August 2001

# Environmental Technology Verification Report

## OPSIS AB
## SM 200 AUTOMATIC
## PARTICLE MONITOR

Prepared by

Battelle
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Battelle

Under a cooperative agreement with

EPA U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

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# ETV Joint Verification Statement

| | | | |
|---|---|---|---|
| **TECHNOLOGY TYPE:** | **Continuous Ambient Fine Particle Monitor** | | |
| **APPLICATION:** | **MEASURING FINE PARTICLE MASS IN AMBIENT AIR** | | |
| **TECHNOLOGY NAME:** | **SM 200 Automatic Particle Monitor** | | |
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups that consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Advanced Monitoring Systems (AMS) Center, one of six technology centers under ETV, is operated by Battelle in cooperation with EPA's National Exposure Research Laboratory. The AMS Center has recently evaluated the performance of continuous monitors used to measure fine particulate mass and species in ambient air. This verification statement provides a summary of the test results for the Opsis AB SM 200 automatic particle monitor.

## VERIFICATION TEST DESCRIPTION

The objective of this verification test is to provide quantitative performance data on continuous fine particle ($PM_{2.5}$) monitors under a range of realistic operating conditions. To meet this objective, field testing was conducted in two phases in geographically distinct regions of the United States during different seasons of the year. The first phase of field testing was conducted at the ambient air monitoring station on the Department of Energy's National Energy Technology Laboratory campus in Pittsburgh, PA, from August 1 to September 1, 2000. The second phase of testing was performed at the California Air Resources Board's ambient air monitoring station in Fresno, CA, from December 18, 2000, to January 17, 2000. Specific performance characteristics verified in this test include inter-unit precision, accuracy and correlation relative to time-integrated reference methods, effect of meteorological conditions, influence of precursor gases, and short-term monitoring capabilities. The SM 200 reports measurement results in terms of $PM_{2.5}$ mass and, therefore, was compared with the federal reference method (FRM) for $PM_{2.5}$ mass determination. Additionally, comparisons with a variety of supplemental measurements were made to establish specific performance characteristics.

Quality assurance (QA) oversight of verification testing was provided by Battelle and EPA. Battelle QA staff conducted a data quality audit of 10% of the test data, and performance evaluation audits were conducted on the FRM samplers used in the verification test. Battelle QA staff conducted an internal technical system audit for Phase I and Phase II. EPA QA staff conducted an external technical systems audit during Phase II.

## TECHNOLOGY DESCRIPTION

The SM 200 (as tested) is an automatic semi-continuous particle sampler that can be equipped with a total suspended particulate, $PM_{10}$, or $PM_{2.5}$ head. The SM 200 can be controlled remotely and can be operated unattended because of the large number of filters in its filter magazine. The SM 200 loads filters from the clean filter magazine automatically and unloads them in the sampled filter magazine after use. After the filter is loaded, it is tested and sampling begins. A Geiger-Muller detector detects the radioactivity before the filter is unloaded. A differential technique is used to measure particle mass and accounts for air density alternations and the effects of the natural radioactivity associated with a sample. The SM 200 beta source is $^{14}C$ , and two interconnected microcontrollers allow sampling and measuring to be done simultaneously. The sampling tube can be heated 2 to 5°C higher than ambient temperature, and the measurement chamber is thermoregulated to minimize air density alterations due to temperature variations. Two gravimetrically determined reference membranes ensure particle measurement quality. A serial port makes it possible to obtain available data while giving the SM 200 instructions. The serial port can be connected directly or by modem to a PC or printer. The SM 200 consists of a sampling module (430 mm long x 600 mm wide by 260 mm high), a pumping module (320 mm long 200 mm wide and 300 mm high), and a collecting module. The sampling module weighs 25 kg, and the pumping module weighs 10 kg. The SM 200 operates on 115/230 V AC, 50/60 Hz.

## VERIFICATION OF PERFORMANCE

**Inter-Unit Precision:** Only one of the duplicate SM 200 monitors was operational during Phase I of testing so no measure of inter-unit precision is available for that period. For the Phase II results, regression analysis showed $r^2$ values of 0.857 and 0.931, respectively, for the hourly data and the 24-hour averages from the duplicate monitors. The slopes of the regression lines (with Monitor 1 as an independent variable) were 0.865 (0.033) and 0.882 (0.101), respectively, for the hourly data and 24-hour averages; and the intercepts were 10.1 (3.6) $\mu g/m^3$ and 7.5 (11.4) $\mu g/m^3$, respectively. The calculated coefficient of variation (CV) for the hourly data was 31% and for the 24-hour data the CV was 8.4%.

**Comparability/Predictability:** During Phase I, comparisons of the 24-hour measurements for the single SM 200 with $PM_{2.5}$ FRM results showed a slope of the regression line of 1.17 (0.14) and an intercept of 3.2 (3.2) $\mu g/m^3$, where the values in parentheses represent the 95% confidence interval. At the 95% confidence level, the slope was significantly different from unity, and the intercept was not statistically different from zero. The regression results show an $r^2$ value of 0.971 for these data. During Phase II, comparison of the 24-hour averages with $PM_{2.5}$ FRM results showed slopes of the regression lines for Monitor 1 and Monitor 2 of 1.394 (0.180) and 1.219 (0.194), respectively; and intercepts of these regression lines were -12.2 (16.0) and -2.2 (16.7) µg/$m^3$, respectively. The regression results show $r^2$ values of 0.918 and 0.870 for Monitor 1 and Monitor 2, respectively.

**Meteorological Effects:** The multivariable analysis model of the 24-hour average data during Phase I ascribed to wind speed, relative humidity, solar radiation, and total precipitation a statistically significant influence on the results of Monitor 1 at the 90% confidence level. Under average conditions during Phase I, these parameters had a combined effect of ~20% on the readings of Monitor 1. Multivariable analysis of the 24-hour average data during Phase II showed that relative humidity and wind speed had a statistically significant influence on the readings of Monitor 1 relative to the FRM values at 90% confidence. However, on average, these parameters had a combined effect of < 1% during Phase II. There was no effect of meteorology on the results of Monitor 2 relative to the FRM.

**Influence of Precursor Gases:** During Phase I, multivariable analysis of the 24-hour average data showed no statistically significant influence of the measured precursor gases on the SM 200 readings. During Phase II, multivariable analysis of the 24-hour average data indicated that the presence of $NO_x$ influences the readings of Monitor 2 relative to the FRM. None of the measured gases had an effect on Monitor 1.

**Short-Term Monitoring:** In addition to 24-hour FRM samples, short-term sampling was performed on a five-sample-per-day basis. The SM 200 results were averaged for each of the sampling periods and compared with the gravimetric results. Considering all short-term results together, linear regression of these data showed slopes of 1.33 and 1.26, respectively, for Monitor 1 and Monitor 2. The intercepts of the regression lines were 1.3 and 3.3 µg/$m^3$, respectively; and the $r^2$ values were 0.845 and 0.838, respectively. These results may not be an accurate representation of the short-term performance of the SM 200 monitors due to a loss of data from excessive filter loading.

**Other Parameters:** Regarding instrument reliability and ease of use, one SM 200 monitor was not operational in Phase I due to a mechanical malfunction. The other SM 200 monitor in Phase I achieved 100% data recovery, excluding a period when on-site operator error caused data loss. In Phase II, data recovery of 66% and 73% was achieved for the duplicate monitors. Filter overloading led to the data loss in Phase II. Such overloading could be minimized by judicious choice of the sampling duration, filter masking, and sampling frequency. Other than filter replacement, no maintenance was performed in Phase II.

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U.S. Environmental Protection Agency

August 2001

# Environmental Technology Verification Report

## ETV Advanced Monitoring Systems Center

## Opsis AB
## SM 200 Automatic Particle Monitor

by

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# Notice

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# Foreword

The U.S. EPA is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of six technology centers. Information about each of these centers can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. In 1997, through a competitive cooperative agreement, Battelle was awarded EPA funding and support to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/07/07_main.htm.

# Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. In particular we would like to thank the staff at the Department of Energy's National Energy Technology Laboratory, including Richard Anderson, Don Martello, and Curt White, for their assistance in conducting Phase I of the verification test reported here. We would like to thank the California Air Resources Board for its assistance in conducting Phase II of verification testing. We would like to acknowledge the efforts of ETV stakeholders for their assistance in planning this verification test and for reviewing the test/QA plan and the verification reports. Specifically, we would like to acknowledge Judith Chow of Desert Research Institute, Jeff Cook of the California Air Resources Board, Tim Hanley of EPA, and Rudy Eden of the South Coast Air Quality Management District. We also would like to thank Tim Hanley of EPA for the loan of a BGI FRM sampler for Phase II.

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## Tables

# List of Abbreviations

| | |
|---|---|
| ADQ | audit of data quality |
| AMS | Advanced Monitoring Systems |
| $^{14}C$ | carbon 14 |
| CARB | California Air Resources Board |
| CI | confidence interval |
| cm | centimeter |
| CO | carbon monoxide |
| CV | coefficient of variation |
| DOE | U.S. Department of Energy |
| DPI | digital pressure indicator |
| DRI | Desert Research Institute |
| EPA | U.S. Environmental Protection Agency |
| ETV | Environmental Technology Verification |
| FRM | federal reference method |
| $H_2S$ | hydrogen sulfide |
| Hg | mercury |
| IMPROVE | Interagency Monitoring for Protection of Visual Environments |
| in. | inch |
| L/min | liters per minute |
| m | meters |
| mg | milligram |
| mm | millimeters |
| NETL | National Energy Technology Laboratory |
| $N_2$ | nitrogen |
| NIST | National Institute of Standards and Technology |
| NO | nitric oxide |
| $NO_2$ | nitrogen dioxide |
| $NO_x$ | nitrogen oxides |
| $O_3$ | ozone |
| ppb | parts per billion |
| QA/QC | quality assurance/quality control |
| QMP | quality management plan |
| R&P | Rupprecht & Patashnick |
| SLAMS | state and local air monitoring stations |
| $SO_2$ | sulfur dioxide |
| TOR | thermal optical reflectance |
| TSA | technical systems audit |
| µg | microgram |
| WINS | well impactor ninety six |

# Chapter 1
# Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in designing, distributing, permitting, purchasing, and using environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of regulators, buyers, and vendor organizations; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA’s National Exposure Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of fine particle monitors for use in continuous monitoring of fine particulate matter in ambient air. This verification report presents the procedures and results of the verification test for the Opsis AB SM 200 automatic particle monitor.

# Chapter 2
# Technology Description

The following description of the SM 200 is based on information provided by the vendor.

The SM 200 is an automatic semi-continuous particle sampler that can be equipped with a total suspended particulate, $PM_{10}$ (for the thoracic fraction of the suspended particulate), or $PM_{2.5}$ (for the respirable fraction) head. The SM 200 can be controlled remotely and can be operated unattended because of the large number of filters in its filter magazine. The SM 200 loads one 47-mm filter from the clean filter magazine into the sampling chamber and, after sampling, unloads the 47-mm filter in the storage filter magazine. The SM 200 holds 40 47-mm filters, which are similar in design and face velocity to the $PM_{2.5}$ FRM sampler.

**Figure 2-1. Opsis AB SM 200 Automatic Particle Monitor**

After the filter is loaded, it is tested and sampling begins. A Geiger-Muller detector detects the radioactivity before the filter is unloaded. A differential technique is used to measure particle mass and accounts for air density alternations and the effects of the natural radioactivity associated with a sample. The SM 200 beta source is $^{14}C$ , and two interconnected microcontrollers allow sampling and measuring to be done simultaneously. The sampling tube can be heated 2 to 5°C higher than ambient temperature, and the measurement chamber is thermoregulated to minimize air density alterations due to temperature variations. Two gravimetrically determined reference membranes ensure particle measurement quality.

A serial port makes it possible to obtain available data while giving the SM 200 instructions. The serial port can be connected directly or by modem to a PC or printer. The SM 200 consists of a sampling module (430 mm long x 600 mm wide by 260 mm high, 17 in long by 24 in wide by 10 in high), a pumping module (320 mm long 200 mm wide and 300 mm high, 12.5 in long by 7.75 in wide by 12 in high), and a collecting module. The sampling module weighs 25 kg (55 pounds), and the pumping module weighs 10 kg (22 pounds). The SM 200 operates on 115/230 V AC, 50/60 Hz.

# Chapter 3
# Test Design and Procedures

## 3.1 Introduction

The objective of this verification test is to provide quantitative performance data on continuous fine particle ($PM_{2.5}$) monitors under a range of realistic operating conditions. To meet this objective, field testing was conducted in two phases in geographically distinct regions of the United States during different seasons of the year. Performing the test in different locations and in different seasons allowed sampling of widely different particulate matter concentrations and chemical composition. At each site, testing was conducted for one month during the season in which local $PM_{2.5}$ levels were expected to be highest. The verification test was conducted according to the procedures specified in the *Test/QA Plan for Verification of Ambient Fine Particle Monitors.*(1)

The first phase of field testing was conducted at the ambient air monitoring station on the Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) campus in Pittsburgh, PA. Sampling during this phase of testing was conducted from August 1 to September 1, 2000. The second phase of testing was performed at the California Air Resources Board's (CARB's) Air Monitoring Station in Fresno, CA. This site is also host to one of the EPA's $PM_{2.5}$ Supersites being managed by Desert Research Institute (DRI). This phase of testing was conducted from December 18, 2000, to January 17, 2001.

## 3.2 Test Design

Specific performance characteristics verified in this test include

- Inter-unit precision
- Agreement with and correlation to relative time-integrated reference methods
- Effect of meteorological conditions
- Influence of precursor gases
- Short-term monitoring capabilities.

To assess inter-unit precision, duplicate SM 200 monitors were tested in side-by-side operation during each phase of testing. During both Phase I and Phase II, the monitors used were serial numbers 275 and 282. Collocation of the SM 200 monitors with reference systems for time-integrated sampling of fine particulate mass and chemical speciation provided the basis for assessing the degree of agreement and/or correlation between the continuous and reference methods. Each test site was equipped with continuous monitors to record meteorological conditions and the concentration of key precursor gases (ozone, nitrogen oxides, sulfur dioxide, etc.). The data from the meteorological and gas monitors were used to assess the influence of these parameters on the performance of the fine particle monitors being tested. Reference method sampling periods of 3, 5, and 8 hours were used in Phase II of this test to establish the short-term monitoring capabilities of the continuous monitors being tested. Statistical calculations, as described in Chapter 5, were used to establish each of these performance characteristics.

Additionally, other performance characteristics of the technologies being verified, such as reliability, maintenance requirements, and ease of use, were assessed. Instrumental features that may be of interest to potential users (e.g., power and shelter requirement and overall cost) are also reported.

## 3.3 Reference Method and Supplemental Measurements

Since no appropriate absolute standards for fine particulate matter exist, the reference methods for this test were well established, time-integrated methods for determining particulate matter mass or chemical composition. It is recognized that comparing real-time measurements with time-integrated measurements does not fully explore the capabilities of the real-time monitors. However, in the absence of accepted standards for real-time fine particulate matter measurements, the use of time-integrated standard methods that are widely accepted was necessary for performance verification purposes. It should be noted that there are necessary differences between continuous and time-integrated, filter-based techniques. For example, in time-integrated sampling, particulate matter collected on a filter may remain there for up to 24 hours, whereas continuous monitors generally retain the particulate sample for one hour or less. Thus, the potential for sampling artifacts differs. Also, in the case of particle mass measurements, the mass of particulate matter is determined after equilibration at constant temperature and humidity, conditions that are almost certain to differ from those during sampling by a continuous monitor.

The SM 200 reports measurement results in terms of $PM_{2.5}$ mass and therefore was compared with the federal reference method (FRM) for $PM_{2.5}$ mass determination.(2) Additionally, comparisons with a variety of supplemental measurements were made to establish specific performance characteristics. Descriptions of the reference method and supplemental measurements used during the verification test are given below.

### *3.3.1 $PM_{2.5}$ Mass*

The primary comparisons of the SM 200 readings were made relative to the FRM for $PM_{2.5}$ mass determination, i.e., the 24-hour time-averaged procedure detailed in 40 CFR Part 50.(2) This method involves manual sampling using any of a number of designated commercially available filter samplers, followed by gravimetric analysis of the collected sample. In this method, a size-selective inlet is used to sample only that fraction of aerosol of interest (i.e., < 2.5 µm aerodynamic diameter). The air sample is drawn into the sampler at a fixed rate (16.7 L/min) over 24-hours, and the aerosol is collected on a Teflon filter for gravimetric analysis. After equilibration of the sample and filter in a temperature- and humidity-controlled environment, the sample is weighed on a microbalance. The particulate matter sample weight is determined by subtracting the weight of the filter alone, determined prior to sampling after similar equilibration. Protocols for sample collection, handling, and analysis are prescribed by EPA(2) and were followed for this verification test.

Filter samples for the $PM_{2.5}$ FRM were collected daily during each phase of the testing using a BGI FRM sampler (RFPS-0498-116), and the $PM_{2.5}$ mass was determined according to the procedures mentioned above. In Phase I, a single BGI FRM sampler (SN 311) was operated daily from noon to noon to collect the FRM samples. During Phase II, two BGI FRM samplers (SN 287 and SN 311) were used and were operated on alternate days to facilitate a midnight-to-midnight sampling schedule.

Collocated samples were collected during each phase to establish the precision of the FRM. A discussion of the collocated sampling is presented in Section 4.4 of this report.

### *3.3.2 Supplemental Measurements*

Various supplemental measurements were used to further establish the performance of the continuous monitors being tested. Meteorological conditions were monitored and recorded continuously throughout each phase of the verification test. These measurements included temperature, relative humidity, wind speed, direction, barometric pressure, and solar radiation. These data were provided to Battelle for Phase I by DOE/NETL and for Phase II by DRI. Likewise, the ambient concentrations of various precursor gases including ozone and nitrogen oxides also were measured continuously during the verification test and used to assess the influence of these parameters on the performance of the monitors tested. Continuous measurements of sulfur dioxide, hydrogen sulfide, nitric oxide, nitrogen dioxide, nitrogen oxides, and ozone were provided for Phase I by DOE/NETL; and continuous measurements of carbon monoxide, ozone, nitric oxide, nitrogen dioxide, and nitrogen oxides were provided for Phase II by DRI. These gases were of interest as potential chemical precursors to aerosol components, and as indicators of ambient pollutant levels.

During Phase I, samples for chemical speciation were collected using an Andersen RAAS speciation sampler configured with five sample trains (one channel at 16.7 L/min and four channels at approximately 8 L/min). The 16.7 L/min channel was operated with a Teflon filter for $PM_{2.5}$ mass determination. Samples for carbon analysis were collected at 8 L/min on quartz filters and analyzed by the IMPROVE thermal optical reflectance method at DRI. Nitrate and sulfate samples were collected on nylon filters downstream of a magnesium-oxide-coated compound annular denuder, and analyzed by ion chromatography at Consol.

To supplement the 24-hour samples, additional samples for $PM_{2.5}$ mass were collected at the Fresno site over shorter sampling periods (i.e., 3-, 5-, 8-hour) to assess the capabilities of the monitors being tested in indicating short-term $PM_{2.5}$ levels. A medium-volume sequential filter sampling system (SFS) sampling at a flow rate of 113 L/min was used to collect the short-term mass and speciation samples during Phase II. The SFS was configured to take two simultaneous samples (i.e., Teflon-membrane/drain disk/quartz-fiber and quartz-fiber/sodium-chloride-impregnated cellulose-fiber filter packs) at 20 L/min through each sampling port. Anodized aluminum nitric acid denuders were located between the inlets and the filters to remove gaseous nitric acid. The remaining 73 L/min required for the 113 L/min total inlet flow was drawn through a makeup air sampling port inside the plenum. The timer was set to take five sets of sequential samples every 24 hours. Solenoid valves, controlled by a timer, switched between one to five sets of filters at midnight each day. A vacuum pump drew air through the paired filter packs when the valves were open. The flow rate was controlled by maintaining a constant pressure across a valve with a differential pressure regulator.

The filters were loaded at the DRI's Reno, NV, laboratory into modified Nuclepore filter holders that were plugged into quick-disconnect fittings on the SFS. One filter pack contained a 47-mm-diameter Teflon-membrane filter with quartz-fiber backup filter. A drain disc was placed between the Teflon-membrane and quartz-fiber filters to ensure a homogeneous sample deposit on the front Teflon-membrane filter and to minimize fiber transfer from one filter to the other. The Teflon-membrane filter collected particles for mass and elemental analysis. The other filter pack contained a 47-mm-diameter quartz-fiber filter with a sodium-chloride-impregnated cellulose-fiber backup filter on a separate stage. The deposit on the quartz-fiber filter was analyzed for ions and carbon. The sodium-chloride-impregnated cellulose-fiber backup filter was analyzed for nitrate to estimate losses due to volatilization of ammonium nitrate from the front filter during sampling.

This sequential filter sampler was operated from midnight to 5:00 a.m. (0000-0500), from 5:00 a.m. to 10:00 a.m. (0500-1000), from 10:00 a.m. to 1:00 p.m. (1000-1300), from 1:00 p.m. to 4:00 p.m. (1300-1600), and from 4:00 p.m. to midnight (1600-2400). These short-term sampling measurements were appropriately summed over 24 hours for comparison with the corresponding 24-hour results of the FRM reference samplers to establish the relationship between the two sets of measurements.

### 3.4 Data Comparisons

The primary means used to verify the performance of the SM 200 monitors was comparison with the 24-hour FRM results. Additional comparisons were made with the supplemental meteorological conditions and precursor gas concentrations to assess the effects of these parameters on the response of the monitors being tested. The short-term sampling results from Fresno in Phase II of the verification test also were used to assess the capabilities of the SM 200 monitors to indicate short-term levels of ambient $PM_{2.5}$. The comparisons were based on statistical calculations as described in Section 5 of this report.

Comparisons were made independently for the data from each phase of field testing; and, with the exception of the inter-unit precision calculations, the results from the duplicate monitors were analyzed and reported separately. Inter-unit precision was determined from a statistical intercomparison of the results from the duplicate monitors.

## 3.5 Site Layout/Instrument Installation

In each phase of testing, the two SM 200 monitors were installed in Battelle's instrument trailer, which is a converted 40-foot refrigerator semi-trailer. The SM 200 monitors were placed on a counter top, with each monitor directly below a 7.6-cm (3 in.) port through the roof of the trailer. Separate inlet tubes, approximately three meters (10 feet) in length, were installed vertically through the sampling ports and secured on the trailer roof using tripods. The inlet was a URG Corporation Stearman Cyclone with a polytetrafluoroethylene coating operating at 16.67 L/min to provide a $PM_{2.5}$ cut point. No coarse fraction or FRM inlet was used. The inlet tubing was not heated or conditioned. The sampled aerosol was size-specified by the cyclone and transported to the masked 47-mm filter holder. Data generated by the SM 200 monitors were recorded internally and downloaded several times throughout each phase of testing as described in Section 4.6.2.

### *3.5.1 Phase I*

Phase I verification testing was conducted at the DOE/NETL facility within the Bruceton Research Center. The facility is located in the South Park area of Pittsburgh, PA, approximately 7 miles from downtown. The air monitoring station where testing was conducted is located on the top of a relatively remote hill within the facility and is impacted little by road traffic. The layout of the testing facility is illustrated schematically in Figure 3-1.

For this test, Battelle provided temporary facilities to augment the permanent facilities in use by the DOE/NETL air monitoring staff. These temporary facilities included a temporary Battelle/ETV platform (16-foot by 14-foot scaffold construction) and a Battelle instrument trailer. The Battelle instrument trailer was positioned parallel with, and approximately 25 feet from, the DOE/NETL instrument trailer. The Battelle/ETV platform was located between the two trailers, with the surface at a height of approximately 2 meters (6 feet).

Most of the DOE/NETL continuous monitoring equipment, including the continuous precursor gas monitors, were located inside the DOE/NETL instrument trailer. A DOE/NETL Rupprecht & Patashnick (R&P) Co. Partisol FRM sampler used to evaluate FRM precision was located outside on a DOE/NETL platform. The SM 200 monitors were installed inside the Battelle trailer, and the BGI FRM sampler was installed on the Battelle/ETV platform. A vertical separation of approximately 2 to 3 meters and a horizontal separation of approximately 3 meters existed between the inlets of the SM 200 monitors and the BGI FRM sampler. A 10-meter (33-foot) meteorological tower was located approximately 20 meters (65 feet) to the north of the DOE/NETL instrument trailer.

### *3.5.2 Phase II*

Phase II of verification testing was conducted at the CARB site. This site is located in a residential/commercial neighborhood about three miles north of the center of Fresno. The two BGI FRM samplers and a 3-meter (10-foot) meteorological tower were located on the roof of the two-story building housing the CARB office. Continuous precursor gas monitors were located

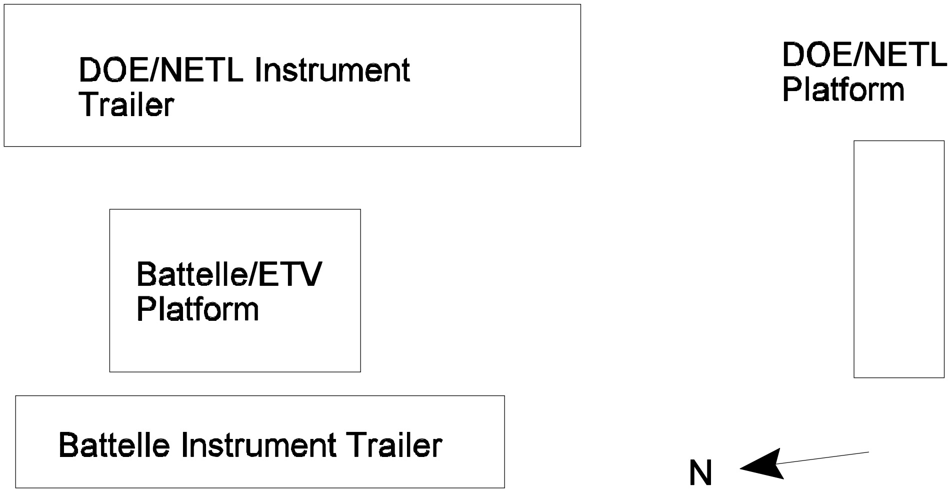

**Figure 3-1. Site Layout During Phase I of Verification Testing (not drawn to scale)**

inside the CARB office space and sampled through a port in the roof of the building. The two BGI FRM samplers were located on the southernmost edge of the rooftop to be as close as possible to the instrument trailer. The Battelle trailer used during Phase I of this verification test also was used during Phase II. For Phase II, the Battelle trailer was located in the parking lot adjacent to the building in which the CARB site is located. The trailer was positioned approximately 25 meters (80 feet) to the south of the building, as shown in Figure 3-2. The SM 200 monitors were located in the Battelle trailer and installed in the same fashion as in Phase I of the verification test. A difference in elevation of approximately 6 meters (20 feet) existed between the top of the trailer and the roof of the building housing the CARB site and between the inlets of the SM 200 monitors and the BGI FRM samplers. In addition to the two BGI FRM samplers used to collect the reference samples, an R&P Partisol FRM sampler was operated on the rooftop by CARB. This sampler was positioned approximately 25 meters (65 feet) to the northeast of the BGI FRM samplers and was used to measure the precision of the BGI FRM reference values. The sequential filter sampler used to collect the short-term samples was located near the R&P FRM sampler.

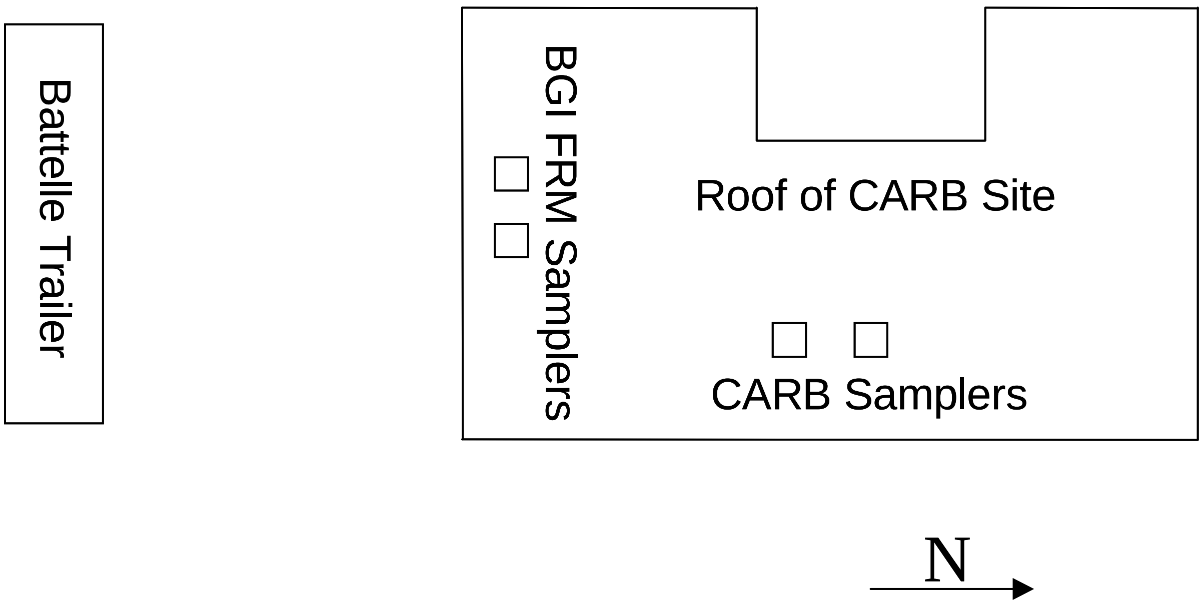

**Figure 3-2. Site Layout During Phase II of Verification Testing (not drawn to scale)**

# Chapter 4
# Quality Assurance/Quality Control

## 4.1 Data Review and Validation

Test data were reviewed and approved according to the AMS Center quality management plan (QMP)(3) and the test/QA plan.(1) The Verification Test Coordinator or the Verification Testing Leader or designee reviewed the raw data, laboratory notebook entries, and data sheets that were generated each day and approved them by initialing and dating the records.

Data from the SM 200 monitors were validated by a representative of Opsis AB and reviewed by the Verification Test Coordinator before being used in statistical calculations. Data were checked for error flags and not used if flagged for power or instrument failure. In general, daily $PM_{2.5}$ concentration averages calculated from the continuous SM 200 data were considered valid if the percent data recovery for the 24-hour sampling period (i.e., noon to noon for Phase I, or midnight to midnight for Phase II) was 75% or greater. However, due to the absence of some data on almost every day in Phase II, it was necessary to relax this criterion to expand the number of days included in the comparison.

## 4.2 Deviations from the Test/QA Plan

The following deviations from the test/QA plan were documented and approved by the AMS Center Manager. None of these deviations had any deleterious effect on the verification data.

- Calibration checks of the temperature and pressure sensors were not performed within one week of the start of Phase II. Subsequent checks of these sensors indicated proper calibration.
- The distance between the reference samplers and the monitors being tested was increased to approximately 25 meters to accommodate changes in the overall site layout for Phase II.

In addition, although not formally a deviation from the test/QA plan, we note that the relative humidity of the conditioning weighing room used by Consol in Phase I occasionally deviated from the specified limits. The impact of this occurrence was minimal, as noted in Section 4.4.1.

## 4.3 Calibration and Parameter Checks of Reference Sampler

The BGI FRM samplers provided by Battelle for this verification test were calibrated using National Institute of Standards and Technology (NIST)-traceable flow meters and temperature and pressure sensors. The calibration and verification of these samplers are described below.

### *4.3.1 Flow Rate Calibration and Verification*

Prior to Phase I of the verification test, a three-point calibration of the sampler flow rate was performed on June 22, 2000. Flows were measured at three set points (16.7 L/min, and approximately +10% and -10% of 16.7 L/min) using a dry gas meter (American Meter Company, Battelle asset number LN 275010, calibrated January 21, 2000). If necessary, the flows were adjusted manually until agreement with the dry gas meter fell within ±2% of the sampler's indicated flow reading.

The on-site operators checked the flow rate of the BGI FRM sampler both before and after Phase I of the verification test using an Andersen Instruments Inc. dry gas meter (identification number 103652, calibrated March 30, 2000). The flow rate was checked prior to testing on both July 19, 2000, and July 30, 2000. In both cases, the measured flow rate was verified to be within 4% of the flow rate indicated by the sampler. After testing, the flow rate was again checked on September 11, 2000, using the same Andersen dry gas meter. In this case, the flow rate did not fall within the 4% acceptance limit. This failure is probably linked to the failure of the ambient temperature thermocouple, on September 7, 2000, after completion of the Phase I sampling (see Section 4.3.2).

Prior to Phase II of the verification test, single point calibration checks of the duplicate BGI FRM FRM samplers was performed at 16.7 L/min on December 15, 2000. These flow rate checks were performed using a BGI DeltaCal calibrator (BGI Inc., serial number 0027, calibrated October 24, 2000) and the measured flow rates were within 4% of the indicated flow on each sampler. Weekly flow rate checks also were performed throughout Phase II using the DeltaCal flow meter. In each case, the measured flow rates were within ±4% of the indicated reading of the BGI FRM and within ±5% of the nominal 16.7 L/min setpoint.

Calibration of the flow rate for the SFS sampler used during Phase II, was maintained by DRI through daily flow checks with a calibrated rotometer, and independent performance evaluation audits conducted by Parson's Engineering. No additional flow verification was performed for this test.

### *4.3.2 Temperature Sensor Calibration and Verification*

Both the ambient temperature sensor and the filter temperature sensor of the BGI FRM sampler were checked at three temperatures (approximately 5, 22, and 45°C) on June 20, 2000. The sensor readings were compared with those from an NIST-traceable Fluke Model 52 thermocouple gauge (Battelle asset number LN 570068, calibrated October 15, 1999). Agreement between the sampler temperature sensors and the calibrated thermocouple was within ±2°C at each temperature.

The temperature sensors also were checked at the DOE/NETL site both before and after Phase I of the verification test by the on-site operators. Prior to testing, the sensors were checked on July 19, 2000, and July 30, 2000, against the readings from a mercury thermometer (Ever Ready, serial number 6419, calibrated October 29, 1999). For these checks, agreement between the sensors and the thermometer was within ±2°C. After the verification period, the ambient temperature sensor suffered a malfunction on September 7. The filter temperature sensor was checked on September 11, 2000, and showed agreement with the mercury thermometer within ±2°C. The sensor was replaced, after completing Phase I, with a new factory-calibrated sensor provided by BGI.

The temperature sensors for the two BGI FRM samplers were checked on January 16, 2001, against readings from a Fluke Model 52 thermocouple gauge (Battelle asset number LN 570077, calibrated October 26, 2000). For each BGI FRM, both the ambient and filter temperature sensor readings agreed with the thermocouple readings within ±2°C.

### *4.3.3 Pressure Sensor Calibration and Verification*

Before Phase I, the barometric pressure sensor in the BGI FRM sampler was calibrated against an NIST-traceable Taylor Model 2250M barometer (Battelle asset number LN 163610, calibrated January 12, 2000) and an NIST-traceable convectron gauge (Granville-Phillips Co., Battelle asset number LN 298084, calibrated August 25, 1999) on June 17 and 18, 2000. The sensor was calibrated at ambient pressure and under a reduced pressure (approximately 100 mm mercury below ambient).

Checks of the pressure sensor were performed at the DOE/NETL site both before and after Phase I of the verification test. The pressure sensor was checked on July 19, 2000, and July 30, 2000, using an NIST-traceable Taylor Model 2250M barometer (Battelle asset number LN 163609, calibrated January 12, 2000). On September 11, 2000, the pressure sensor of the BGI FRM sampler was again checked against the same barometer, but did not agree within the acceptance criterion of 5 mm mercury. This failure is possibly associated with the failure of the ambient temperature sensor on September 7, 2000.

The ambient pressure sensor for both BGI FRM samplers used in Phase II was checked against the pressure readings of a BGI DeltaCal on January 16, 2001. Agreement between the BGI FRM pressure readings and those of the DeltaCal was within ±5 mm mercury for both samplers.

### *4.3.4 Leak Checks*

Leak checks of the BGI FRM sampler were performed every fourth day during Phase I of the verification test. These leak checks were conducted immediately following the cleaning of the WINS impactor and were performed according to the procedures in the operator's manual for the BGI FRM sampler. All leak checks passed the acceptance criteria provided in the operator's manual.

Leak checks of the BGI FRM and SFS samplers were performed daily during Phase II of the verification test. These leak checks were conducted during set-up for each 24-hour sampling period. All leak checks passed before the sampler set-up was completed.

## 4.4 Collocated Sampling

### *4.4.1 Phase I—Pittsburgh*

To establish the precision of the $PM_{2.5}$ FRM, the BGI FRM sampler was collocated with an R&P $PM_{2.5}$ FRM sampler for Phase I, including a period of two weeks prior to and one week after Phase I of the verification test. During the sampling periods before and after Phase I, the BGI and R&P FRM samplers were located on the same platform and within 4 meters of one another. During the Phase I testing period, these samplers were separated by a distance of approximately 25 meters. The samples from the BGI FRM sampler were collected and analyzed by Consol, and the samples from the R&P FRM sampler were collected and analyzed by on-site Mining Safety and Health Administration staff.

Figure 4-1 shows the results of the collocated FRM sampling conducted for Phase I. These data were compared by linear regression; and the calculated slope, intercept, and $r^2$ values are 0.939 (0.033), 1.28 (0.66) $\mu g/m^3$, and 0.957, respectively, where the values in parentheses are 95% CIs. Despite completely independent operations (i.e., separate sampling staff and weighing facilities), these data show very good agreement between the BGI FRM and the R&P FRM samplers. The data also indicate that, although the humidity in the conditioning/weighing room at Consol was not always within the specified FRM limits, the influence of the elevated humidity was not severe.

### *4.4.2 Phase II—Fresno*

During Phase II of testing, duplicate BGI FRM samplers (SN 287 and SN 311) were used to collect the 24-hour FRM reference samples. These samplers were operated one at a time on alternate days to facilitate midnight-to-midnight sampling. Likewise, an R&P Partisol sampler was used by CARB to collect 24-hour FRM samples. The R&P FRM sampler was located approximately 25 meters from the BGI FRM samplers. The same on-site operators performed the sampling for the FRM samplers; however, DRI performed the gravimetric analyses for the BGI FRM samplers and CARB performed the analyses for the R&P FRM sampler.

Figure 4-2 shows the results for the collocated FRM sampling conducted for Phase II. Only 12 days of collocated sampling were available from the Fresno site. The linear regression of these data shows a slope of 1.096 (0.047) and intercept of -1.0 (2.1) $\mu g/m^3$ and $r^2$ value of 0.982, where the numbers in parentheses indicate the 95% CIs.

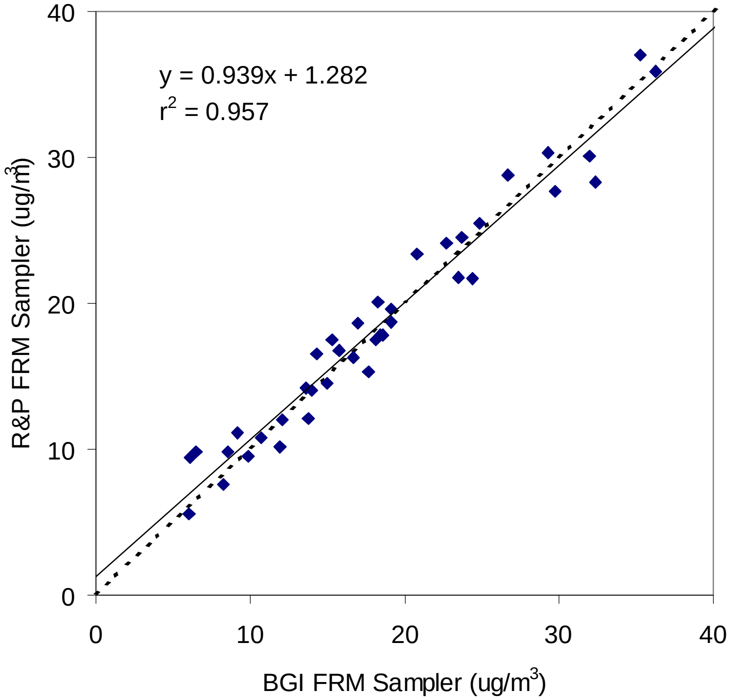

**Figure 4-1. Comparison of Collocated PM$_{2.5}$ FRM Samplers for Phase II of Verification Testing**

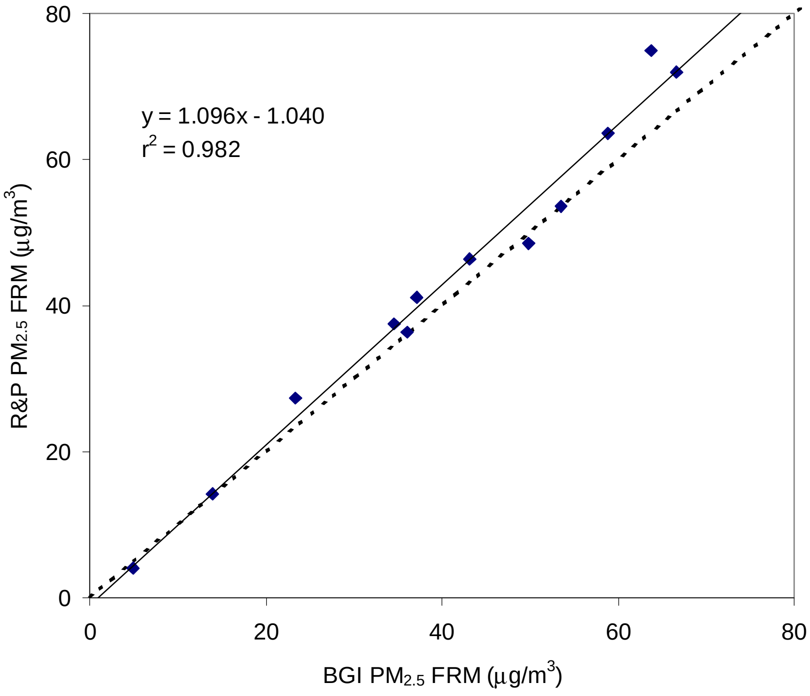

**Figure 4-2. Comparison of Collocated PM$_{2.5}$ FRM Samplers for Phase II of Verification Testing**

### *4.4.3 Summary*

The results from the collocated FRMs in both Pittsburgh and Fresno show agreement that is consistent with the goals for measurement uncertainty of $PM_{2.5}$ methods run at state and local air monitoring stations (SLAMS). These goals are identified in Appendix A to 40 CFR Part 58, Section 3.5(4) which states: “The goal for acceptable measurement uncertainty has been defined as 10 percent coefficient of variation (CV) for total precision and ± 10% for total bias.” Since the collocated FRMs in both Pittsburgh and Fresno were operated by independent organizations, a comparison to the SLAMS data quality objectives for $PM_{2.5}$ is an appropriate way to assess whether the measurement systems were producing data of acceptable quality. In both Pittsburgh and Fresno, the results of the collocated sampling meet the data quality objectives for the total bias. In Fresno, the collocated sampling results show a CV of 6.3%, which meets the data quality objectives for precision. In Pittsburgh, the calculated CV was 10.5%. However, this value is driven largely by scatter in the low concentration regime. When a single data pair is removed, the CV becomes 9.1%, which meets the data quality objectives for total precision. (It should be noted, as well, that the Fresno collocated results consist of only 12 data points.) Thus, the collocated FRM results from Pittsburgh and Fresno show that the reference measurements were suitable for verifying the performance of continuous fine particle monitors.

## 4.5 Field Blanks

### *4.5.1 Phase I—Pittsburgh*

During Phase I, at least 10% of the collected reference samples were field blanks. The observed filter mass difference of the field blanks ranged from -7 µg to 16 µg, and the corresponding $PM_{2.5}$ concentrations (which were determined using an assumed sample volume of 24 $m^3$) were all less than 0.7 $\mu g/m^3$, averaging 0.15 $\mu g/m^3$. FRM results for Phase I were not blank corrected.

### *4.5.2 Phase II—Fresno*

During Phase II, at least 10% of the collected reference samples (both the BGI FRM samplers and the DRI sequential filter sampler) were field blanks. The results were added to a database containing historical field blank data. These blanks showed mass differences of 2 µg, with a standard deviation of 8 µg. Assuming a sample volume of 24 $m^3$ (i.e., FRM volume), these blanks account for ~0.1 $\mu g/m^3$. Assuming a sample volume of 36 $m^3$ (i.e., 3-hour short-term sampling period with sequential filter sampler), these blanks account for ~0.6 $\mu g/m^3$. These blank values are negligible, even for the short-term sampling periods, in comparison with the $PM_{2.5}$ mass levels that were present during the Phase II testing (see Section 6.2). FRM results for Phase II were blank corrected using the data available from the historical database.

## 4.6 Data Collection

### *4.6.1 Reference Measurements*

During Phase I, daily records of the sampling activities for the BGI FRM sampler were recorded on individual data sheets by the on-site operators, and summary data from the BGI FRM sampler were downloaded daily using portable data logging modules. Information recorded on the data sheets included identification of the sampling media (i.e., filter ID numbers) and the start and stop times for the sampling periods. Summary data from the sampler included the parameters listed above, in addition to the sampling duration, volume sampled, and average temperature and pressure readings.

During Phase II, summary data from the BGI FRM samplers were logged daily on sampling sheets by the on-site operators. These data included sample identification, start times for the sampling period, sampling duration, volume sampled, and average temperature and pressure readings.

### *4.6.2 SM 200 Monitors*

Data from each of the SM 200 monitors were recorded in an internal memory buffer throughout each phase of the verification test. For each day, the data were stored in tabular format with hourly values reported for $PM_{2.5}$ concentration ($\mu g/m^3$), along with approximately 20 instrumental parameters. For Phase I, these data for the daily results were recorded into a record book. During Phase II, hourly values were recorded on an on-site PC.

These files were imported into a spreadsheet for analysis, and copies of the data were stored by the Verification Test Coordinator on a floppy disk as well as on a computer hard drive.

## 4.7 Assessments and Audits

### *4.7.1 Technical Systems Audit*

**Phase I—Pittsburgh**

The technical systems audit (TSA) ensures that the verification tests are conducted according to the test/QA plan(1) and that all activities associated with the tests are in compliance with the ETV pilot QMP.(3) The Battelle Quality Manager conducted an internal TSA on August 3, 2000, at the Pittsburgh test site. All findings noted during this TSA were documented and submitted to the Verification Test Coordinator for correction. The corrections were documented by the Verification Test Coordinator and reviewed by Battelle's Quality Manager, Verification Testing Leader, and Center Manager. None of the findings adversely affected the quality or outcome of this phase of the verification test. All corrective actions were completed to the satisfaction of the Battelle Quality Manager. The records concerning this TSA are permanently stored with the Battelle Quality Manager.

**Phase II—Fresno**

An internal TSA was conducted by the Battelle Quality Manager on January 9, 2001, at the Fresno test site. An external TSA was also conducted concurrently by EPA quality staff, Ms. Elizabeth Betz and Ms. Elizabeth Hunike. All findings noted during these TSAs were documented and submitted to the Verification Test Coordinator for corrective action. None of the findings adversely affected the quality or outcome of this phase of the verification test for the SM 200. All corrective actions were completed to the satisfaction of the Battelle Quality Manager and the EPA.

### 4.7.2 *Performance Evaluation Audit*

**Phase I—Pittsburgh**

The reference sampler provided by Battelle for this verification test was audited during Phase I to ensure that it was operating properly. During Phase I of the verification test, the flow rate of the BGI FRM sampler was audited on August 28, using a dry gas meter (American Meter Company, Battelle asset number LN 275010, calibrated April 17, 2000). The measured flow rate was within the ± 4% acceptance criterion with respect to the internal flow meter and within the ±5% acceptance criterion with respect to the nominal flow rate.

Both temperature sensors in the BGI FRM sampler were checked on August 28, using a Fluke 52 thermocouple (Battelle asset number LN 570068, calibrated October 15, 1999). Agreement between each sensor and the thermocouple was within the ±2°C acceptance criterion.

**Phase II—Fresno**

A performance evaluation audit was conducted to ensure that the two BGI FRM samplers used during Phase II of testing were operating properly. The flow rates of the samplers were audited on January 16 and 17, 2001, using a dry gas meter (Schlumberger, SN 103620, calibrated July 6, 2000). For each sampler, the measured flow rate was within the ±4% acceptance criterion with respect to the internal flow meter and within the ±5% acceptance criterion with respect to the nominal flow rate.

The temperature readings for the two samplers were checked with a mercury thermometer (Fisher Scientific, SN 7116). Agreement between each sensor and the thermocouple was within the ±2°C acceptance criterion.

The pressure sensors for the two samplers were checked against a Druck digital pressure indicator (DPI) (SN 6016/00-2, calibrated June 28, 2000). Agreement between each sensor and the DPI was within the acceptance criterion of ±5 mm mercury.

### 4.7.3 *Audit of Data Quality*

Battelle's Quality Manager ensured that an audit of data quality (ADQ) of at least 10% of the verification data acquired during the verification test was completed. The ADQ traced the data from initial acquisition, through reduction and statistical comparisons, to final reporting. Reporting of findings followed the procedures described above for the Phase I TSA. All findings were corrected to the satisfaction of the Battelle Quality Manager.

# Chapter 5
# Statistical Methods

Performance verification is based, in part, on statistical comparisons of continuous monitoring data with results from the reference methods. A summary of the statistical calculations that have been made is given below.

## 5.1 Inter-Unit Precision

The inter-unit precision of the SM 200 monitors was determined based on procedures described in Section 5.5.2 of EPA 40 CFR 58, Appendix A, which contains guidance for precision assessments of collocated non-FRM samplers. Simultaneous measurements from the duplicate SM 200 monitors were paired, and the behavior of their differences was used to assess precision. For both the hourly and the 24-hour $PM_{2.5}$ measurements, the coefficient of variation (CV) is reported. The CV is defined as the standard deviation of the differences divided by the mean of the measurements and expresses the variability in the differences as a percentage of the mean. As suggested by the EPA guidance, only measurements above the limit of detection were used in precision calculations. Inter-unit precision was assessed separately for each phase of the verification test.

## 5.2 Comparability/Predictability

The comparability between the SM 200 and the $PM_{2.5}$ FRM was assessed, since the SM 200 monitors yield measurements with the same units of measure as the $PM_{2.5}$ FRM reference method. The relationship between the two was assessed from a linear regression of the data using the $PM_{2.5}$ FRM results as the independent variable and the SM 200 monitor results as the dependent variable as follows:

$$C_i = \mu + \beta \times R_i + \varepsilon_i \qquad (1)$$

where $R_i$ is the $i^{th}$ 24-hour FRM $PM_{2.5}$ measurement; $C_i$ is the average of the hourly SM 200 measurements over the same 24-hour time period as the $i^{th}$ reference measurement; $\mu$ and $\beta$ are the intercept and slope parameters, respectively; and $\varepsilon_i$ is error unexplained by the model. The average of the hourly SM 200 measurements is used because this is the quantity that is most comparable to the reference sampler measurements.

Comparability is expressed in terms of bias between the SM 200 monitor and the $PM_{2.5}$ FRM reference method and the degree of correlation (i.e., $r^2$) between the two. Bias was assessed based on the slope and intercept of the linear regression of the data from the $PM_{2.5}$ FRM and the

SM 200 monitor. In the absence of bias, the regression equation would be $C_i = R_i + \varepsilon_i$ (slope = 1, intercept = 0), indicating that the 24-hour average of hourly SM 200 measurements is simply the $PM_{2.5}$ FRM measurement plus random error. A value of $r^2$ close to 1 implies that the amount of random error is small; that is, the variability in the hourly measurements is almost entirely explained by the variability in the $PM_{2.5}$ FRM measurements.

Quantities reported include $r^2$, intercept, and slope, with estimates of the 95% CIs for the intercept and slope. Comparability to the FRM was determined independently for each of the two duplicate SM 200 monitors being tested and was assessed separately for each phase of the verification test.

## 5.3 Meteorological Effects/Precursor Gas Influence

The influence of meteorological conditions on the correlation between the SM 200 monitors and the $PM_{2.5}$ FRM reference samplers was evaluated by using meteorological data such as temperature and humidity as parameters in multivariable analyses of the reference/monitor comparison data. The same evaluation was done with ambient precursor pollutant concentrations as the model parameters. The model used is as follows:

$$C_i = \mu + \beta \times R_i + \Sigma \gamma_j \times X_{ji} + \varepsilon_i \qquad (2)$$

where $X_{ji}$ is the meteorological or precursor gas measurement for the $i^{th}$ 24-hour time period, $\gamma_j$ is the associated slope parameters, and other notation is as in Equation 1. Comparability results are reported again after these variables are adjusted for in the model. Additionally, estimates and standard errors of $\gamma_j$ are provided. Meteorological effects and precursor gas interferences were assessed independently for each of the two duplicate SM 200 monitors tested and were assessed separately for each phase of the verification test. In conducting these multivariable analyses, a significance level of 90% was used in the model selection. This significance level is less stringent than the 95% level used in other aspects of the verification, and was chosen so that even marginally important factors could be identified for consideration.

Note that the multivariable model ascribes variance unaccounted for by linear regression against the FRM to the meteorological or precursor gas parameters. The model treats all candidate parameters equally. The model discards the least significant parameter and is rerun until all remaining variables have the required significance (i.e., predictive power). The results of the model should not be taken to imply a cause-and-effect relationship. It is even possible that the parameters identified as significant for one unit of a monitoring technology may differ from those identified for the duplicate unit of that technology due to differences in the two data sets.

## 5.4 Short-Term Monitoring Capabilities

This assessment was based on linear regression analysis of results from the SM 200 monitors and the short-term (3-, 5-, and 8-hour) sampling results from the two BGI FRM samplers generated in Phase II only. The analysis was conducted, and the results are reported in a fashion identical to that for the comparability results for the 24-hour samples described in Section 5.2.

These comparisons were made only after establishing the relationship between the short-term sampling results and the corresponding 24-hour results. The relationship between the two sets of reference measurements was made by linear regression using the weighted sum of the results from the short-term sampling as the dependent variable and the 24-hour FRM results as the independent variable in the regression analysis. Comparability was assessed using Equation 1, replacing the average of hourly measures with the average of short-term sampler measurements. The short-term sampling results also have been used to assess the effects of meteorological conditions and precursor gas concentrations on the response of the monitors. These short-term results were used in place of the 24-hour measurements in the analysis described in Section 5.3 for Phase II only. Independent assessments were made for each of the duplicate SM 200 monitors, and the data from each phase of testing were analyzed separately.

# Chapter 6
# Test Results

## 6.1 Phase I—Pittsburgh (August 1 - September 1, 2000)

Samples were collected daily between August 1 and September 1, 2000, using a $PM_{2.5}$ FRM sampler. During this period, the daily $PM_{2.5}$ concentration as measured by the BGI FRM sampler ranged from 6.1 $\mu g/m^3$ to 36.2 $\mu g/m^3$, with an average daily concentration of 18.4 $\mu g/m^3$. Typically, the $PM_{2.5}$ composition was dominated by sulfate and carbon species. On average, the measured sulfate concentration, determined by ion chromatography, accounted for approximately 47% of the daily $PM_{2.5}$ mass. Total carbon, as measured by the IMPROVE thermal optical reflectance (TOR) method, accounted for approximately 38% of the $PM_{2.5}$ mass, with elemental carbon contributing approximately 22% and organic carbon contributing approximately 77% of the total carbon. Additionally, nitrate contributed about 8.3% of the daily $PM_{2.5}$ concentration.

Table 6-1 summarizes the meteorological conditions during Phase I, and Table 6-2 summarizes the observed concentrations of the measured precursor gases during this period.

**Table 6-1. Summary of Daily Values for the Measured Meteorological Parameters During Phase I of Verification Testing**

| | Wind Speed (mph) | Vertical Wind Speed (mph) | Wind Direction (degrees) | Air Temp. @ 10 m (C) | Air Temp. @ 2 m (C) | RH (%) | Solar Radiation ($W/m^2$) | Press. (mbar) | Total Precip. (in.) |
|---|---|---|---|---|---|---|---|---|---|
| Average | 3.35 | 0.09 | 196 | 20.0 | 16.6 | 89.4 | 162.8 | 979.7 | 0.0014 |
| Max | 6.45 | 0.29 | 298 | 24.1 | 22.5 | 95.8 | 246.1 | 986.7 | 0.03 |
| Min | 1.88 | -0.03 | 106 | 14.6 | 12.1 | 80.2 | 47.9 | 974.5 | 0.00 |

**Table 6-2. Summary of Daily Values for the Measured Precursor Gas Concentrations During Phase I of Verification Testing**

| | $SO_2$ (ppb) | $H_2S$ (ppb) | NO (ppb) | $NO_2$ (ppb) | $NO_x$ (ppb) | $O_3$ (ppb) |
|---|---|---|---|---|---|---|
| Average | 6.9 | 1.5 | 3.1 | 10.1 | 13.0 | 24 |
| Max | 12.8 | 2.9 | 10.4 | 17.4 | 27.4 | 51 |
| Min | 2.7 | -0.6 | 0.14 | 5.3 | 5.3 | 5 |

### *6.1.1 Inter-Unit Precision*

During Phase I of the verification test, only one SM 200 monitor was operational. One of the units delivered to the test site had an internal mechanical failure associated with the filter changing mechanism. This failure could not be diagnosed and rectified prior to the end of Phase I. As a result, no data are available for that unit and no measure of inter-unit precision could be established for Phase I.

### *6.1.2 Comparability/Predictability*

During Phase I, the SM 200 monitor was set up to make 24-hour measurements from noon to noon to correlate with the measurements of the $PM_{2.5}$ FRM. Unfortunately, after a power outage the SM 200 monitor was restarted without retrieving the stored data. As a result, the data from the first two weeks of Phase I were overwritten and are not available. In Figures 6-1a and 6-1b, the available noon-to-noon measurements from the one operational SM 200 monitor are shown along with the $PM_{2.5}$ FRM measurements for Phase I of the verification test. These data were analyzed by linear regression according to Section 5.2 to establish the comparability of the SM 200 monitor and the $PM_{2.5}$ FRM. The calculated slope, intercept, and $r^2$ value of the regression analyses are presented in Table 6-3 for the SM 200.

The regression results for the 24-hour average $PM_{2.5}$ concentrations for Monitor 1 and the $PM_{2.5}$ FRM results show an $r^2$ value of 0.971. The slope of the regression line is 1.17 (0.14) and the intercept of the line is 3.2 (3.2) $\mu g/m^3$, where the numbers in parentheses are the 95% CIs. The uncertainty in the slope of this plot does not include unity at the 95% confidence interval and therefore indicates a statistical bias. The intercept is statistically indistinguishable from zero at the 95% confidence level.

### *6.1.3 Meteorological Effects*

A multivariable analysis, as described in Section 5.3, was performed to determine if the meteorological conditions had an influence on the readings of the SM 200 monitor. This analysis involved a backward elimination process to remove from the analysis model those parameters showing no statistically significant influence on the results. This analysis indicates that wind speed, relative humidity, solar radiation, and total precipitation all have a statistically significant influence on the SM 200 readings relative to the FRM values at the 90% confidence level. However, the effects are small; e.g., the combined effect of these parameters is less than the uncertainty of FRM readings (i.e., < 10%).

The regression analysis indicates a relationship of the form:

$$\text{Monitor 1} = 1.05*\text{FRM} - 3.19*\text{WS} - 1.15*\text{RH} - 0.00473*\text{RAD} + 64.6*\text{TP} + 124.2\ \mu g/m^3$$

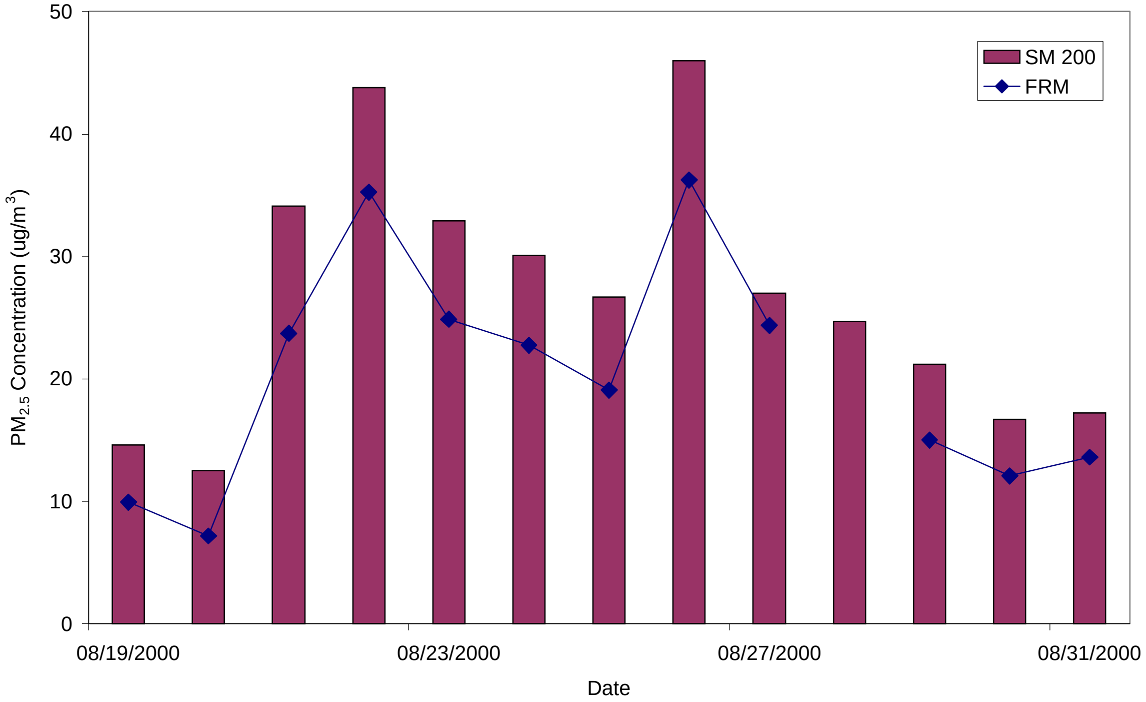

**Figure 6-1a. Daily $PM_{2.5}$ FRM Concentrations and the 24-Hour $PM_{2.5}$ Averages from SM 200 Monitor During Phase I of Verification Testing**

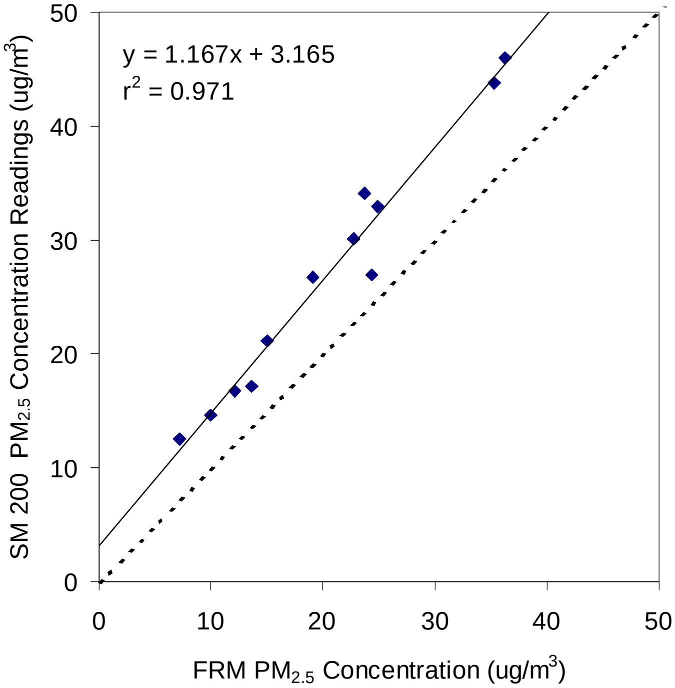

**Figure 6-1b. Correlation Plot of the 24-Hour Concentrations from SM 200 Monitor and the $PM_{2.5}$ FRM Results During Phase I of Verification Testing**

where FRM represents the $PM_{2.5}$ FRM results, WS is the average daily wind speed in mph, RH is the average relative humidity in percent, RAD is the average solar radiation in $W/m^2$, and TP is the total precipitation in inches.

Using the average values for these meteorological parameters and for the $PM_{2.5}$ concentration during Phase I (Table 6-1), the equation above would predict an average value of 29.3 $\mu g/m^3$ for Monitor 1:

$$\begin{aligned} \text{Monitor 1} &= 1.05*18.4 - 3.19*3.35 - 1.15*89.4 \\ &\quad - 0.00473*162.8 + 64.6*0.0014 + 124.2 \\ &= 29.3\ \mu g/m^3 \end{aligned}$$

whereas the linear equation from Table 6-3 would predict an average $PM_{2.5}$ value of

$$\begin{aligned} \text{Monitor 1} &= 1.17*18.4 + 3.2 \\ &= 24.7\ \mu g/m^3, \end{aligned}$$

Thus, the multivariable model shows a difference of approximately 20% relative to the linear regression.

**Table 6-3. Comparability of the SM 200 Monitor with the $PM_{2.5}$ FRM During Phase I**

| Regression Parameter | Monitor 1 | Monitor 2 |
|---|---|---|
| Slope (95% CI) | 1.17 (0.14) | NA |
| Intercept ($\mu g/m^3$) (95% CI) | 3.2 (3.2) | NA |
| $r^2$ | 0.971 | NA |

NA - Not Available

### *6.1.4 Influence of Precursor Gases*

As described in Section 5.3, a multivariable analysis was performed to determine if precursor gases had an influence on the readings of the SM 200 monitor. This analysis involved a backward elimination process to remove from the analysis model those parameters showing no statistically significant influence on the results. This analysis showed that none of the gases measured (ozone, carbon monoxide, nitric oxide, sulfur dioxide, nitrogen dioxide, nitrogen oxides, hyrogen sulfide) had a statistically significant influence on the SM 200 readings relative to the FRM at 90% confidence.

## 6.2 Phase II—Fresno (December 18, 2000 - January 17, 2001)

During Phase II, daily 24-hour $PM_{2.5}$ concentrations averaged 74 µg/$m^3$ and ranged from 4.9 µg/$m^3$ to 146 µg/$m^3$. A strong diurnal pattern was observed in the $PM_{2.5}$ concentration, with the peak levels occurring near midnight. Particle composition was dominated by nitrate and carbon. On average, the overall $PM_{2.5}$ concentration comprised 22% nitrate and 40% total carbon. Sulfate accounted for only about 2% of the daily $PM_{2.5}$ mass. Both nitrate and sulfate were determined by ion chromatography, and carbon was determined by the IMPROVE TOR method.

Table 6-4 summarizes the meteorological conditions during Phase II and Table 6-5 summarizes the observed concentrations of the measured precursor gases during this period.

**Table 6-4. Summary of Daily Values for the Measured Meteorological Parameters During Phase II of Verification Testing.**

| | Wind Speed (mps) | Wind Direction (Degrees) | Air Temp. (C) | RH (%) | Solar Radiation (W/$m^2$) | Press. (mmHg) |
|---|---|---|---|---|---|---|
| Average | 1.43 | 186 | 8.3 | 75.4 | 88.2 | 756.2 |
| Max | 4.18 | 260 | 12.8 | 92.0 | 123.5 | 761.7 |
| Min | 0.91 | 116 | 4.6 | 51.6 | 17.1 | 747.3 |

**Table 6-5. Summary of Daily Values for the Measured Precursor Gas Concentrations During Phase II of Verification Testing**

| | CO (ppm) | $O_3$ (ppb) | NO (ppb) | $NO_2$ (ppb) | $NO_x$ (ppb) |
|---|---|---|---|---|---|
| Average | 1.9 | 13 | 61.8 | 32.6 | 94.4 |
| Max | 3.3 | 28 | 119.9 | 50.3 | 170.2 |
| Min | 0.4 | 6 | 4.1 | 14.8 | 18.9 |

### *6.2.1 Inter-Unit Precision*

Duplicate SM 200 monitors were installed on December 20, 2000, and collected hourly $PM_{2.5}$ measurements for the remainder of Phase II of testing. Figure 6-2a shows these hourly measurements as a time series plot for the two monitors. Breaks in the data indicate periods during which no data are available from the SM 200 monitors. Frequently these breaks were caused by excessive loading on the Teflon filters used for sampling. To collect sufficient mass on the filters, the SM 200 monitors were installed with metal masks above the filters, which limited the sampling area of the filters while maintaining a 16.7 L/min flow rate. Unfortunately, this practice resulted in clogging the filters as indicated by error codes in the data files. Overall, data were available from

SM 200 Monitor 1 for 66% of the field period and from Monitor 2 for 73% of the period. Figure 6-2b shows the available hourly data as a scatter plot to illustrate the correlation

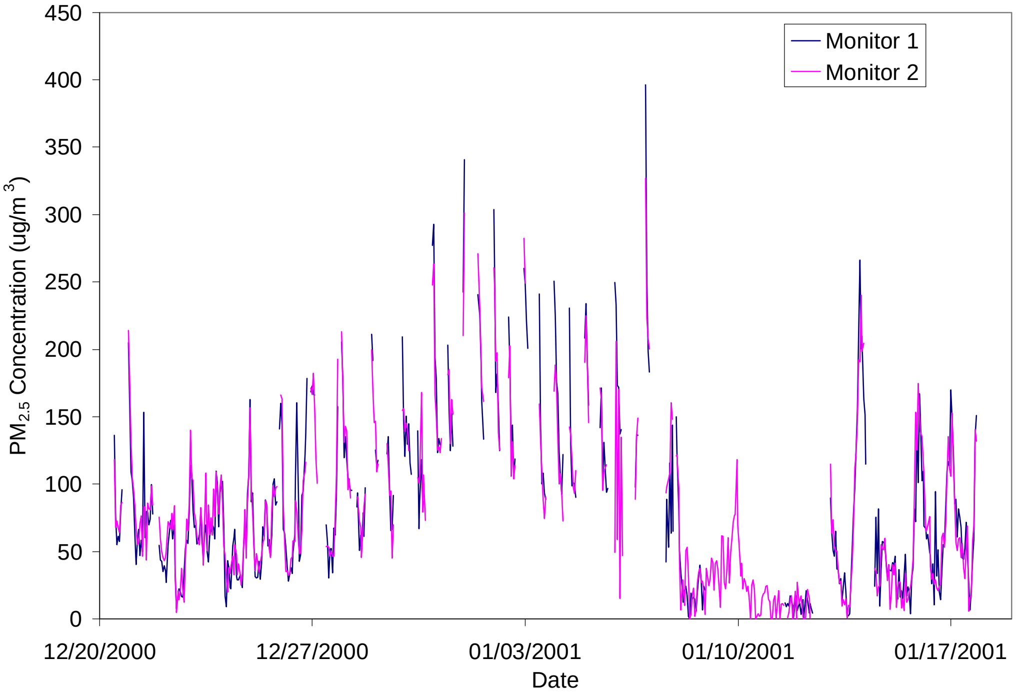

**Figure 6-2a. Hourly $PM_{2.5}$ Concentrations from Duplicate SM 200 Monitors During Phase II of Verification Testing**

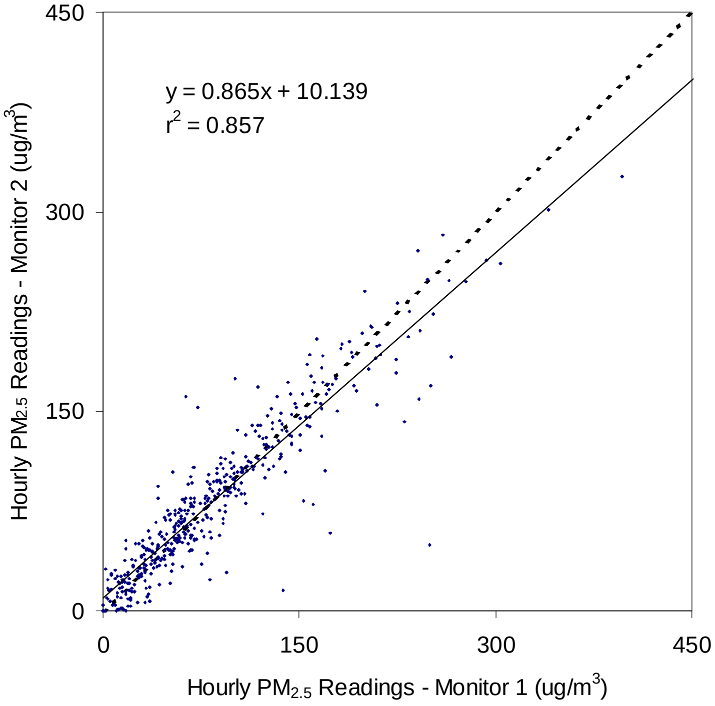

**Figure 6-2b. Correlation Plot of Hourly $PM_{2.5}$ Concentrations from SM 200 Monitors During Phase II of Verification Testing**

between the two monitors during Phase II of testing. These data were analyzed by linear regression, and the results of this analysis are presented in Table 6-2. The CV for these values was also determined according to Section 5.1, and the calculated CV is shown in Table 6-4.

For comparison with the PM$_{2.5}$ FRM reference measurements, the hourly data were averaged from midnight to midnight for each day to correspond with the 24-hour sampling periods used in Phase II of the verification test. In Figure 6-3a the midnight-to-midnight averages for Phase II of the verification test are presented for the two SM 200 monitors. A correlation plot of these data is shown in Figure 6-3b, and the results of a linear regression analysis of these data are presented in Table 6-6. The coefficient of variation for these noon-to-noon average values was also calculated and is shown in Table 6-6.

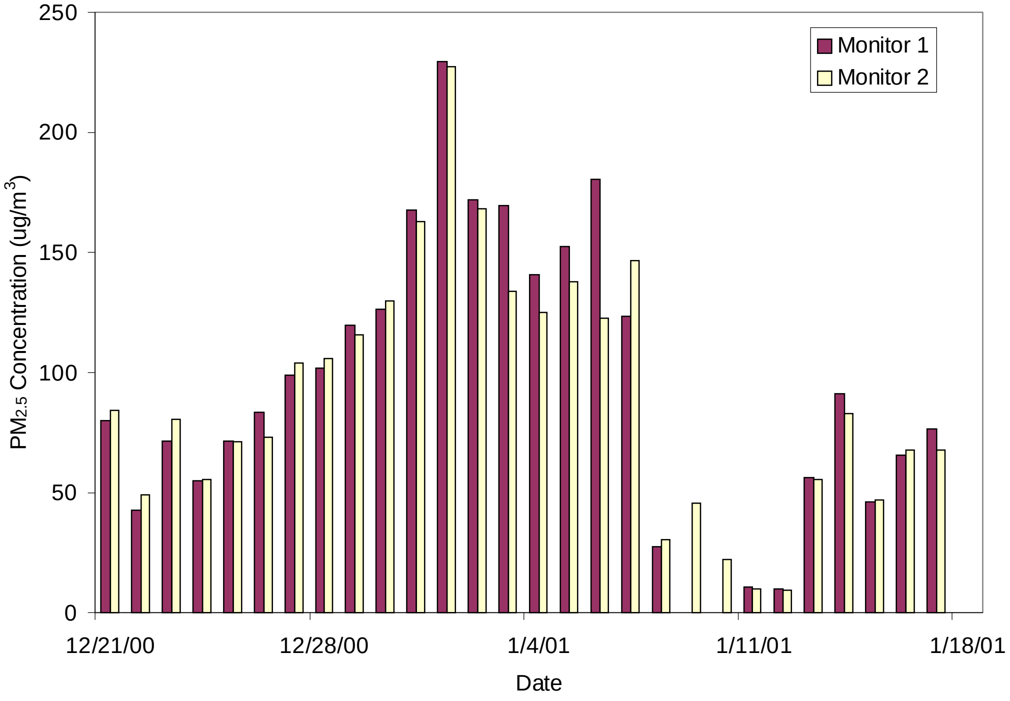

**Figure 6-3a. Midnight-to-Midnight PM$_{2.5}$ Average Concentrations from Duplicate SM 200 Monitors During Phase II of Verification Testing**

The slopes of the regression lines for both the hourly data and the 24-hour average data indicate a bias between the duplicate monitors (i.e., the slopes are different from unity). The regression results of the hourly data showed a slope of 0.865 (0.033), an intercept of 10.1 (3.6) µg/m$^3$, and an $r^2 = 0.857$ where the numbers in parentheses are the 95% CIs. The 24-hour data showed a slope of regression line of 0.882 (0.101), an intercept of 7.5 (11.4) µg/m$^3$, and an $r^2 = 0.931$. On average, the hourly data readings for Monitor 1 read 1.4 µg/m$^3$ greater than the readings for Monitor 2, and the corresponding difference between the two monitors for the 24-hour averages is 4.2 µg/m$^3$. These differences are small relative to the typical PM$_{2.5}$ concentrations present in Phase II. In each case, because of the random variations in the difference of the readings, a Student's t-test indicates no bias between the monitors.

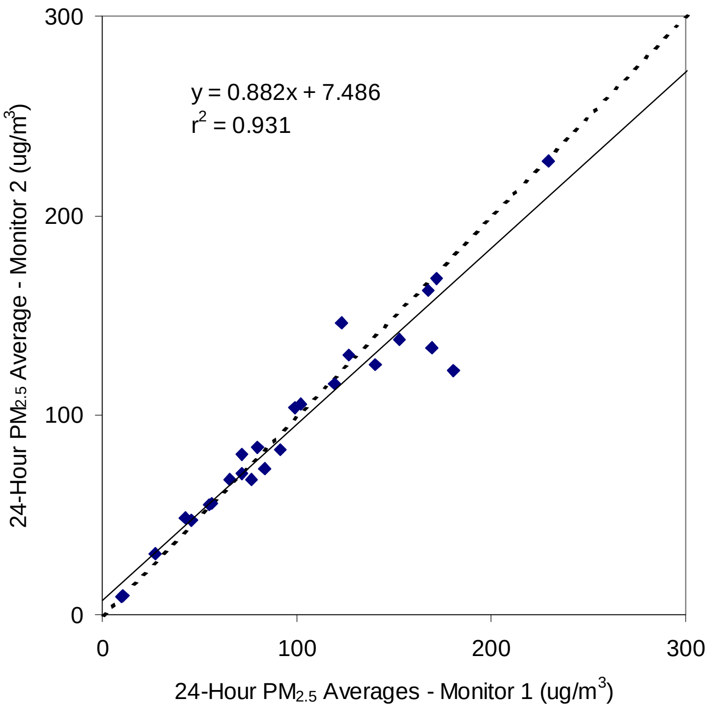

**Figure 6-3b. Correlation Plot of the 24-Hour PM$_{2.5}$ Average Concentrations from Duplicate SM 200 Monitors During Phase II of Verification Testing**

**Table 6-6. Linear Regression and Coefficient of Variation Results for Hourly and 24-Hour Average PM$_{2.5}$ Concentrations from Duplicate SM 200 Monitors During Phase II**

| Parameter | Hourly Data | 24-Hour Average Data |
|---|---|---|
| Slope (95% CI) | 0.865 (0.033) | 0.882 (0.101) |
| Intercept (µg/m$^3$) (95% CI) | 10.1 (3.6) | 7.5 (11.4) |
| r$^2$ (95% CI) | 0.857 | 0.931 |
| CV | 31.0 % | 8.4 % |

### *6.2.2 Comparability/Predictability*

Because of the large amount of data that was unavailable because of filter clogging, approximately 50% of the days for each monitor did not meet the 75% data completeness requirement for 24-hour averages noted in Section 4.1. However, the available data from the SM 200 monitors seem to track the FRM results; and, as such, the results presented here are for averages calculated from the available data, for days with at least 40% completeness. On average for the days used in this comparison, the 24-hour average data for Monitor 1 have a 70% completeness, and the 24-hour average data for Monitor 2 have a 73% completeness.

In Figure 6-4a, the midnight-to-midnight averages of the SM 200 measurements are shown, along with the $PM_{2.5}$ FRM measurements for Phase II of the verification test. These $PM_{2.5}$ concentration values were analyzed by linear regression according to Section 5.2 to establish the comparability of each of the SM 200 monitors with the $PM_{2.5}$ FRM sampler. The regression plot is shown in Figure 6-4b, and the calculated slope, intercept, and $r^2$ value of the regression analyses are presented in Table 6-7 for each monitor.

The regression results show slopes of 1.39 (0.18) and 1.22 (0.19) for Monitor 1 and Monitor 2 respectively, where the numbers in parentheses are the 95% CIs. In each case, the slope was statistically different from unity at the 95% confidence level, indicating a bias relative to the FRM. However, the intercepts of the regression lines were not statistically different from zero at the 95% confidence level. The correlation between the SM 200 monitors and the FRMs is represented by $r^2$ values of 0.918 for Monitor 1 and 0.870 for Monitor 2

### *6.2.3 Meteorological Effects*

As with the data from Phase I, multivariable analysis was performed to determine if the meteorological conditions had an influence on the readings of the SM 200. This analysis involved a backward elimination process to remove from the analysis model those parameters showing no statistically significant influence on the results. This analysis indicates that, during Phase II, there were no observed meteorological effects on Monitor 2 relative to the FRM at the 90% confidence level. However, relative humidity and wind speed had a statistically significant influence on the readings of Monitor 1 relative to the FRM values at 90% confidence. The regression analysis indicates a relationship of the form:

$$\text{Monitor 1} = 1.62*\text{FRM} + 1.16*\text{RH} + 13.8*\text{WS} - 135.5\ \mu g/m^3$$

where FRM represents the measured $PM_{2.5}$ FRM values in $\mu g/m^3$, RH represents the average relative humidity in percent, and WS represents the mean wind speed in meters per second.

Assuming the average values for each of these parameters during Phase II, this equation would predict an average $PM_{2.5}$ value of 91.6 $\mu g/m^3$, whereas the linear regression results presented in Table 6-7 would predict a value of 91.0 $\mu g/m^3$, i.e., a difference of <1%.

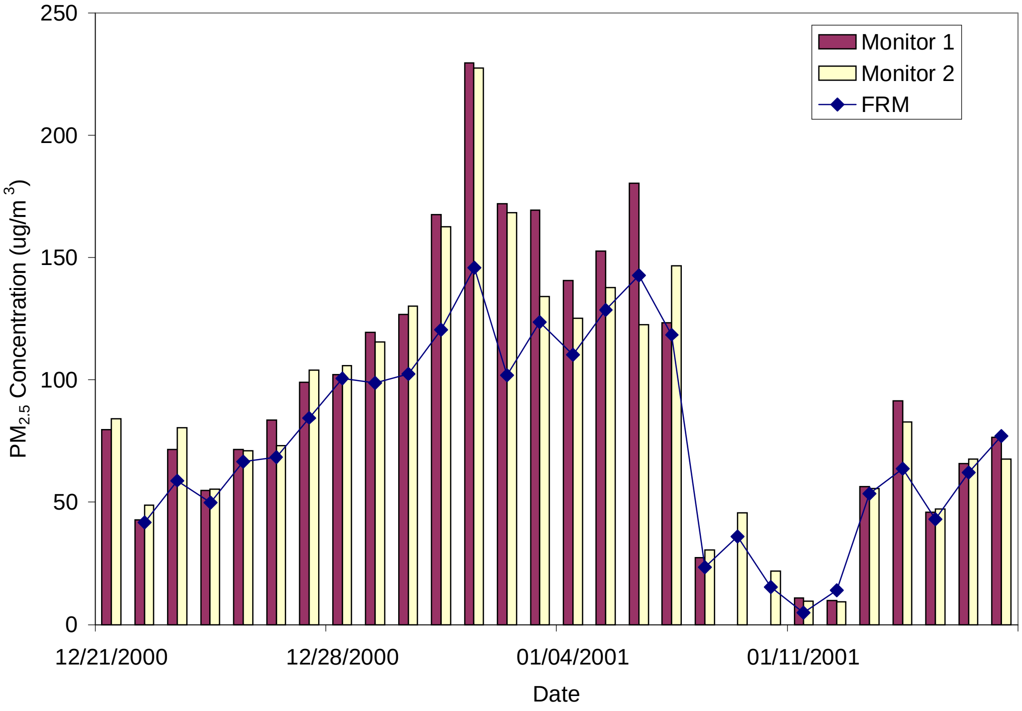

**Figure 6-4a. Midnight-to-Midnight Average Concentrations from Duplicate SM 200 Monitors and PM$_{2.5}$ FRM Results During Phase II of Verification Testing**

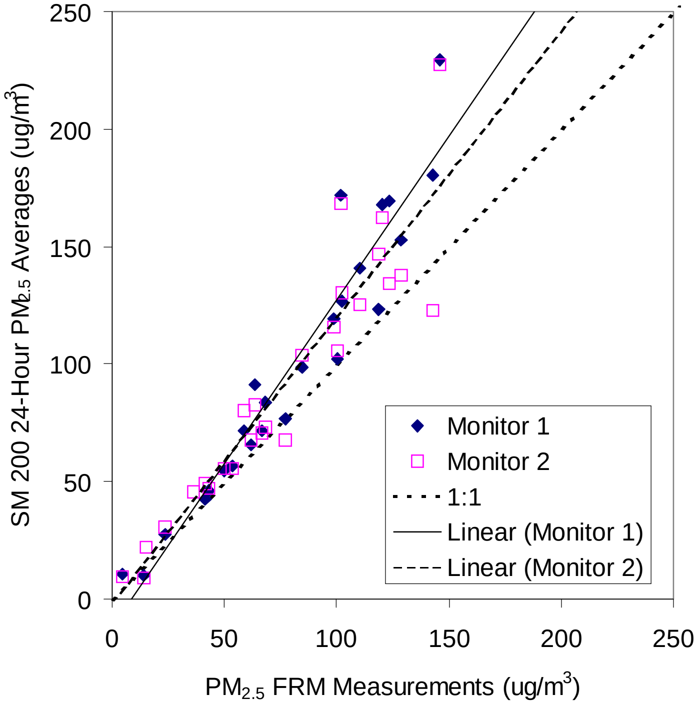

**Figure 6-4b. Correlation Plot from Duplicate SM 200 Monitors and the PM$_{2.5}$ FRM During Phase II of Verification Testing**

**Table 6-7. Comparability of the SM 200 Monitors with the $PM_{2.5}$ FRM During Phase II**

| Regression Parameter | Monitor 1 | Monitor 2 |
|---|---|---|
| Slope (95% CI) | 1.394 (0.180) | 1.219 (0.194) |
| Intercept (µg/$m^3$) (95% CI) | -12.2 (16.0) | -2.2 (16.7) |
| $r^2$ | 0.918 | 0.870 |

### *6.2.4 Influence of Precursor Gases*

Multivariable analysis was also performed to establish if a relationship exists between precursor gases (carbon monoxide, nitrogen dioxide, nitric oxide, nitrogen oxides, ozone) and the SM 200 readings relative to the FRM. This analysis showed no influence of the precursor gases on the readings of Monitor 1, at the 90% confidence level. For Monitor 2, a relationship of the form:

$$\text{Monitor 2} = 1.42 \cdot \text{FRM} - 0.0267 \cdot \text{NOx} + 8.7\ \mu g/m^3$$

was observed, where $NO_x$ is the concentration of nitric oxide in ppb.

Using the average values for these parameters during Phase II, this equation would predict an average $PM_{2.5}$ value of 111.2 µg/$m^3$, whereas the linear regression results presented in Table 6-7 would predict a value of 88.0 µg/$m^3$.

### *6.2.5 Short-Term Monitoring*

During Phase II of the verification test, short-term monitoring was conducted on a five-sample-per-day basis throughout the test period. Table 6-8 presents the averages and the ranges of the time-integrated $PM_{2.5}$ concentrations for these sampling periods during Phase II. Figure 6-6 shows the correlation between the time-weighted sum of the short-term measurements from the sequential filter sampler and the 24-hour FRM measurements. The slope and intercept of the regression line are 0.930 (0.077), and 2.2 (6.6) µg/$m^3$, respectively, with an $r^2$ value of 0.960, where the numbers in parentheses are 95% CIs.

In Figure 6-6, the averages of the SM 200 readings for all the short-term monitoring periods are plotted versus the corresponding $PM_{2.5}$ concentration values from the reference sampler. Linear regression analysis of these data was performed separately for each SM 200 monitor, and the results are presented in Table 6-9. Regression analyses were also performed separately for each of the five time periods during which the short-term samples were collected (i.e., 0000-0500, 0500-1000, 1000-1300, 1300-1600, and 1600-2400). These regression results are also presented in Table 6-9. For these analyses, all available data were used.

**Table 6-8. Summary of $PM_{2.5}$ Levels During Phase II of Verification Testing**

| $PM_{2.5}$ Concentration ($\mu g/m^3$) | Sampling Period | | | | |
|---|---|---|---|---|---|
| | 0000-0500 | 0500-1000 | 1000-1300 | 1300-1600 | 1600-2400 |
| Average | 81.0 | 52.2 | 56.8 | 46.7 | 87.7 |
| Maximum | 163.2 | 131.4 | 140.9 | 136.6 | 180.7 |
| Minimum | 3.4 | 7.7 | 4.8 | 2.2 | 7.2 |

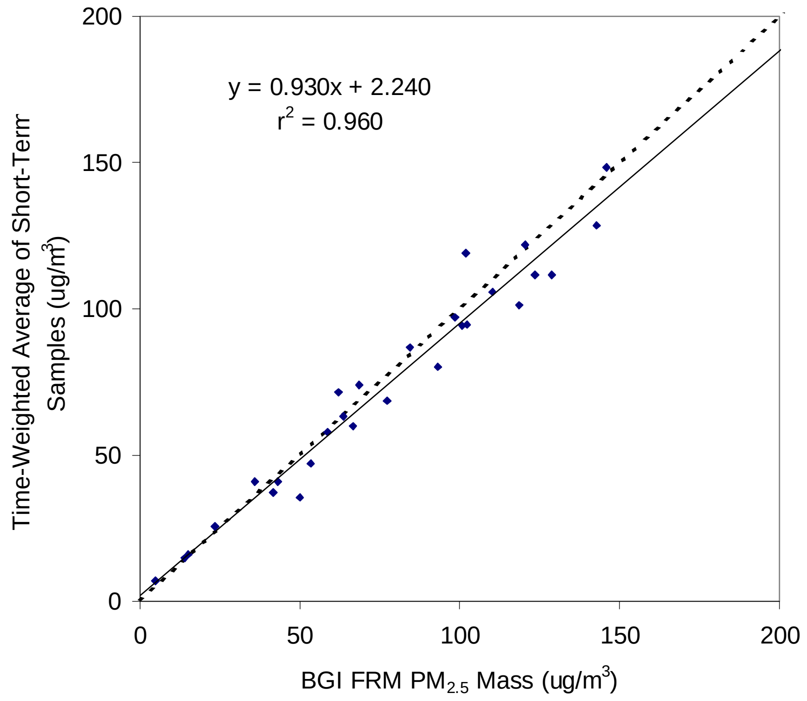

**Figure 6-5. Correlation Plot of the Time-Weighted Averages for the Short-Term Samples and the $PM_{2.5}$ FRM**

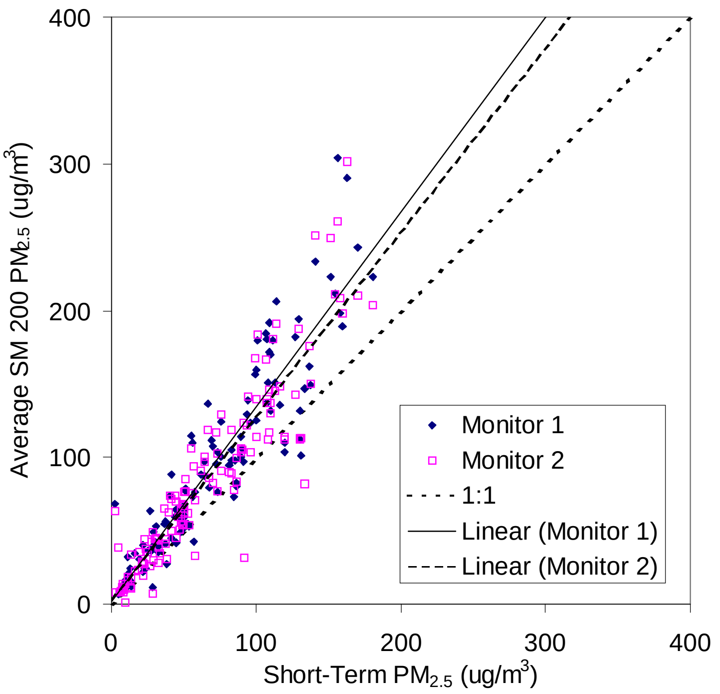

**Figure 6-6. Correlation Plot of Short-Term Monitoring Results and the Corresponding Averages from the Duplicate SM 200 Monitors During Phase II of Verification Testing**

**Table 6-9. Regression Analysis Results for the Short-Term Monitoring**

| Short-Term Monitoring Period | Monitor 1 | | | Monitor 2 | | |
|---|---|---|---|---|---|---|
| | Slope | Intercept (µg/m³) | $r^2$ | Slope | Intercept (µg/m³) | $r^2$ |
| All | 1.33 | 1.3 | 0.845 | 1.26 | 3.3 | 0.838 |
| 0000-0500 | 1.45 | -5.5 | 0.867 | 1.45 | -5.9 | 0.888 |
| 0500-1000 | 1.52 | -5.2 | 0.859 | 0.91 | 14.3 | 0.432 |
| 1000-1300 | 1.72 | -5.8 | 0.950 | 1.61 | -5.5 | 0.926 |
| 1300-1600 | 1.05 | 10.4 | 0.828 | 1.16 | 5.1 | 0.883 |
| 1600-2400 | 1.32 | -11.4 | 0.796 | 1.09 | 2.5 | 0.813 |

The short-term monitoring results indicate considerable variation in how well the SM 200 monitors correlate with the reference measurements overall and for most of the five short-term monitoring periods. The slopes of the regression lines range from 1.05 to 1.72 for Monitor 1 and 0.91 to 1.61 for Monitor 2. (It should be noted that the reference measurements have not been corrected to account for the observed difference between the time-weighted average of the short-term samples and the FRM.) No statistically significant intercept was observed with either monitor for any of the five sampling periods. The $r^2$ values were mostly in the range of 0.8 to 0.95. However, Monitor 2 exhibited an $r^2$ value of only 0.432 in the 0500-1000 time period.

### 6.3 Instrument Reliability/Ease of Use

During Phase I and Phase II, the SM 200s were operated with a filter shim. This mechanical device was placed over the filter by the vendor to concentrate the mass on the 47-mm diameter to a smaller diameter. The concentrations in Phase II were high at times; therefore, the sampler overloaded.

During Phase I testing, one unit was not operational because of a mechanical malfunction in the filter handling mechanism. This malfunction could not be identified and repaired before the end of Phase I. Consequently no data are available for that unit. Additionally, a substantial amount of data were lost as a result of operator error. However, for the half of the field period where data are available (from one monitor), 100% data recovery was achieved.

During Phase II of the verification test, data recovery of 66% was achieved for Monitor 1 and 73% for Monitor 2. The loss of data is probably the result of overloading of the sample filters during very high $PM_{2.5}$ concentration episodes. The SM 200 monitors were installed with metal masks to limit the sampling area of the filters while maintaining a 16.7 L/min flow rate. New filters were loaded into each of the monitors approximately weekly. No operating problems arose; and, other than replacement of the filters in the two monitors, no maintenance was performed on either monitor during Phase II of testing.

### 6.4 Shelter/Power Requirements

The SM 200 monitors were installed and operated inside an instrument trailer during each phase of testing. The monitors and pumps were run on a single 15-A circuit. Vendor literature indicates a range of operating temperatures of 5 to 35°C; however, these limits were not verified in this test.

### 6.5 Instrument Cost

The price of the SM 200, as tested, is approximately $15,000 to $20,000. Teflon filters for the SM 200 are the only consumable associated with this technology. Typically, a single filter can be used for up to a day of sampling, and the SM 200 monitors have the capacity to hold 40 filters.

# Chapter 7
# Performance Summary

The SM 200 is a semi-continuous particle monitor designed to provide indications of the ambient particulate matter concentration with time resolution down to one hour. Duplicate SM 200 monitors were evaluated under field test conditions in two separate phases of this verification test. The duplicate monitors were operated side by side and were installed with a $PM_{2.5}$ cyclone to provide size selection of the aerosol. The results from each phase of this verification test are summarized below.

## 7.1 Phase I—Pittsburgh (August 1 - September 1, 2000)

Only one of the duplicate SM 200 monitors was operational during Phase I of testing so no measure of inter-unit precision is available for that period. Data were available from the other SM 200 only for the second half of the Phase I field period because of operator error associated with the data collection system during the first portion of testing. Comparisons of the 24-hour measurements for the single SM 200 with $PM_{2.5}$ FRM results showed a slope of the regression line of 1.17 (0.14) and an intercept of 3.2 (3.2) $\mu g/m^3$, where the values in parentheses represent the 95% confidence interval. At the 95% confidence level, the slope was statistically different from unity, and the intercept was not statistically different from zero. The regression results show an $r^2$ value of 0.971 for these data.

Multivariable analysis of the 24-hour average data showed that wind speed, relative humidity, solar radiation, and total precipitation all had a statistically significant influence on the results of Monitor 1 at the 90% confidence level. These parameters had a combined effect of ~20% on average on the SM 2000 readings during Phase I.

Multivariable analysis of the 24-hour average data showed no statistically significant influence of the measured precursor gases on the SM 200 readings.

## 7.2 Phase II—Fresno (December 18, 2000 - January 17, 2001)

Regression analysis showed $r^2$ values of 0.857 and 0.931, respectively, for hourly and 24-hour average data during Phase II. The slopes of the regression lines (with Monitor 1 as an independent variable) were 0.865 (0.033) and 0.882 (0.101), respectively, for the hourly data and 24-hour averages; and the intercepts were 10.1 (3.6) $\mu g/m^3$ and 7.5 (4.4) $\mu g/m^3$, respectively. The calculated CV for the hourly data was 31% and for the 24-hour data the CV was 8.4%.

Comparison of the 24-hour averages with $PM_{2.5}$ FRM results showed slopes of the regression lines for Monitor 1 and Monitor 2 of 1.394 (0.180) and 1.219 (0.194), respectively; and intercepts of these regression lines were -12.2 (7.7) and -2.2 (8.1) $\mu g/m^3$, respectively. The regression results show $r^2$ values of 0.918 and 0.870 for Monitor 1 and Monitor 2, respectively.

Multivariable analysis of the 24-hour average data showed that relative humidity and wind speed had a statistically significant influence on the readings of Monitor 1 relative to the FRM values at 90% confidence. There was no effect of meteorology on the results of Monitor 2 relative to the FRM.

Multivariable analysis of the 24-hour average data indicated that the presence of $NO_x$ influences the readings of Monitor 2 relative to the FRM. None of the measured gases had an effect on Monitor 1.

In addition to 24-hour FRM samples, short-term sampling was performed on a five-sample-per-day basis. The SM 200 results were averaged for each of the sampling periods and compared with the gravimetric results. Linear regression of these data showed slopes of 1.33 and 1.26, respectively, for Monitor 1 and Monitor 2. The intercepts of the regression lines were 1.3 and 3.3 $\mu g/m^3$, respectively; and the $r^2$ values were 0.845 and 0.838, respectively. These results may not be an accurate representation of the short-term performance of the SM 200 monitors due to a loss of data from excessive filter loading.

Regarding instrument reliability and ease of use, one SM 200 monitor was not operational in Phase I due to a mechanical malfunction. The other SM 200 monitor in Phase I achieved 100% data recovery, excluding a period when on-site operator error caused data loss. In Phase II, data recovery of 66% and 73% was achieved for the duplicate monitors. Filter overloading led to the data loss in Phase II. Such overloading could be minimized by judicious choice of the sampling duration, filter masking, and sampling frequency. Other than filter replacement, no maintenance was performed in Phase II.

# Chapter 8
# References

1. *Test/QA Plan for the Verification of Ambient Fine Particle Monitors*, Battelle, Columbus, Ohio, June 2000.

2. "National Ambient Air Quality Standards for Particulate Matter; Final Rule," U.S. Environmental Protection Agency, 40 CFR Part 50, *Federal Register*, 62 (138):38651-38701, July 18, 1997.

3. *Quality Management Plan (QMP) for the Advanced Monitoring Systems Pilot*, Version 2.0, Battelle, Columbus, Ohio, October 2000.

4. "Quality Assurance Requirements for State and Local Air Monitoring Stations (SLAMS)." Appendix A to 40 CFR, Part 58, *Federal Register*, 62 (138), p.65, July 18, 1997.