damage to the filter

An analysis of the acetone rinse blanks is presented in Table 6-2. The particulate mass detection limit was calculated as three times the standard deviation of the results of the field blank acetone rinses and the acetone recovery blank. The resulting detection limit of approximately 3.7 mg further indicates that the filterable particulate levels at the turbine were near detection limits. Therefore, the filterable particulate data from Method PRE-4 are presented in Section 5 for qualitative purposes only.

Table 6-2. Results from Acetone Blank Rinses.

| Sample Fraction | Mass (mg) |
|---|---|
| PM10 cyclone catch rinse | 0.07 |
| PM2.5 cyclone catch rinse (2.5-10 µm) | 0.19 |
| <PM2.5 rinse (<2.5 µm) | 0.57 |
| Recovery Blank | 2.71 |
| Detection Limit (3*standard deviation) | **3.7** |

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. Standards from the National Institute of Standards and Technology (NIST) 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.

Results from the field blank are presented in Table 6-3. Only magnesium, phosphorous and silicon were present at detectable levels. The average concentration of the stack samples was within an order or magnitude of the field blank for phosphorous. The concentrations of magnesium and silicon in the ambient sample were within an order or magnitude of the field blank concentrations.

Table 6-3. XRF Elemental Analysis Field Blank Results.

| Element | mg/dscm |
|---|---|
| Mg | 7.4E-5 |
| P | 7.5E-5 |
| Si | 8.2E-5 |

Results from the trip blank are presented in Table 6-4. Only aluminum, magnesium and sodium were present at detectable levels. The average concentration of the stack samples was within an order or magnitude of the trip blank for magnesium. The concentrations of aluminum and magnesium in the ambient sample were less than the concentrations in the trip blank. The average sodium concentration in the ambient sample was within an order of magnitude of the concentration in the trip blank.

Table 6-4. XRF Elemental Analysis Trip Blank Results.

| Element | mg/dscm |
|---|---|
| Al | 1.2E-4 |
| Mg | 3.0E-4 |
| Na | 2.8E-4 |

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.

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.

Elemental carbon was below detection limits on the dilution tunnel filter blank (Table 6-5). The average stack-sample organic carbon concentration was within an order of magnitude of the field and trip blank concentrations. The OC concentration in the ambient sample was less than the concentrations in the field blank and the trip blank.

Table 6-5. OC/EC Analysis Field and Trip Blank Results (mg/dscm).

| | Field Blank | Trip Blank |
|---|---|---|
| OC | 6.2E-2 | 3.2E-2 |
| EC | ND | ND |

SULFATE, NITRATE, AND CHLORIDE ANALYSIS

The primary standard solutions containing NaCl, $NaNO_3$ and $(Na)_2SO_4$ 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 quality assurance (QA) check. These standards (ERA Wastewater Nutrient and ERA Mineral WW) were traceable to 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.

All ions in the field blank were below detection limits.

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 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 mass selective detector (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.

Results from the field blank are presented in Table 6-6. Compounds below detection limits in the field blank are not included in the table. (Results to be available for final draft)

Table 6-6. PUF/XAD Field Blank Results (mg/dscm).

| Compound | Field Blank (1) | MDL (1) |
|---|---|---|
| | | |

MDL- Method detection limit
1- Assumed sample volume of approximately 40 $m^3$.

VOC ANALYSIS

Calibration curves were performed weekly. Volatile organic compounds 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.

Results from the Tenax field blank are shown in Table 6-7. Of all the VOCs detected in the field blank, only heptadecane, hexadecane, pentadecane and tetradecane have average stack concentrations that are an order of magnitude greater than their concentrations in the field blank; the concentrations of styrene and p-isopropyltoluene are higher in the field blank than their average stack concentrations. Most field blank VOC concentrations are greater than their concentrations in the ambient sample. Only m&p-xylenes, nonane, ethylbenzene, o-xylene and naphthalene are greater in the ambient sample, but they are all still within two times of the blank concentrations.

Table 6-7. Tenax Field Blank (mg/dscm).

| Compound | Field Blank |
|---|---|
| Ethylbenzene | 2.2E-3 |
| m&p-xylene | 3.4E-3 |
| Styrene | 4.8E-2 |
| o-xylene | 1.9E-3 |
| Nonane | 2.3E-3 |
| Benzaldehyde | 2.1E-2 |
| alpha-Pinene | 2.5E-3 |
| Propylbenzene | 4.1E-4 |
| m-ethyltoluene | 8.7E-4 |
| Phenol | 5.6E-3 |
| 1,2,4-trimethylbenzene | 7.8E-4 |
| Decane | 7.8E-3 |
| p-isopropyltoluene | 1.2E-2 |
| (+/-)-limonene | 1.0E-3 |
| Acetophenone | 6.0E-3 |
| Undecane | 4.1E-3 |
| Naphthalene | 4.4E-4 |
| Dodecane | 2.4E-3 |
| Tridecane | 7.8E-4 |
| Biphenyl | 2.1E-3 |
| Tetradecane | 1.0E-3 |
| Pentadecane | 1.9E-3 |
| Hexadecane | 5.9E-4 |
| Heptadecane | 3.5E-4 |
| Hexadecanoic acid | 2.9E-2 |

INORGANIC RESIDUE ANALYSIS

A reagent blank was analyzed in the same manner as the field samples, as described in Section 3. The results are presented in Table 6-8. S, Zn and sulfate are the only compounds with stack concentrations more than an order of magnitude greater than the equivalent reagent blank concentration. The average sample concentrations of Be, Cd, Cr, Co, Fe, Pb, Mo, Ni, P, K, Si, Ag, Tl, Sn, Ti, V and Zr are all less than the concentrations in the reagent blank, with most having sample concentrations approximately equal to the reagent blank concentrations.

Table 6-8. Method 202 Water Reagent Blank Results (mg/dscm).

| Compound | | Concentration |
|---|---|---|
| Fluoride | | 9.0E-3 |
| Chloride | | 6.1E-2 |
| Nitrate (as N) | | 1.9E-2 |
| Sulfate (as $SO_4^=$) | < | 5.2E-3 |
| Al | < | 9.6E-4 |
| Ba | < | 3.2E-5 |
| Be | < | 3.2E-5 |
| B | < | 3.2E-4 |
| Cd | < | 6.4E-5 |
| Ca | | 3.2E-2 |
| Cr | < | 1.3E-4 |
| Co | < | 3.2E-4 |
| Cu | < | 1.9E-4 |
| Fe | < | 6.4E-4 |
| Pb | < | 6.4E-4 |
| Mg | | 4.9E-3 |
| Mn | < | 1.6E-4 |
| Mo | < | 1.6E-4 |
| Ni | < | 6.4E-4 |
| P | < | 1.9E-3 |
| K | < | 3.2E-2 |
| Si | | 1.8E-2 |
| Ag | < | 3.2E-4 |
| Na | | 1.1E-1 |
| Sr | | 1.2E-4 |
| S | | 1.2E-2 |
| Tl | < | 1.9E-3 |
| Sn | < | 1.6E-3 |
| Ti | < | 3.2E-4 |
| V | < | 3.2E-4 |
| Zn | < | 3.2E-4 |
| Zr | < | 3.2E-4 |

< - below limit of quantitation (Detection limit x 3.33)

# Section 7
# DISCUSSION AND FINDINGS

PM 2.5 emissions from a natural gas-fired turbine measured by the dilution tunnel technique were found to be approximately 18 times lower than that measured by conventional in-stack methods (Methods PRE-4/202).

Dilution tunnel sampling is designed to capture filterable matter and any aerosols that condense under simulated stack plume conditions. Stack gas is cooled to ambient temperatures, typically 60-70 °F in these tests, in the dilution tunnel and samples are then collected from the diluted air mass. Conventional in-stack methods are designed to collect particles that are filterable at the stack temperature along with capturing those likely to condense in ambient air by collecting them in a series of aqueous impingers placed in an ice bath. The gas temperature leaving the impingers is typically 55-65 °F; thus, both systems cool the sample gas to similar final temperatures. However the in-stack methods cool the sample rapidly without dilution by quenching the gas sample in water maintained at near freezing temperature, while the dilution tunnel cooled the sample more slowly by mixing it with ambient air. Since aerosol condensation mechanisms depend on temperature, concentration, residence time and other factors, it is not surprising that the results of the two methods differ. However, mechanistic variations alone cannot account for the magnitude of the difference observed in these tests.

As shown in Table 5-1, filterable PM 2.5 measured by the in-stack method (9.6 E-5 lb/MMBtu) is less than the dilution tunnel value of 1.7 E-4 lb/MMBtu. In fact, 99 percent of the mass found by Method PRE-4/202 was contained in the condensable fraction collected in the impingers. This is similar to what was found in earlier tests on gas-fired units (England et al., 2000). A review of those data led us to suspect the validity of the conventionally obtained data on condensables and initiate a more extensive analysis of this fraction in this study than that prescribed by Method 202. Most of the inorganic CPM mass appears to be composed of sulfate, chloride and ammonium, with small contributions from Na, Ca, Zn, Ba, Mn, Sr (Figure 7-1). When all species are summed, the total mass is less than the inorganic CPM mass, with approximately 24 percent of the mass unaccounted for by the sum of species. $SO_2$ stack

emissions measured by the dilution tunnel averaged approximately 0.1 ppm. The extensive instrumental analysis (discussed in Section 4) of the impinger solutions does not find any significant levels of other metals.

Table 7-1 presents a comparison of the sulfate measurements, expressed as sulfate ion in mg/dscm. The sulfate levels in the impinger aliquot from the Method 202 train and those from the Method 8 train are approximately equals, and are consistent with previous tests of gas-fired units. The sulfate measured in the Method 202 aliquot is approximately two times higher than the $SO_2$ (as $SO_4^{=}$) measured by the potassium carbonate-impregnated cellulose-fiber filter downstream of the dilution tunnel. Previous test on the natural gas show sulfur at undetectable levels. Compared to the measured $SO_2$ value, the sulfate levels measured by the dilution tunnel account for approximately one percent of the $SO_2$ in the flue gas and are within an order of magnitude of sulfate measured in the ambient sample.

Table 7-1. Comparison of Sulfate Measurements (mg/dscm).

| | Run 1 | Run 2 | Run 3 | Run 4 | Average |
|---|---|---|---|---|---|
| Impinger aliquot (M202) | 1.1 | 1.1 | 0.76 | 0.99 | 0.99 |
| Impinger aliquot (M8) | 1.2 | 1.2 | 0.79 | 1.1 | 1.1 |
| Dilution tunnel | 0.0032 | 0.020 | 0.0019 | NV | 0.0084 |
| Ambient (1) | 0.0021 | -- | -- | -- | 0.0021 |
| Dilution tunnel $SO_2$ measurement (as $SO_4^{=}$) | 0.69 | 0.86 | 0.48 | 0.06 | 0.52 |

(1) One ambient sample taken on separate day.

The formation of artifact sulfate caused by $SO_2$ absorption in the aqueous solutions appears likely. Both $SO_2$ and oxygen are soluble in water and the dissolved $H_2SO_3$ can slowly oxidize to sulfate. This is implicitly recognized by Method 202 which recommends purging the impingers with nitrogen (air is also acceptable) to minimize this bias. Method 202 also provides the option of omitting the post-test purge if the pH of the impingers is above 4.5; while the pH of the impingers met this criterion in our test, we performed the nitrogen purge anyway. However, earlier studies of systems having $SO_2$ levels of approximately 2000 ppm show that that these artifacts occur in spite of post-test purging (Filadelfia and McDaniel, 1996).

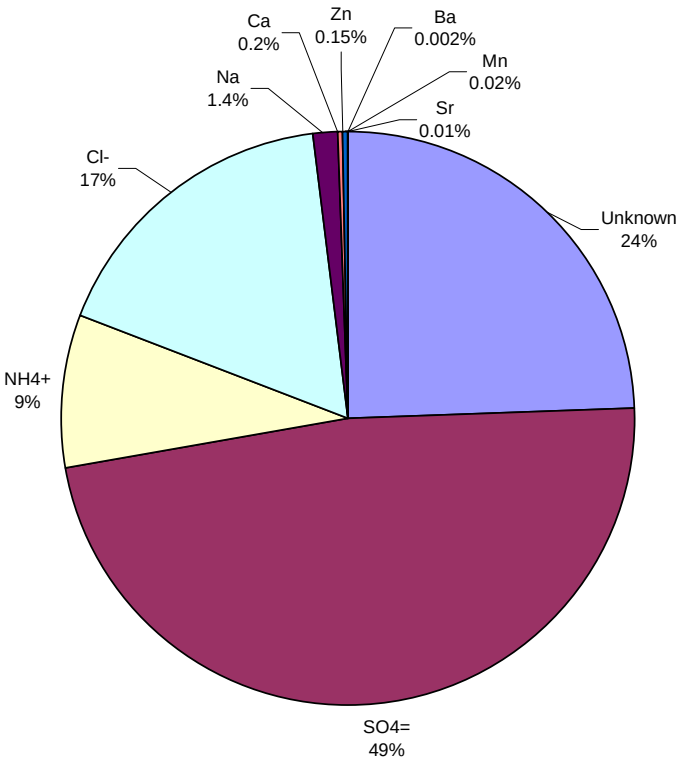



Figure 7-1. Inorganic CPM Residue Speciation Results.

In the absence of any documented reports to evaluate artifact formation at low $SO_2$ concentrations, a laboratory scale study was conducted evaluating potential bias at these concentrations. The experiments passed simulated combustion gas containing representative amounts of $O_2$, $CO_2$, $N_2$, $NO_x$, and $SO_2$ through Method 202 impinger trains. No condensable substances were added. Tests were performed both with and without post-test nitrogen purges for 1-hour and 6-hour sampling runs for mixtures containing 0, 1, and 10 ppm $SO_2$.

Significant amounts of sulfate, proportional to the $SO_2$ concentration in the gas, were found to be present in impingers that had not been purged. However, while the post-test purge definitely reduced the sulfate concentrations it did not eliminate artifact formation. Purging was less efficient for the 6-hour runs relative to the 1-hour runs, indicating that most of the $SO_2$ oxidation occurs within this period. This result shows that the sulfate, and hence most of the condensable

particulate collected by Method 202 in our field test results come from this mechanism of artifact sulfate formation from dissolved $SO_2$.

Corio and Sherwell (2000) reviewed emissions data collected from fossil fuel fired units by Method 201A/202 and raised the question of artifact formation. Table 7-2 presents some of their data (Lakewood Cogeneration and Kamite Milford units) along with data collected by the DOE PM 2.5 program for gas-fired sources (Sites D and E) and its predecessor conducted for API (Sites A, B and C). These data compare results from the filterable and condensable particulate fractions, along with the composition of CPM.

As can be seen in Table 7-2, the CPM data from Site E presented in this report are slightly higher than the Lakewood Cogeneration data and lower than the PM2.5 program data collected at other gas-fired combustion units, except for Site C. The filterable fraction is also comparable to the Lakewood Cogeneration units, but higher than refinery gas-fired boiler (Site A) and natural gas-fired steam generator (Site C) tested as part of the API PM2.5 program.

The CPM emission factors obtained using the Method PRE-4/202 trains are in general agreement with those found in the EPA's AP-42 emission factor database (0.0030 lb/MMBtu from tests versus 0.0047 lb/MMbtu in AP-42) for stationary gas turbines (Table 7-3), but the filterable catch is almost an order of magnitude lower than the AP-42 factor (EPA, 2000). Since the EPA results were obtained using the same method, a similar bias in the condensable catch is likely in those data. Nevertheless, the semi-quantitative agreement of our results with those presented in the EPA database provides additional confidence in the validity of the results found here.

Table 7-2. Comparison of Data from Corio and Sherwell (2000) and PM2.5 Program Data.

| Source | Unit Type | Filterable PM | | Condensable PM | | Makeup of CPM | |
|---|---|---|---|---|---|---|---|
| | | lb/MMBtu | % of Total PM10 | lb/MMBtu | % of Total PM10 | Inorganic Fraction (% of Total CPM) | Organic Fraction (% of Total CPM) |
| Lakewood Cogeneration | Natural Gas-fired Boiler | 0.0019 | 46 | 0.0022 | 54 | 0.0015 (66) | 0.00076 (34) |
| Lakewood Cogeneration – Unit #1 | Natural Gas-fired Turbine | 0.00021 | 14 | 0.0012 | 86 | 0.0010 (81) | 0.00023 (19) |
| Lakewood Cogeneration – Unit #2 | Natural Gas-fired Turbine | 0.00052 | 33 | 0.0011 | 67 | 0.00084 (78) | 0.00024 (22) |
| Kamine Milford[1] | Natural Gas-fired Turbine | 0.0132 | 56 | 0.0105 | 44 | 0.0045 (43) | 0.0060 (57) |
| Kamine Milford[2] | Natural Gas-fired Turbine | 0.0015 | 12 | 0.0112 | 88 | 0.0067 (60) | 0.0045 (40) |
| Kamine Milford[3] | Natural Gas-fired Turbine | 0.0012 | 10 | 0.0107 | 90 | 0.0079 (74) | 0.0028 (26) |
| Kamine Milford[4] | Natural Gas-fired Turbine | 0.0014 | 12 | 0.0100 | 88 | 0.0066 (66) | 0.0034 (34) |
| Site A | Refinery Gas-fired Boiler | 0.00016 | 2 | 0.0097 | 98 | 0.0091 (94) | 0.00064 (6) |
| Site B | Refinery Gas-fired Process Heater | 0.00064 | 12 | 0.0046 | 88 | 0.0048 (97) | 0.00024 (3) |
| Site C | Natural Gas-fired Steam Generator | 0.00008 | 6 | 0.0012 | 94 | 0.00052 (44)[5] | 0.00048 (41)[5] |
| Site D | Refinery Gas-fired Process Heater | 0.00061 | 3 | 0.025 | 97 | 0.023 (92)[5] | 0.0017 (7)[5] |
| Site E | Natural Gas-fired Turbine | 0.00029 | 9 | 0.0030 | 91 | 0.0027 (91)[5] | 0.00055 (6)[5] |

[1] Steam injection (SI) on, waste heat recovery boiler (WHRB) off.
[2] SI off, WHRB off.
[3] SI on, WHRB on.
[4] SI off, WHRB on.
[5] Remaining CPM mass accounted for by back-half filter and was not characterized.

Table 7-3. Comparison of EPA AP-42 Database and PM2.5 Program Data.

| Source | Unit Type | Total PM10 | Filterable PM | | Condensable PM | |
|---|---|---|---|---|---|---|
| | | lb/MMBtu | lb/MMBtu | % of Total PM10 | lb/MMBtu | % of Total PM10 |
| AP-42 | Natural Gas Combustion | 0.0075 | 0.0019 | 25 | 0.0056 | 75 |
| AP-42 | Natural Gas-Fired Stationary Gas Turbine for Electricity Generation (Uncontrolled) | 0.0066 | 0.0019 | 29 | 0.0047 | 71 |
| Site A | Refinery Gas-fired Boiler | 0.0099 | 0.00016 | 2 | 0.0097 | 98 |
| Site B | Refinery Gas-fired Process Heater | 0.0052 | 0.00064 | 12 | 0.0046 | 88 |
| Site C | Natural Gas-fired Steam Generator | 0.0013 | 0.00008 | 6 | 0.0012 | 94 |
| Site D | Refinery Gas-fired Process Heater | 0.026 | 0.00061 | 3 | 0.025 | 97 |
| Site E | Natural Gas-fired Turbine | 0.0033 | 0.00029 | 9 | 0.0030 | 91 |

These results show that traditional source testing methods, such as EPA Method 202, probably overestimate particulate mass emissions by erroneously determining high levels of condensable particulate sulfate. In addition, this method may also overestimate the condensable organic fraction. The low filterable PM results 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 tunnels provide conditions that more closely simulate true atmospheric condensation conditions, as compared to impinger condensation, results obtained by this technique are more representative of the actual particulate emissions from gas-fired combustion sources such as this boiler.

FORMALDEHYDE

Formaldehyde emissions from the turbine were measured using DNPH cartridges downstream of the dilution tunnel. A number of field blanks were taken during the test in addition to a tunnel blank, which sampled only ambient air through the tunnel. Although the field blanks did not contain any detectable amounts of formaldehyde, the tunnel blank did. Figure 7-2 shows the stack sample results corrected for the concentration in the tunnel blank and the tunnel blank and ambient concentrations, uncorrected. In some cases, the concentration in the tunnel blank was greater than the sample concentration, causing the result to be negative. All concentrations have been corrected for the dilution ratio, and are in-stack concentrations. It is apparent from the figure that the formaldehyde concentrations are significantly different when the duct burners are

on compared to when they are off and the gas turbine is the only emission source. In addition, the emissions from the gas turbine only are below the detection limit, indicating that the gas turbine is not a significant source of formaldehyde emissions.

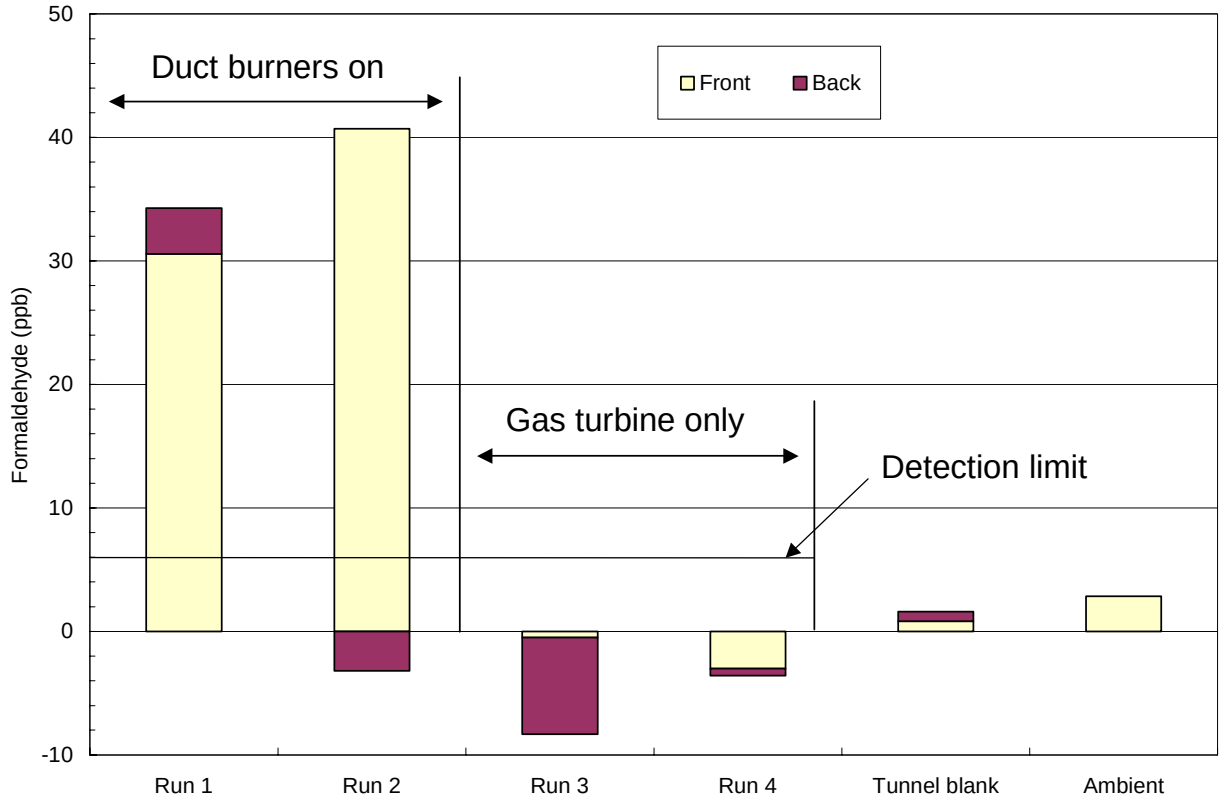



Figure 7-2. Tunnel Blank-Corrected Formaldehyde Concentrations, as Measured by the Dilution Tunnel (Site E).

## POTENTIAL EMISSIONS MARKER SPECIES

The results obtained using the dilution tunnel are believed to provide the best representation of the chemical species present in the stack gas emissions. Ions, carbon, and other 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 good markers of natural gas combustion for this source.

Concentrations of all detected species have a higher in-stack average concentration than their concentrations in the ambient air sample (Figure 7-3), indicating that the species originate from the combustion process. The average concentrations of Br, Cl, K, Mg, Na, Pb, S, chloride, nitrate, and sulfate are within a factor of ten of their respective ambient air concentrations. OC, EC and ammonium are the species with the higher concentrations that are more than an order of magnitude greater than the ambient concentrations, and might be potential marker species.

However, some species cannot reliably be distinguished because their in-stack concentrations are within a factor of ten from the minimum method detection limits (Figure 7-4); these include: Ag, Br, Co, Mn, Mo, P, Pb, Sr, Ti, V, Zr, chloride, nitrate, sulfate, ammonium, and EC. The above two criteria leave OC and ammonium as potential marker species.

Subtraction of the ambient from in-stack concentrations provides an indication of which species can be considered to be emissions markers. Ignoring species found near detection limits, the resulting emissions profile (Figure 7-5) suggests that these are OC, Cl, ammonium, and Fe.

The uncertainty of several of these values is large, as reflected in the high standard deviations, casting doubt on any of the species being definitively used as an emissions marker. The sum of the species shown in Figure 7-5 comprises 122 percent of the PM2.5 mass. Other compounds were present at lower levels but the low concentrations and high or unknown standard deviations associated with these suggest that they may not be reliable markers.

Another potentially useful marker for source emissions is the organic emissions profile. All of the SVOCs detected were present at low concentrations. Approximately fifty percent of the SVOC compounds at detectable levels in the stack gas are within a factor of ten of their concentration in the ambient air. Total SVOCs accounts for approximately 5 percent of the OC measured by the dilution tunnel indicating the presence of unspeciated organics. This large difference is at least partly due to the difference in analytical methods since the TOR method defines OC somewhat arbitrarily, as well as by the presence of organics that are not quantifiable by the methods used in this study.

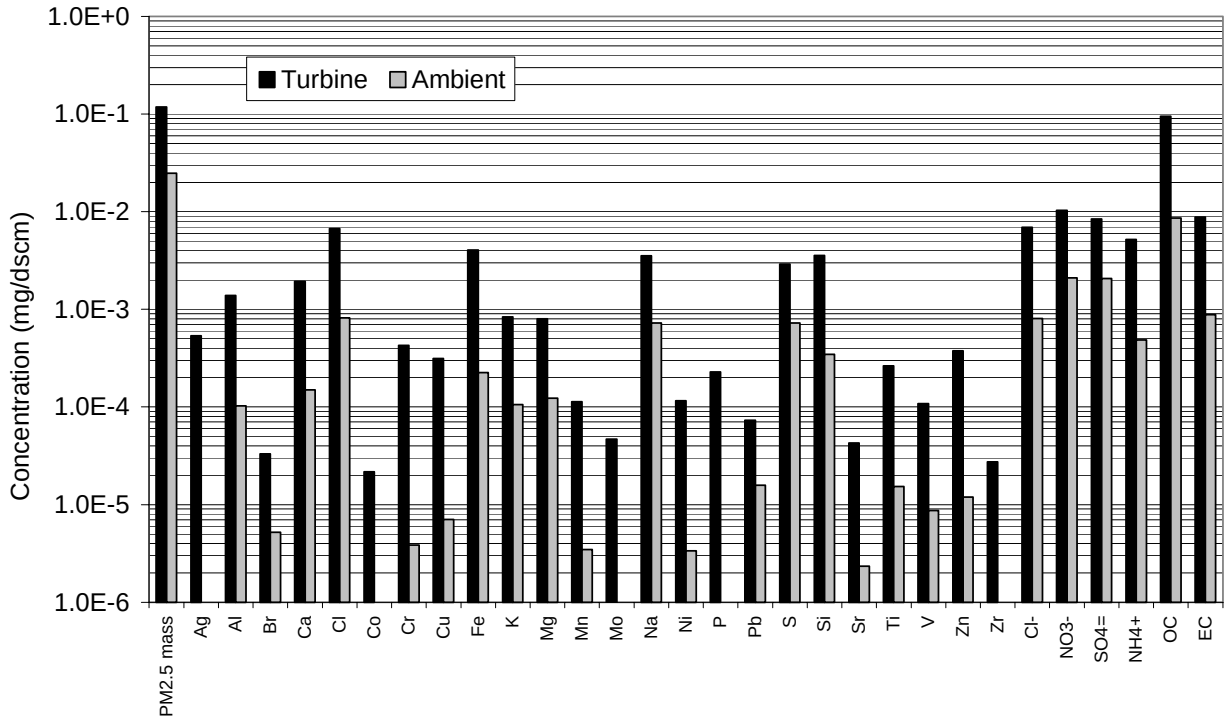



Figure 7-3. Mass Speciation for Dilution Tunnel Ambient and Stack Samples (Site E).

Organic carbon emissions for Site E were approximately equal to those found at Site A studied earlier in the API PM2.5 project (Table 7-4), and within an order of magnitude of those from Site C. In contrast, measurable SVOC emissions at Site E were slightly higher than those at Site A, resulting in a greater percentage of OC being speciated. VOC emissions from Site E were comparable to other sites to date.

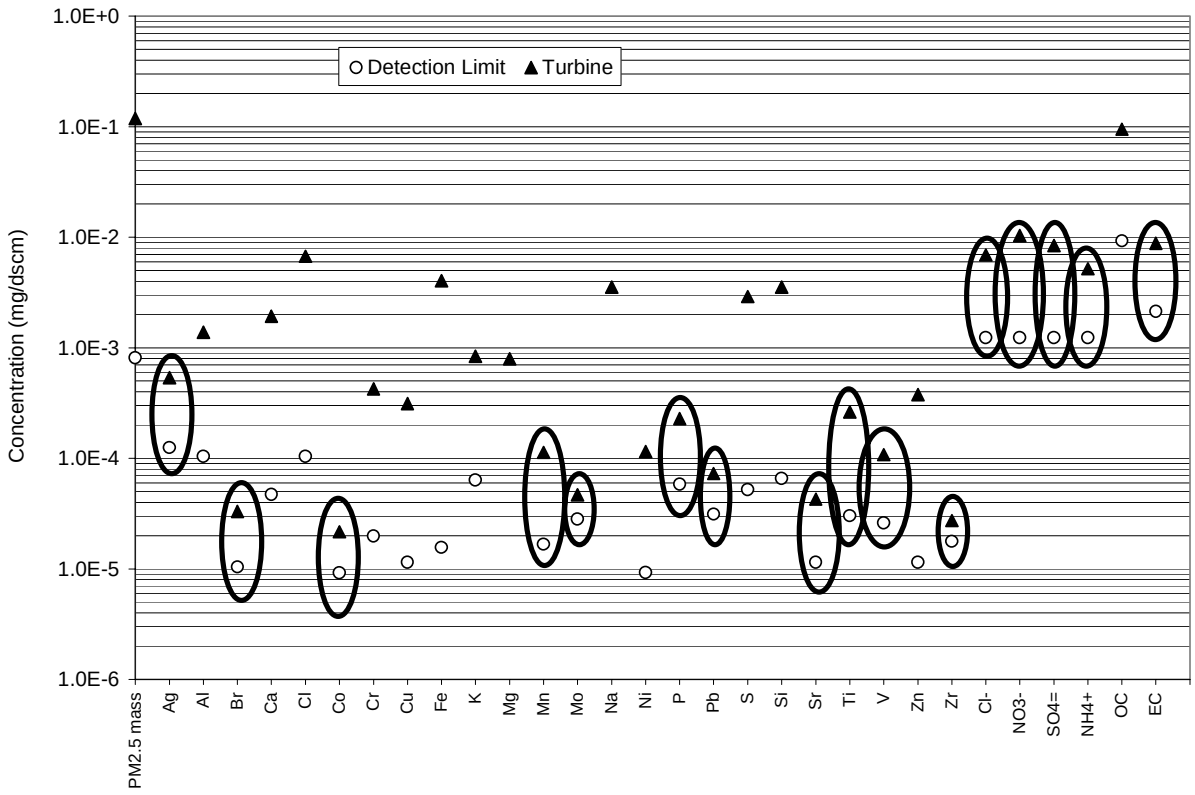



Figure 7-4. Comparison of Average Sample Concentration and Detection Limits (Site E).

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 are more likely to be found within the volatile and semivolatile organic compounds. For Site E, approximately half of the SVOCs present at detectable levels were at least 10 times greater than levels in the ambient air. In particular, 1,4+1,5+2,3-dimethylnaphthalene, 1+2-ethylnaphthalene, 2,3,5+I-trimethylnaphthalene and xanthone are present at elevated concentrations relative to the other SVOCs and their respective ambient concentrations, and 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 combustion sources.

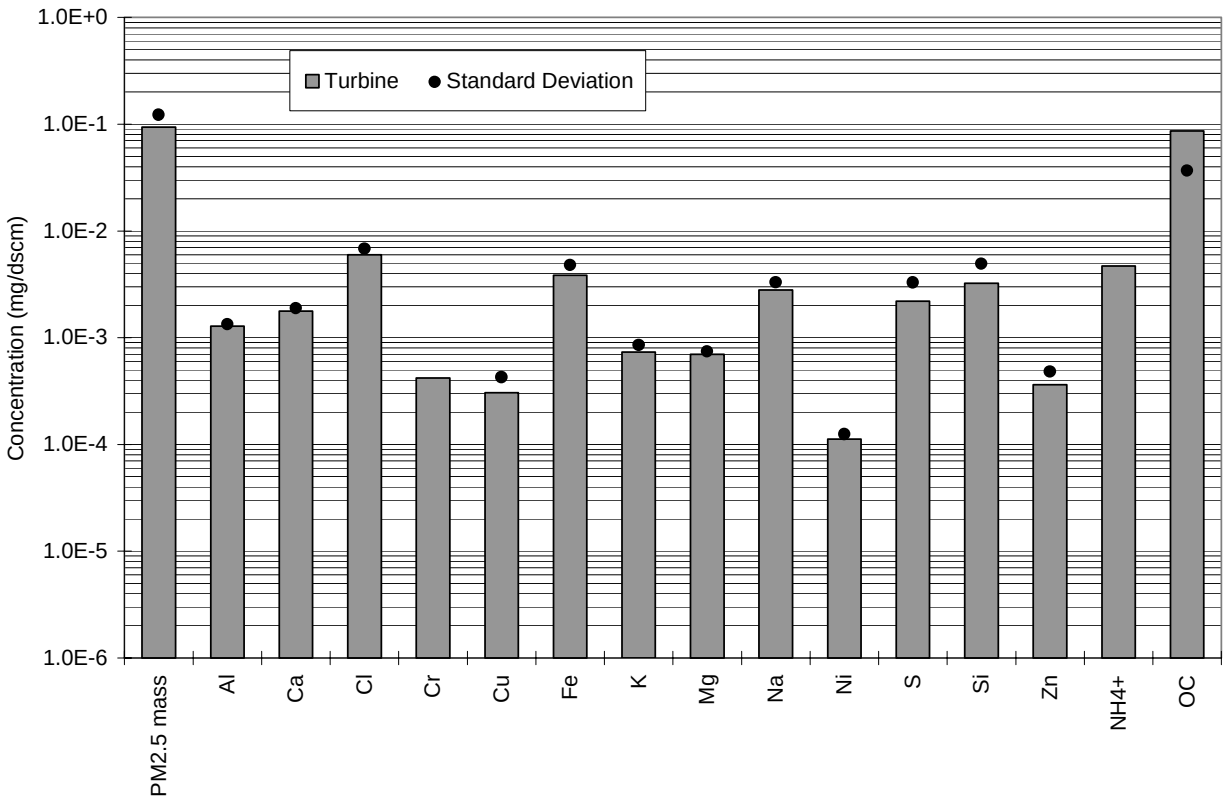



Figure 7-5. Average Sample Concentration Minus Ambient Concentration (Site E).

Volatile organic species found at levels significantly different to the ambient air include hexadecanoic acid, nonanal, acetophenone, decanal, and styrene, which may be potential marker species. 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.

Table 7-4. Average Organic Aerosol Emission Factor 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 D | Refinery Gas-fired Process Heater | 6.5E-5 | 7.1E-6 | 7.2E-5 | 1.6E-5 | 7.6E-4* |
| Site E | Natural Gas-fired Turbine | 1.4E-4 | 1.2E-5 | 1.5E-4 | 7.7E-6 | 5.6E-4* |

* Does not include VOCs from canister samples

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