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August 2001

Environmental Technology Verification Report

THERMO ANDERSEN
FH 62 C14 AMBIENT DUST MONITOR

Prepared by

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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 PARTICLATE MASS IN AMBIENT AIR**
TECHNOLOGY NAME:	**FH 62 C14 Ambient Dust 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 Thermo Andersen FH 62 C14 ambient dust monitor.

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VERIFICATION TEST DESCRIPTION

The objective of this verification test is to provide quantitative performance data on continuous fine particle 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, 2001. Specific performance characteristics verified in this test include inter-unit precision, agreement with and correlation to time-integrated reference methods, effect of meteorological conditions, influence of precursor gases, and short-term monitoring capabilities. The FH 62 C14 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 systems audit for Phase I and Phase II. EPA QA staff conducted an external technical systems audit during Phase II.

TECHNOLOGY DESCRIPTION

The FH 62 C14 monitor measures the concentration of particulate matter in ambient air. The FH 62 C14 monitor uses the principle of beta attenuation through particulate matter collected on a moveable filter tape using a C_{14} source. When a new section of the filter tape moves into the measuring position, ambient air is pulled through the inlet and the sample tube. Airborne dust particles are deposited on the filter, and a single filter spot remains in the chamber for particulate collection and measurement. The filter section moves out, and a fresh filter section moves into the measuring position. A new cycle starts with an automatic zero adjustment. The chamber for particulate collection and measurement is between the source and the detector. The beta beam passes through the filter and the accumulated dust layer. The intensity of the beta beam is attenuated with increasing dust mass load, leading to a decreasing count rate from the detector. The FH 62 C14 monitor consists of a central unit, a sampling system, a rotary vane pump, and a recording unit. Different preseparators allow various particle sizes to be detected. The FH 62 C14 monitor operates at 100 to 240 volts alternating current and is 315 mm high x 450 mm wide x 320 to 400 mm deep. Measured values can be read from a liquid crystal display or printed. The duplicate FH 62 C14 monitors were each operated with a conventional PM_{10} head and $PM_{2.5}$ sharp cut cyclone to provide size selection.

VERIFICATION OF PERFORMANCE

Inter-Unit Precision: During Phase I the 5-minute readings of the duplicate FH 62 C14 monitors showed recurring negative artifacts apparently associated with condensation of moisture in the early morning hours. The unit-to-unit regression of the 5-minute data gave results [slope = 0.565 (0.019), intercept = 9.5 (1.2) $\mu g/m^3$, r^2 = 0.374, where the values in parentheses are 95% confidence intervals] that were undoubtedly affected by those artifacts. Regression analysis of the 24-hour FH 62 C14 averages showed an r^2 value of 0.875 for the duplicate monitors, with a slope of 0.948 (0.183) and an intercept of -1.29 (5.9) $\mu g/m^3$. At the 95% confidence level, the slope was not significantly different from unity, and the intercept was not significantly different from zero. The calculated coefficient of variation (CV) for the 24-hour average data was 20.6%. During Phase II, inter-unit regression analysis showed r^2 values of 0.987 and 0.999 for the 30-minute readings and the 24-hour averages, respectively. The slopes of the regression lines were 1.002 (0.006) and 1.005 (0.012) for the 30-minute data and 24-hour averages , respectively, indicating no inter-unit bias; and the intercepts were 0.69 (0.65) $\mu g/m^3$ and 0.29 (1.34) $\mu g/m^3$, respectively. The calculated CV for the 30-minute data was 15.4% and for the 24-hour data the CV was 4.4%.

Comparability/Predictability: During Phase I, comparisons of the 24-hour averages with $PM_{2.5}$ FRM results showed r^2 values of 0.856 and 0.802 for Monitor 1 and Monitor 2, respectively. The slopes of the regression lines for Monitor 1 and for Monitor 2 were 1.60 (0.35) and 1.56 (0.41), respectively, indicating a positive bias of about 60% relative to the FRM. No statistically significant intercept was observed in either case at 95% confidence level. Comparison of the 24-hour averages with $PM_{2.5}$ FRM results during Phase II showed the r^2 values of 0.958 and 0.953 for Monitor 1 and Monitor 2, respectively. Slopes of the regression lines for Monitor 1 and Monitor 2 were 1.23 (0.10) and 1.22 (0.11), respectively, indicating a positive bias of about 23% relative to the FRM. No statistically significant intercept was observed in either case at the 95% confidence level.

Meteorological Effects: The multivariable 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 readings of one of the monitors relative to the FRM at 90% confidence. Similarly, barometric pressure and total precipitation were ascribed a statistically significant influence on the other monitor. The overall magnitude of these effects was ~4% for Monitor 1 and ~15% for Monitor 2, on average. Multivariable analysis of the 24-hour average data during Phase II ascribed to relative humidity a statistically significant influence on the readings of one of the monitors relative to the FRM, at a 90% confidence level. However, the average magnitude of the effect during Phase II was negligible (i.e., ~0.1%).

Influence of Precursor Gases: The measured precursor gases had no effect on the results of either monitor relative to the FRM at the 90% confidence level during either Phases I or II.

Short-Term Monitoring: In addition to 24-hour FRM samples, short-term sampling (3-, 5-, and 8-hour intervals) was performed on a five-sample-per-day basis in Phase II. The FH 62 C14 results were averaged for each of the sampling periods and compared with the gravimetric results. Linear regression of these data showed slopes of 1.25 and 1.24, respectively, for Monitor 1 and Monitor 2, when all short-term intervals are included. These results indicate a positive bias of about 25% relative to the FRM data, which is consistent with the result noted above from comparison of 24-hour FRM data in Phase II. The intercepts of the regression lines were 5.0 (4.2) and 4.8 (4.3) $\mu g/m^3$; respectively, and the r^2 values were 0.931 and 0.927, respectively.

Other Parameters: Approximately 10 days of data were lost at the beginning of Phase I owing to insufficient memory of the two monitors. Other than data loss associated with that cause, 100% data recovery was achieved by each of the FH 62 C14 monitors during Phase I. No operating problems arose during Phase I of testing, and no maintenance was performed on either monitor during this phase. During Phase II of the verification test, 100% data recovery was achieved. No maintenance was performed, and no operating problems arose for either monitor.

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Vice President
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Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

Thermo Andersen
FH 62 C14 Ambient Dust Monitor

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Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, has financially supported and collaborated in the extramural program described here. This document has been peer reviewed by the Agency and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

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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.

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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. We would like to acknowledge George Allen of the Harvard School of Public Health and Sky Patton, Sam Lanasa, and Jim Morton of Thermo Andersen for their help with the verification test and discussions regarding this report.

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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
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
IMPROVE	Interagency Monitoring for Protection of Visual Environments
in.	inch
L/min	liters per minute
mm	millimeters
mg	milligram
NETL	National Energy Technology Laboratory
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
SCC	Sharp Cut Cyclone
SLAMS	state and local air monitoring stations
SO_2	sulfur dioxide
TOR	thermal optical reflectance
TSA	technical systems audit
WINS	well impactor ninety six

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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 ambient fine particle matter. This verification report presents the procedures and results of the verification test for the Thermo Andersen FH 62 C14 ambient dust monitor.

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Chapter 2
Technology Description

The following description of the FH 62 C14 monitor is based on information provided by the vendor.

The FH 62 C14 monitor measures the concentration of particulate matter in ambient air. The FH 62 C14 monitor uses the principle of beta attenuation through particulate matter collected on a moveable filter tape using a C_{14} source. When a new section of filter tape moves into the measuring position, ambient air is pulled through the inlet and the sample tube. Airborne dust particles are deposited on the filter, and a single filter spot remains in the chamber for particulate collection and measurement. The filter section moves out, and a fresh filter section moves into the measuring position. A new cycle starts with an automatic zero adjustment. The chamber for particulate collection and measurement is between the source and the detector. The beta beam passes through the filter and the accumulated dust layer. The intensity of the beta beam is attenuated with increasing dust mass load, leading to a decreasing count rate from the detector.

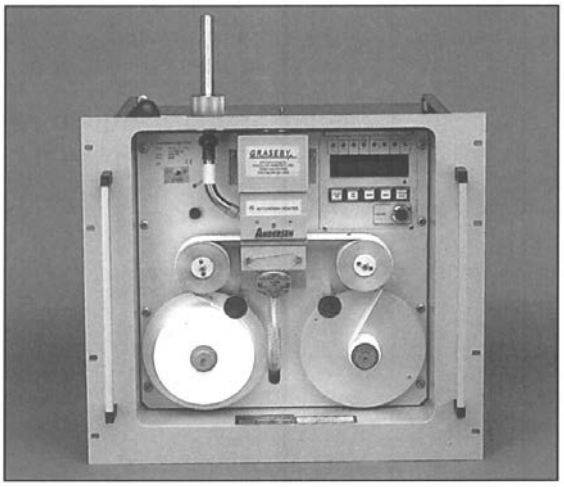

Figure 2-1. Thermo Andersen FH 62 C14 Ambient Dust Monitor

The FH 62 C14 monitor consists of a central unit, a sampling system, a rotary vane pump, and a recording unit. Different preseparators allow various particle sizes to be detected. The FH 62 C14 monitor operates at 100 to 240 volts alternating current and is 315 mm high x 450 mm wide x 320 to 400 mm deep. Measured values can be read from a liquid crystal display or printed.

During this verification test, each FH 62 C14 monitor was operated with a PM_{10} head and a $PM_{2.5}$ sharp cut cyclone (SCC) for particle size selection.

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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 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 time-integrated reference methods
- Effect of meteorological conditions
- Influence of precursor gases
- Short-term monitoring capabilities.

To assess inter-unit precision, duplicate FH 62 C14 monitors were tested in side-by-side operation during each phase of testing. During Phase I, the monitors tested were serial number 106 and serial number 108. During Phase II, the monitors tested were serial number 117 and serial number 121. Collocation of the FH 62 C14 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 requirements 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 FH 62 C14 monitor 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. Descriptions of the reference method and supplemental measurements used during the verification test are given below.

3.3.1 $PM_{2.5}$ Mass

The FRM for $PM_{2.5}$ mass determination, i.e., the 24-hour time-averaged procedure detailed in 40 CFR Part 50,[(2)] 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

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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 the 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), operated at 16.7 L/min flow, 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, wind 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

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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 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 BGI 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 FH 62 C14 monitor was comparison with the 24-hour FRM results. Additional comparisons were made with the supplemental meteorological conditions and precursor gas measurements to assess the effects of these parameters on the response of the monitors being tested. The short-term monitoring results from Phase II of the verification test also were used to assess the capabilities of the FH 62 C14 monitor 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 are reported separately. Inter-unit precision was determined from a statistical intercomparison of the results from the duplicate monitors.

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3.5 Site Layout/Instrument Installation

During Phase I of the verification test, the two FH 62 C14 monitors were operated in outdoor enclosures provided by Andersen. During Phase II of the verification test, the two FH 62 C14 monitors were operated inside the Battelle instrument trailer. A PM_{10} head and $PM_{2.5}$ Sharp Cut Cyclone (SCC) were used with each FH 62 C14 monitor to provide particle size selection. Data generated by the FH 62 C14 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 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, was 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 FH 62 C14 monitors were installed with the BGI FRM sampler on the Battelle/ETV platform. The monitors were housed in separate outside enclosures provided by the vendor. The enclosures were positioned on the platform next to the Battelle instrument trailer and were within approximately 3 meters (10 feet) of the BGI FRM sampler. A vertical separation of less than 1 meter existed between the inlets of the FH 62 C14 monitors and the BGI FRM. The instrument enclosures were not temperature or humidity controlled and were in direct sunlight during daylight hours.

3.5.2 Phase II

Phase II of verification testing was conducted at the CARB site on First Street in Fresno. This site is located in a residential/commercial neighborhood about 3 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 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

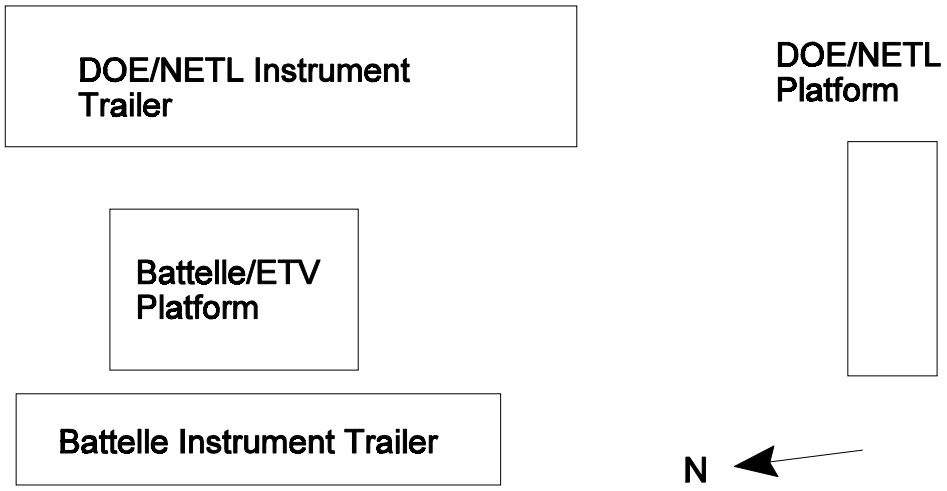

Figure 3-1. Site Layout During Phase I of Verification Testing (not drawn to scale)

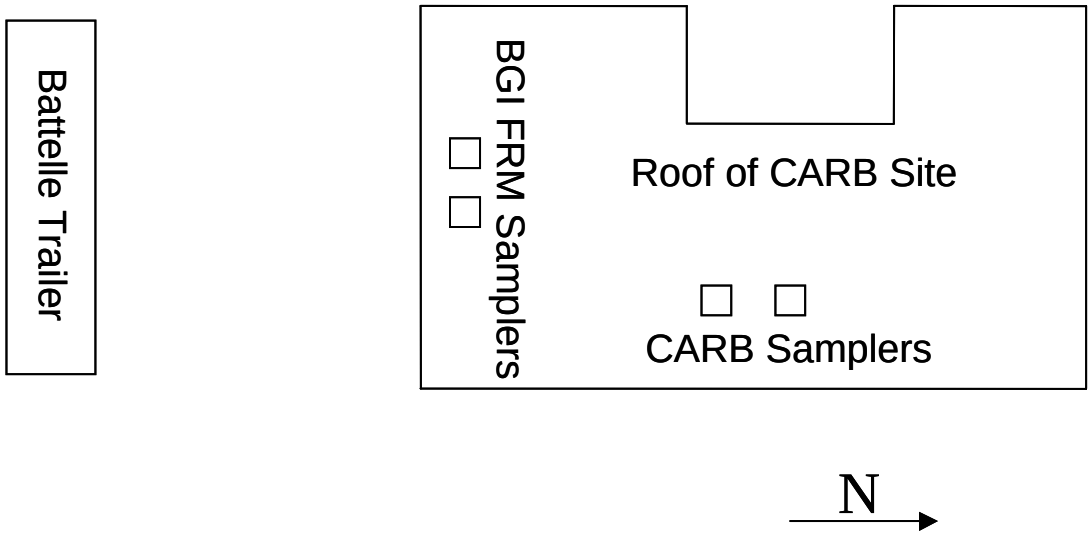

Figure 3-2. Site Layout During Phase II of Verification Testing (not drawn to scale)

approximately 25 meters (80 feet) to the south of the building, as shown in Figure 3-2. 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 FH 62 C14 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 FRM reference values. The sequential filter sampler used to collect the short-term samples was located near the R&P FRM sampler.

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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 test/QA plan.[1] The Verification Test Coordinator, or the Verification Test Leader or designee reviewed the raw data, laboratory notebook entries, and the data sheets that were generated each day and approved them by initialing and dating the records.

Data from the FH 62 C14 monitors were validated by a representative of Thermo Andersen 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. Daily $PM_{2.5}$ concentration averages calculated from the continuous FH 62 C14 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.

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 about 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 continuing 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 Testing (NIST)-traceable flow meters and temperature and pressure sensors. The calibration and verification of these samplers are described below.

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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 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 samplers were 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 samplers and the SFS 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.

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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 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 analyzed by linear regression; and the calculated slope, intercept, and r^2 values are 0.939 (0.067), 1.28 (1.33) $\mu g/m^3$, and 0.957, respectively, where the values in parentheses are 95% confidence intervals (CIs). Despite completely independent operations (i.e., separate sampling staff and weighing facilities), these data show 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, with no vertical separation. 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 BGI and R&P 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 (0.106) and intercept of -1.0 (4.7) $\mu g/m^3$ and r^2 values of 0.982, where the numbers in parentheses indicate the 95% CIs.

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

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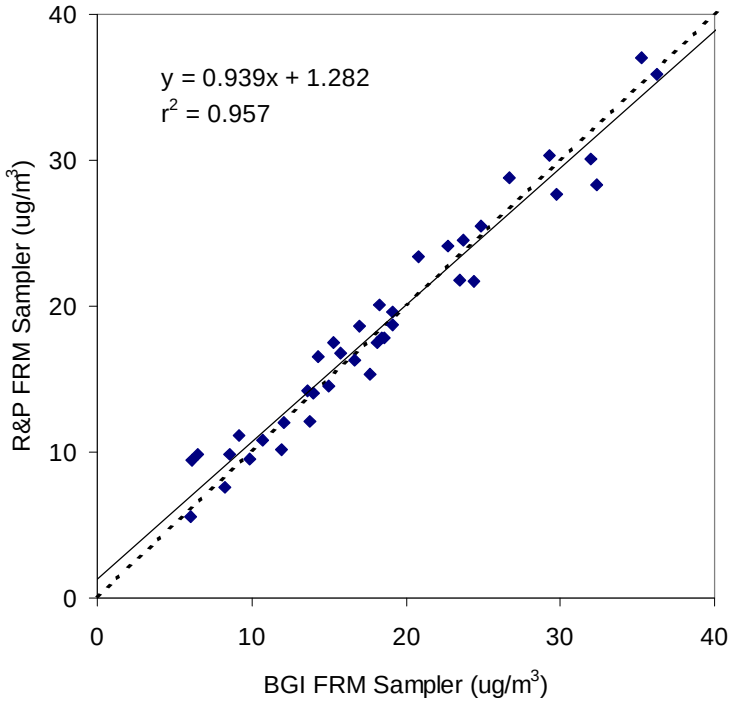

Figure 4-1. Comparison of Collocated $PM_{2.5}$ FRM Samplers for Phase I of Verification Testing

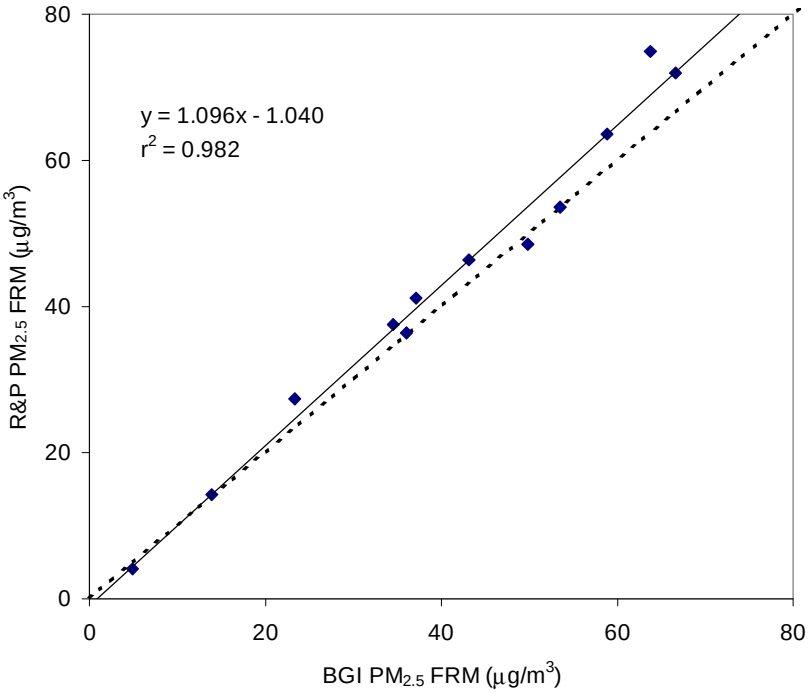

Figure 4-2. Comparison of Collocated $PM_{2.5}$ FRM Samplers for Phase II of Verification Testing

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 a scatter in the low concentration regime. When a single low 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 µg/m^3, averaging 0.15 μg/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 (for 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. On average, 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 µg/m^3. Assuming a sample volume of 3.6 m^3 (i.e., 3-hour short-term sample from sequential filter sampler), these blanks account for ~ 0.6 µg/m^3. These blank values were 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.

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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 FH 62 C14 Monitors

During Phase I, data from each of the FH 62 C14 monitors were recorded every 5 minutes and stored in an internal memory buffer. These data were stored in tabular format showing the date and time, the instrument status code, an error flag, and the $PM_{2.5}$ concentration values ($\mu g/m^3$). During Phase II, the data were recorded every 30 minutes in the same format as in Phase I.

The recorded data were downloaded directly onto a computer and saved as text files. These data 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 text/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 AMS 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 FH62 C14. All corrective actions were completed to the satisfaction of the Battelle Quality Manager and the EPA.

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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, and none of the findings adversely affected the quality of the verification test for the FH 62 C14 monitors.

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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 FH 62 C14 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 FH 62 C14 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 FH 62 C14 monitor and the $PM_{2.5}$ FRM was assessed, since the FH 62 C14 monitor yields measurements with the same units of measure as the $PM_{2.5}$ FRM. 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 FH 62 C14 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 FH 62 C14 monitor measurements over the same 24-hour time period as the i^{th} reference measurement; μ and β are the intercept and slope parameters, respectively; and ε_i is error unexplained by the model. The average of the hourly FH 62 C14 monitor measurements is used because this quantity is most comparable to the reference sampler measurements.

Comparability is expressed in terms of bias between the FH 62 C14 monitor and the $PM_{2.5}$ FRM 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 FH 62 C14 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 FH 62 C14 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 95% confidence intervals (CIs) for the intercept and slope. Comparability to the FRM was determined independently for each of the two duplicate FH 62 C14 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 FH 62 C14 monitors and the $PM_{2.5}$ FRM reference samplers was evaluated, by using meteorological data as parameters in multivariable analyses of the reference/monitor comparison. 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 meteorological or precursor gas measurement for the i^{th} 24-hour time period, γ_j is the associated slope parameter, and other notation is in Equation 1. Comparability results are reported again after these variables are adjusted for in the model. Additionally, estimates of γ_j are provided. Meteorological effects and precursor gas interferences were assessed independently for each of the two duplicate FH 62 C14 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.

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5.4 Short-Term Monitoring Capabilities

This assessment was based on linear regression analysis of results from the FH 62 C14 monitors and the short-term (3-, 5-, and 8-hour) sampling results from the sequential filter sampler 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 FRM 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 FRM measurements in the analysis described in Section 5.3 for Phase II only. Independent assessments were made for each of the duplicate FH 62 C14 monitors, and the data from each phase of testing were analyzed separately.

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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

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6.1.1 Inter-Unit Precision

Fine particle mass concentration readings from the two FH 62 C14 monitors were recorded every 5 minutes during Phase I of the verification test. Unfortunately, approximately 10 days of data were lost during Phase I owing to a data storage problem that went undetected until approximately two weeks into Phase I. The data from August 12 through September 1 for the two FH 62 C14 monitors are shown in Figure 6-1.

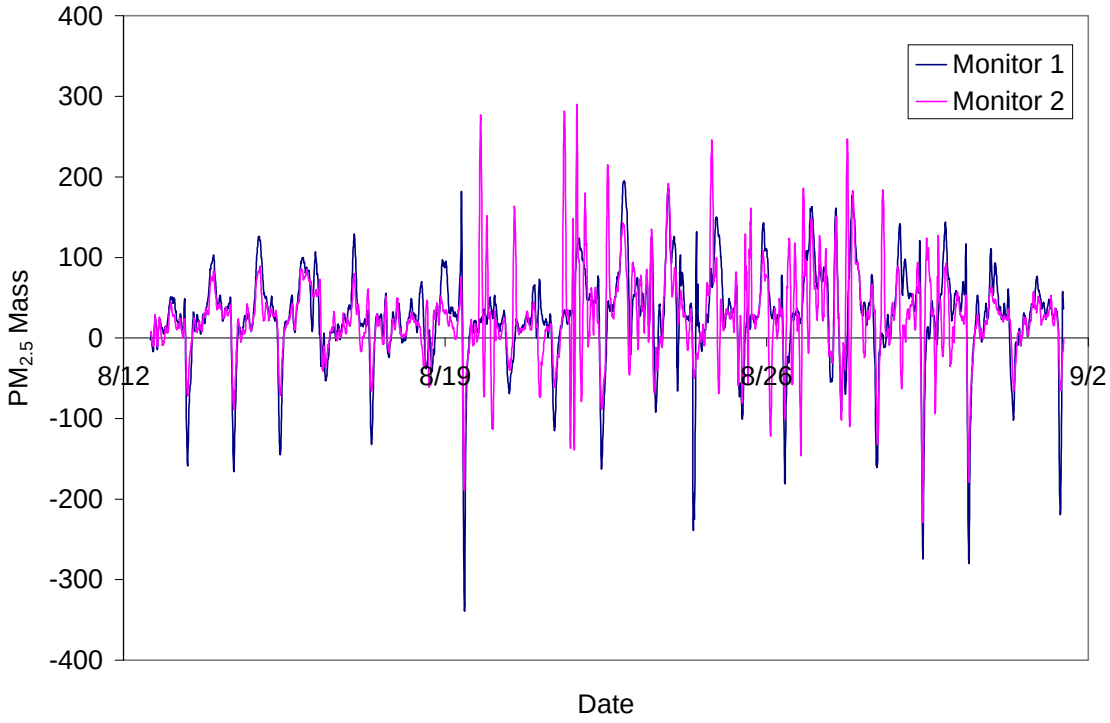

Figure 6-1. $PM_{2.5}$ Readings from Duplicate FH 62 C14 Monitors During Phase I of Verification Testing

This figure illustrates that a periodic dip to large negative values in the reported $PM_{2.5}$ concentration was observed in both FH 62 C14 monitors throughout Phase I of the verification test. This dip occurred almost daily between approximately 8:00 a.m. and noon, and is attributed to condensation and evaporation of moisture in the instrument. Additionally, Monitor 2 shows periods with high frequency oscillations in the signal that are not necessarily related to condensation.

For comparison with the $PM_{2.5}$ FRM reference measurements, the 5-minute data were averaged from noon to noon for each day to correspond with the 24-hour sampling periods used in Phase I of the verification test. These averages were calculated using all 5-minute data shown in Figure 6-1, i.e., both the positive and negative concentration values. In Figure 6-2a, the noon-to-noon averages for Phase I of the verification test are presented for the two FH 62 C14 monitors, and a correlation plot of these data is shown in Figure 6-2b.

The CV for both the 5-minute data and the 24-hour averages was determined according to Section 5.1. The calculated CV for the 5-minute data is 46.7% and for the 24-hour average data is 20.6%. Additionally, the 5-minute data and the 24-hour data were analyzed by linear regression and the results of this analysis are presented along with the CV values in Table 6-3. The regression results of the 5-minute data show a slope that is much different from 1.0, an elevated intercept value, and an r^2 value of 0.37. These results are certainly due in part to the daily negative artifacts shown in Figure 6-1.

For the 24-hour average concentration results, the regression results show an r^2 value of 0.875, a slope of 0.948 (0.183), and an intercept of -1.3 (5.9) mg/m^3, where the numbers in parentheses represent the 95% CIs. For this regression line, the slope is not statistically different from unity, and the intercept is statistically indistinguishable from zero. Thus, even with the negative artifacts included, the 24-hour averages from the two FH 62 C14 monitors are closely similar.

Table 6-3. Linear Regression and Coefficient of Variation Results for the 24-Hour Average $PM_{2.5}$ Concentration Values from Duplicate FH 62 C14 Monitors During Phase I of Verification Testing

Parameter	5-Minute Data	24-Hour Average Data
Slope (95% CI)	0.565 (0.019)	0.948 (0.183)
Intercept ($\mu g/m^3$) (95% CI)	9.5 (1.2)	-1.29 (5.9)
r^2	0.374	0.875
CV	46.7%	20.6 %

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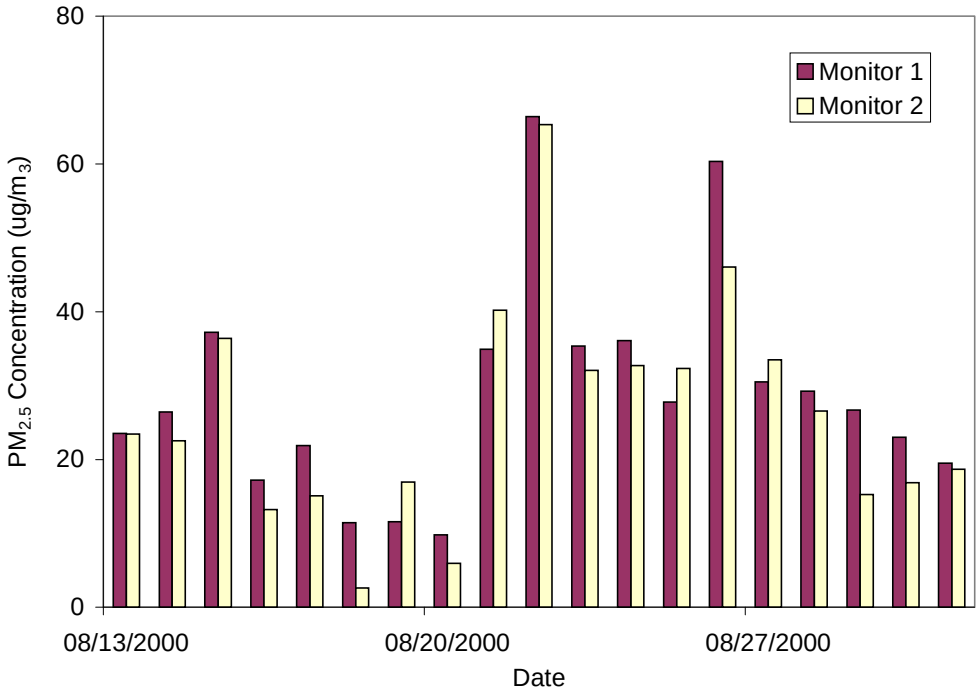

Figure 6-2a. Noon-to-Noon Average $PM_{2.5}$ Concentrations from Duplicate FH 62 C14 Monitors Measured During Phase I of Verification Testing

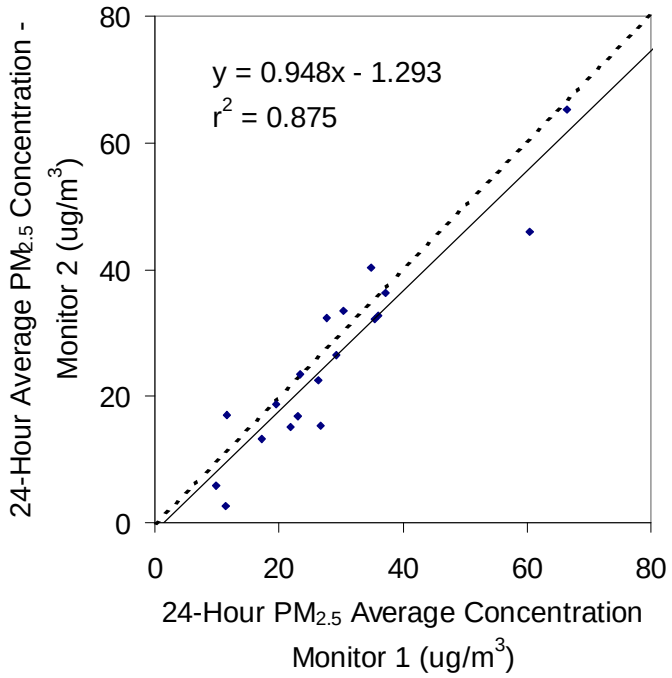

Figure 6-2b. Correlation Plot of 24-Hour $PM_{2.5}$ Concentrations from Duplicate FH 62 C14 Monitors During Phase I of Verification Testing

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6.1.2 Comparability/Predictability

In Figure 6-3a, the noon-to-noon averages of the measurements from the FH 62 C14 monitors are shown, along with the $PM_{2.5}$ FRM measurements for Phase I of the verification test. Figure 6-3b is a correlation plot of the FH 62 C14 and FRM results. These figures show that the FH 62 C14 24-hour results usually exceeded the corresponding FRM results. These $PM_{2.5}$ concentration values were analyzed by linear regression according to Section 5.2 to establish the comparability of each of the FH 62 C14 monitors with the $PM_{2.5}$ FRM. The calculated slope, intercept, and r^2 value of the regression analyses are presented in Table 6-4 for each monitor.

The regression results in Table 6-4 show r^2 values of 0.856 and 0.802, respectively, for Monitor 1 and Monitor 2. The intercepts of the lines are statistically indistinguishable from zero at the 95% confidence level. However, the slopes of the regression lines are 1.60 (0.35) and 1.56 (0.41) for Monitor 1 and Monitor 2, respectively, indicating that both monitors exhibited a significant positive bias relative to the Phase I FRM results.

Table 6-4. Comparability of the FH 62 C14 Monitors with the $PM_{2.5}$ FRM for Phase I

Regression Parameter	Monitor 1	Monitor 2
Slope (95% CI)	1.60 (0.35)	1.56 (0.41)
Intercept ($\mu g/m^3$) (95% CI)	-1.03 (7.1)	-3.37 (8.4)
r^2	0.856	0.802

6.1.3 Meteorological Effects

A multivariable model, as described in Section 5.3, was used to determine if the 24-hour average readings of the FH 62 C14 monitors were affected by meteorological conditions. This analysis involved a backward elimination process to remove from the analysis model those parameters showing no statistically significant influence on the results. The multivariable model indicated the following relationship for Monitor 1:

$$\text{Monitor 1} = 1.68*\text{FRM} - 3.71*\text{WS} - 2.27*\text{RH} - 0.14*\text{RAD} - 46.7*\text{TP} + 236.8\ \mu g/m^3$$

where FRM represents the measured $PM_{2.5}$ FRM values in $\mu g/m^3$, WS is the average wind speed in mph, RH represents the average relative humidity in percent, RAD is the average daily solar radiation in W/m^2, and TP is the total daily precipitation in centimeters. For Monitor 2, the analysis shows the following relationship:

$$\text{Monitor 2} = 1.52*\text{FRM} + 1.21*\text{BP} - 30.3*\text{TP} - 1184\ \mu g/m^3$$

where BP is the barometric pressure in mbar.

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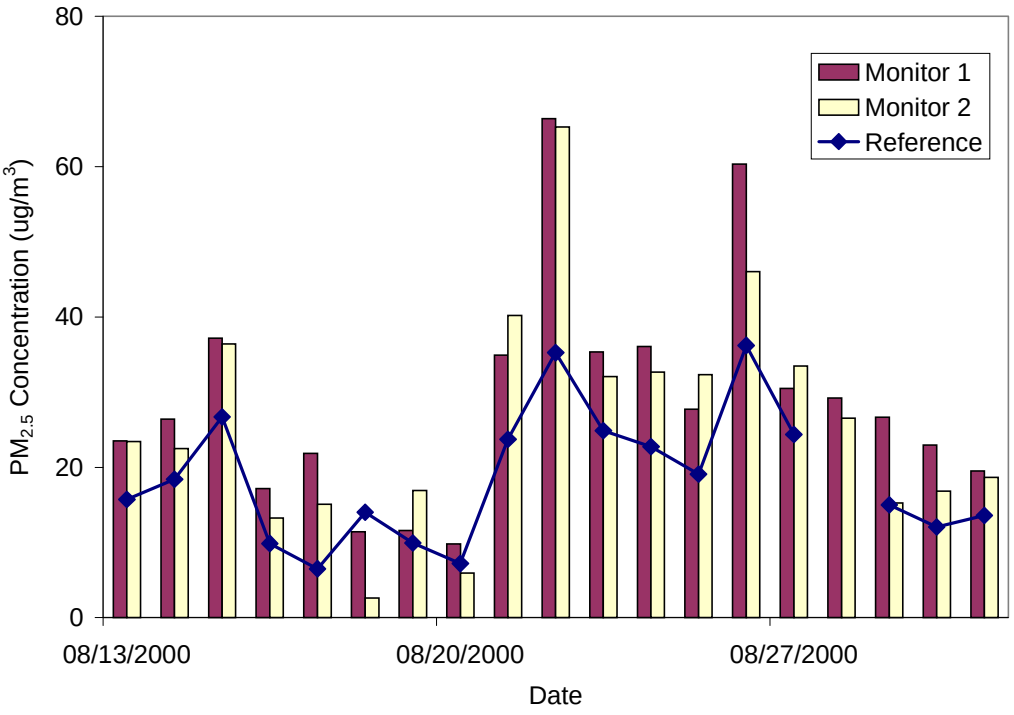

Figure 6-3a. Daily $PM_{2.5}$ Concentrations and the 24-Hour $PM_{2.5}$ Average Concentrations from Duplicate FH 62 C14 Monitors During Phase I of Verification Testing

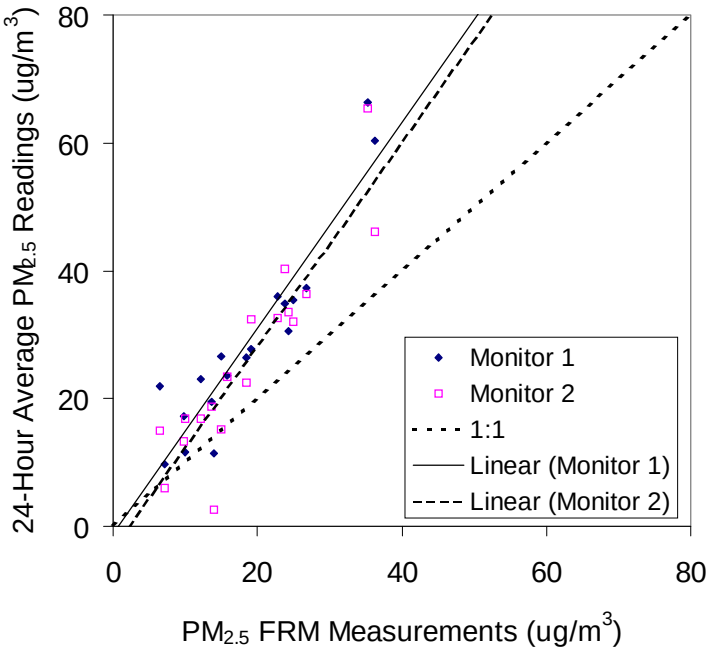

Figure 6-3b. Correlation Plot of the 24-Hour Averages from Duplicate FH 62 C14 Monitors and the $PM_{2.5}$ FRM Results During Phase I of Verification Testing

In both cases, the factor relating the FH 62 C14 results and the FRM results changes by 5% or less, relative to the linear regression results in Table 6-4. As a result, the FH 62 C14 reading expected at a given FRM value is not much affected by the meteorological parameters. For example, using the average values for $PM_{2.5}$ and the various meteorological parameters during Phase 1 (Section 6.1), the above equation would predict an average $PM_{2.5}$ reading of 29.5 $\mu g/m^3$ for Monitor 1:

Monitor 1 = 1.68*18.4 - 3.71*3.35 - 2.27*89.4

- 0.14*162.8 - 46.7*0.0014 + 236.8

= 29.5 $\mu g/m^3$.

Based on the linear regression results (Table 6-4) and the average $PM_{2.5}$ concentration during Phase 1, Monitor 1 would read,

Monitor 1 = 1.60*18.4 $\mu g/m^3$ - 1.0 $\mu g/m^3$

= 28.4 $\mu g/m^3$

i.e., the multivariable model results in a difference of approximately 3.9% relative to the linear regression results.

Similarly, the multivariable model would predict a $PM_{2.5}$ reading of 29.4 $\mu g/m^3$ for Monitor 2:

Monitor 2 = 1.52* 18.4 + 1.21*979.7 - 30.3*0.0014 - 1184

= 29.4 $\mu g/m^3$

whereas the linear equation would predict

Monitor 2 = 1.56*18.4 -3.4

= 25.3 $\mu g/m^3$

i.e., a difference of approximately 15%.

6.1.4 Influence of Precursor Gases

Multivariable analysis was also performed to establish if a relationship exists between precursor gases and the FH 62 C14 readings relative to the FRM. This analysis showed no influence of the precursor gases measured during Phase I on the readings of either monitor, at the 90% confidence level.

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

During Phase II, daily 24-hour $PM_{2.5}$ concentrations averaged 74 $\mu g/m^3$ and ranged from 4.9 $\mu g/m^3$ to 146 $\mu g/m^3$. 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, nitrate and carbon comprised 22% and 40% of the overall $PM_{2.5}$ concentration, respectively. 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 6-5 summarizes the meteorological conditions during Phase II and Table 6-6 summarizes the observed concentrations of the measured precursor gases during this period.

Table 6-5. 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 6-6. 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

Fine particulate mass concentration readings from the two FH 62 C14 monitors were recorded every 30 minutes during Phase II of the verification test. The data from December 18, 2000, through January 17, 2001, for the two FH 62 C14 monitors are shown in Figure 6-4a. In Figure 6-4b, these same data are plotted against one another to illustrate the correlation between the two monitors. The two traces in Figure 6-4a are barely distinguishable from one another, and Figures 6-4a and b illustrate that the two monitors tracked each other closely during Phase II.

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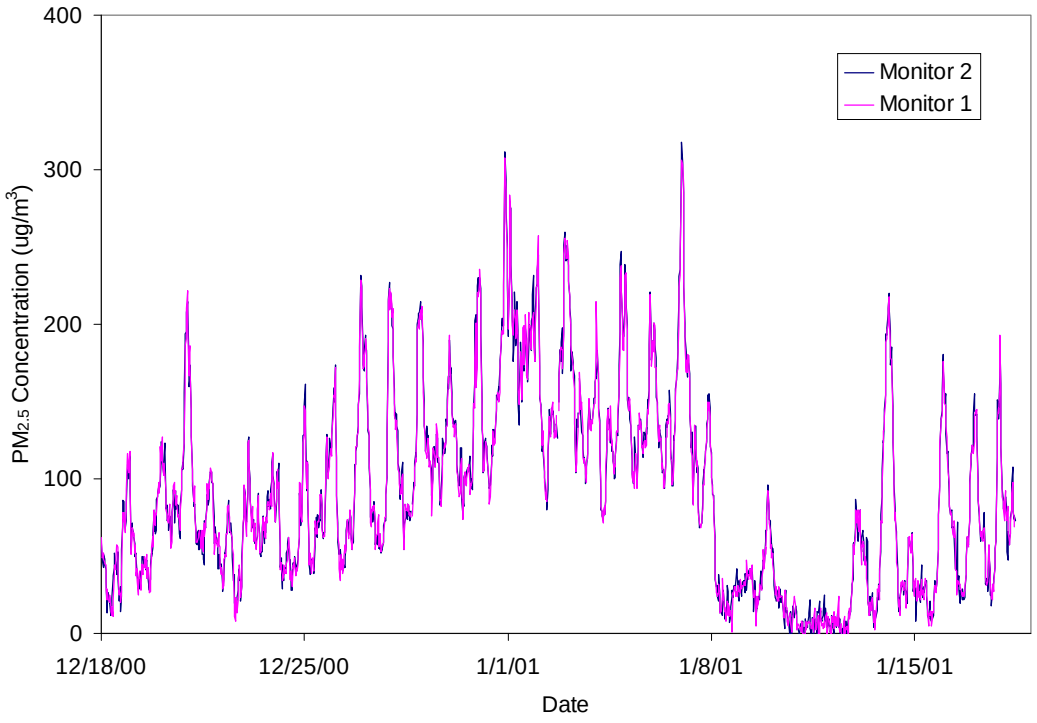

Figure 6-4a. Time Series Plot from Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

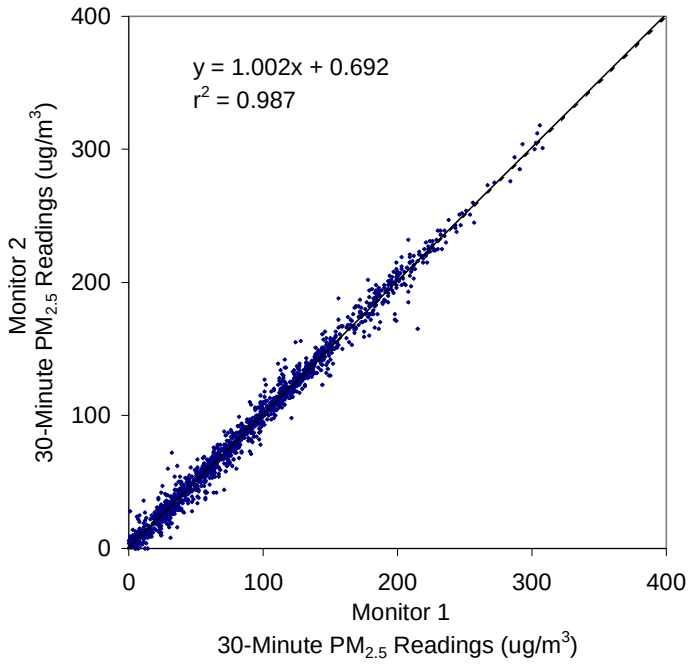

Figure 6-4b. Correlation Plot of the 30-Minute $PM_{2.5}$ Data from Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

For comparison with the $PM_{2.5}$ FRM reference measurements, the 30-minute 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 6-5a, the 24-hour averages for Phase II of the verification test are presented for the two FH 62 C14 monitors. A correlation plot of these data is shown in Figure 6-5b.

These data were analyzed by linear regression, and the results of this analysis are presented in Table 6-7. The CV for the 30-minute data and the 24-hour averages were also determined and are shown in Table 6-7.

Table 6-7. Linear Regression and Coefficient of Variation Results for 24-Hour Average $PM_{2.5}$ Concentrations from Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

Parameter	30-Minute Data	24-Hour Average Data
Slope (95% CI)	1.002 (0.006)	1.005 (0.012)
Intercept ($\mu g/m^3$) (95% CI)	0.692 (0.65)	0.290 (1.34)
r^2	0.987	0.999
CV	15.4%	4.4%

The 30-minute data from the duplicate monitors show an r^2 value of 0.987. The results of the regression analysis show a slope of 1.002 (0.006) indicating that no bias existed between the two monitors. The regression results show a statistically significant intercept of 0.69 (0.65) $\mu g/m^3$. However, a Student's t-test confirms a small, but statistically significant, bias between the duplicate FH 62 C14 monitors, with Monitor 2 reading higher than Monitor 1 by 0.91 $\mu g/m^3$ on average (i.e., about 1.2% of the 74 $\mu g/m^3$ average $PM_{2.5}$ level in Phase II). The calculated CV for the 30-minute data is 15.4%.

For the 24-hour average concentration results, the regression results show an r^2 value of 0.999. The calculated CV for the 24-hour averages is 4.4%. As with the 30-minute data, a Student's t-test indicates a statistically significant bias of 0.77 $\mu g/m^3$ between the averages of the duplicate monitors. However, the slope of the correlation plot [1.005 (0.012)] is not statistically different from unity at the 95% confidence level, and the intercept of 0.29 (1.34) $\mu g/m^3$ is not statistically different from zero at the 95% confidence level.

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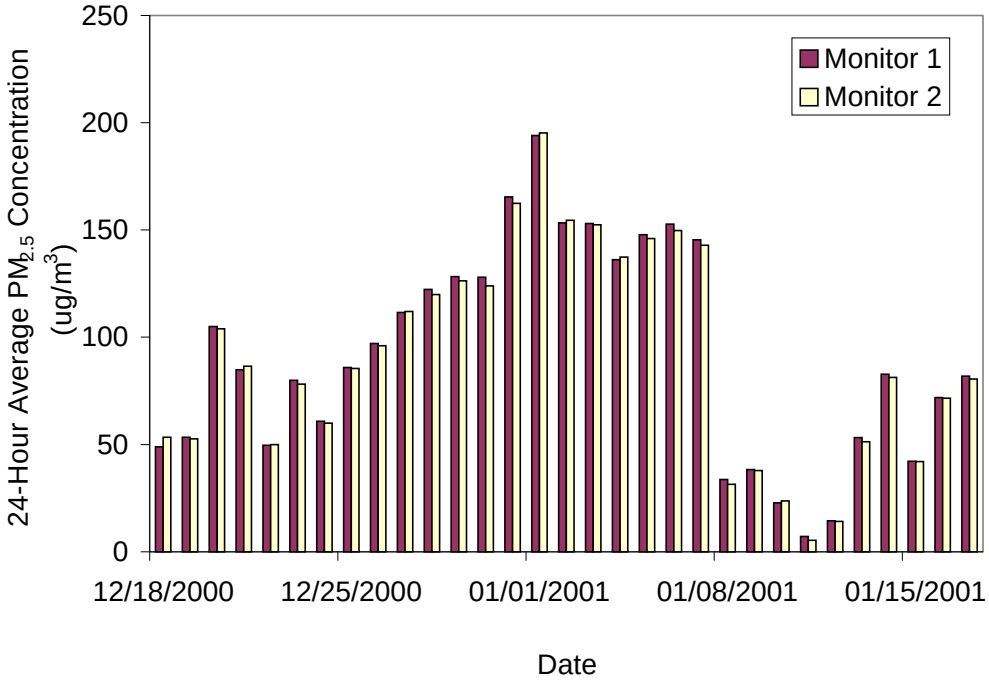

Figure 6-5a. 24-Hour Average $PM_{2.5}$ Concentrations from Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

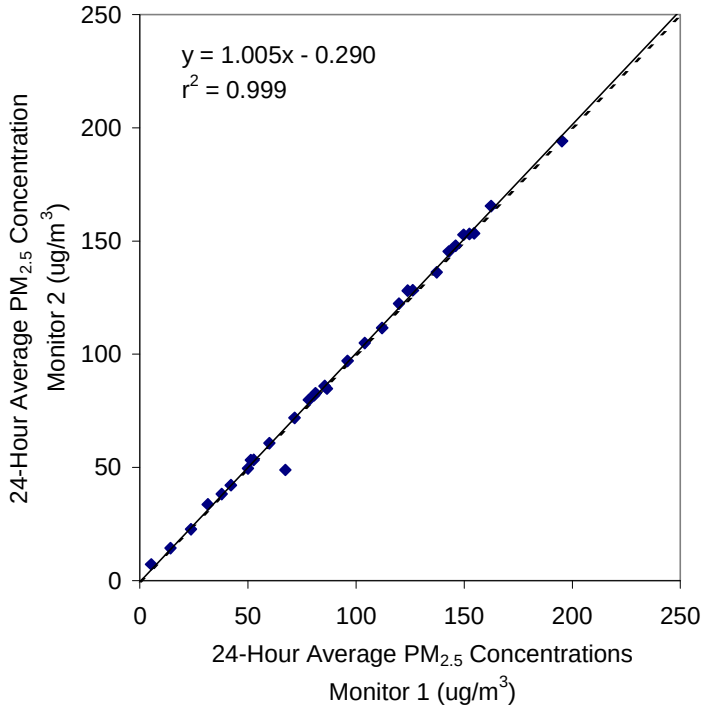

Figure 6-5b. Correlation Plot of the 24-Hour Average $PM_{2.5}$ Concentrations from Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

6.2.2 Comparability/Predictability

In Figure 6-6a, the midnight-to-midnight averages of the FH 62 C14 measurements are shown, along with the $PM_{2.5}$ FRM measurements for Phase II of the verification test. Figure 6-6b shows a correlation plot of these 24-hour data. These $PM_{2.5}$ concentration values were analyzed by linear regression according to Section 5.2 to establish the comparability of each of the FH 62 C14 monitors with the $PM_{2.5}$ FRM sampler. The calculated slope, intercept, and r^2 value of the regression analyses are presented in Table 6-8 for each monitor.

Table 6-8. Comparability of the FH 62 C14 Monitors with the $PM_{2.5}$ FRM Sampler for Phase II

Regression Parameter	Monitor 1	Monitor 2
Slope (95% CI)	1.234 (0.100)	1.224 (0.105)
Intercept ($\mu g/m^3$) (95% CI)	0.94 (8.4)	0.84 (8.8)
r^2	0.958	0.953

The r^2 values of the regression analyses were 0.958 for Monitor 1 and 0.953 for Monitor 2. For both Monitors 1 and 2, the regression slopes were 22 to 23% greater than unity and statistically different from unity at the 95% confidence level, indicating a positive bias relative to the FRM. The intercepts of the regression lines were not statistically different from zero at the 95% confidence level.

It should be noted that the flow rates of the FH 62 C14 monitors were found to be high by 7 to 10% during part of the Phase II testing and were recalibrated by a representative of Thermo Andersen on January 5, 2001. This factor may have caused the FH 62 C14 monitors to read erroneously high by up to 10% prior to January 5. Prior to January 5, the average difference between the FH 62 C14 monitors and the FRM was 34%, and after January 5 the average difference was 19% for Monitor 1 and 14% 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 FH 62 C14 monitors. 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 1 relative to the FRM at the 90% confidence level. However, the multivariable model ascribed to relative

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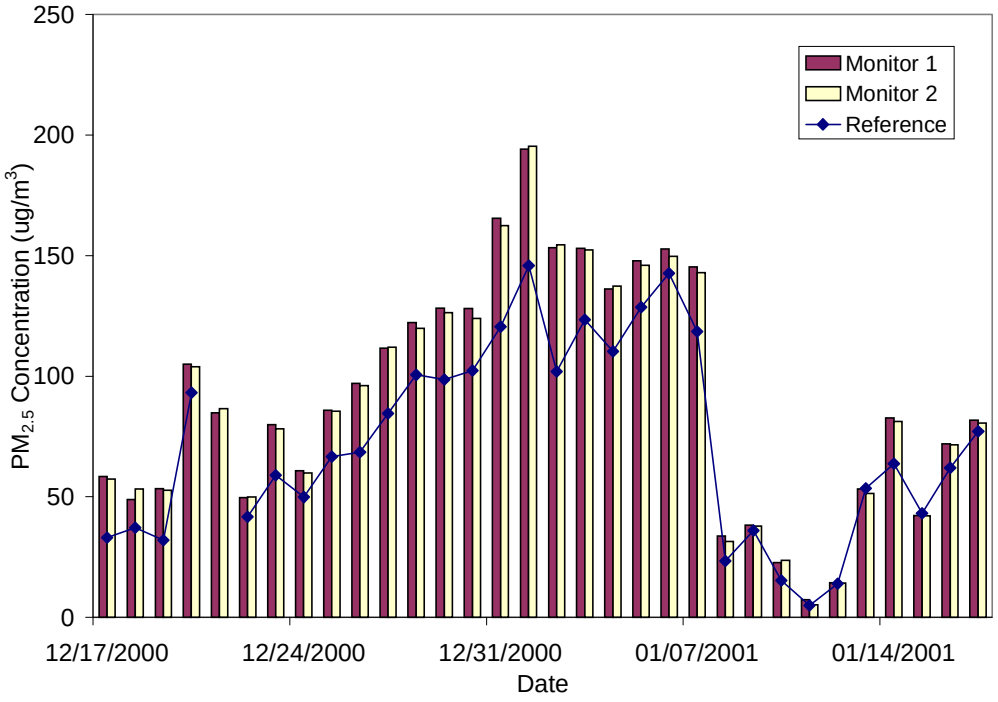

Figure 6-6a. Midnight-to-Midnight Average Concentrations from Duplicate FH 62 C14 Monitors and the $PM_{2.5}$ FRM Results During Phase II of Verification Testing

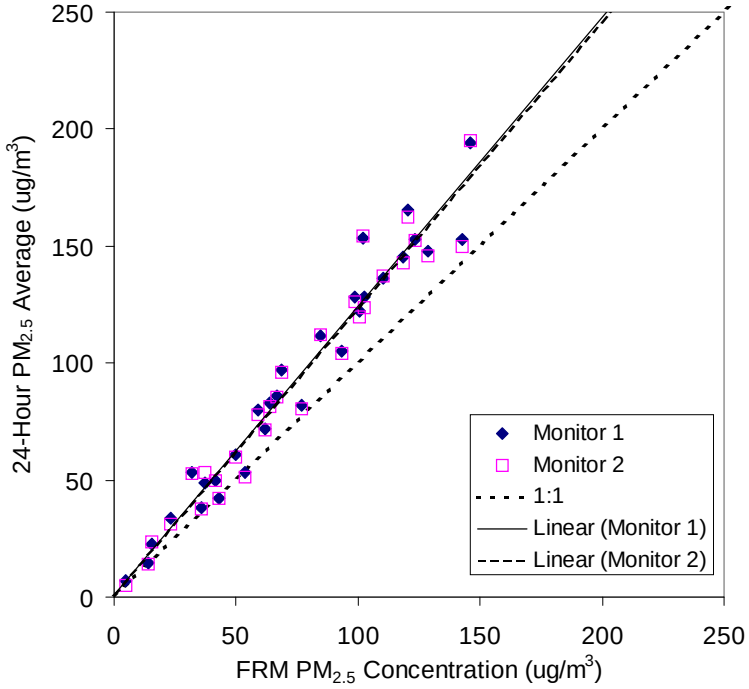

Figure 6-6b. Correlation Plot of 24-Hour Average Concentrations from Duplicate FH 62 C14 Monitors and the $PM_{2.5}$ FRM During Phase II of Verification Testing

humidity a statistically significant influence on the readings of Monitor 2 relative to the FRM values at a 90% confidence level. The regression analysis indicates a relationship of the form:

$$\text{Monitor 2} = 1.26*\text{FRM} + 0.494*\text{RH} - 39.0\ \mu g/m^3$$

where FRM represents the measured $PM_{2.5}$ FRM values in $\mu g/m^3$, and RH represents the average relative humidity in percent. Using the average relative humidity and $PM_{2.5}$ concentration during Phase II (Section 6.1), the multivariable equation above would predict an average value of 91.5 $\mu g/m^3$, whereas the linear equation would predict 91.4 $\mu g/m^3$. The difference between these values (approximately 0.1%) shows that although a statistically significant effect is indicated, the overall effect was negligible.

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, and ozone) and the FH 62 C14 readings relative to the FRM. This analysis showed no influence of the precursor gases on the readings of either monitor, at the 90% confidence level.

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 6-9 presents the averages and the ranges of $PM_{2.5}$ concentrations for these sampling periods during Phase II. Figure 6-7 shows the correlation between the time-weighted average 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) $\mu g/m^3$, respectively, with an r^2 value of 0.960, where the numbers in parentheses are 95% CIs.

Table 6-9. Summary of $PM_{2.5}$ Levels During Short-Term Sampling Periods in 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

In Figure 6-8, the averages of the FH 62 C14 monitor 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 FH 62 C14 monitor, and the results are presented in Table 6-10. Regression analyses were also performed

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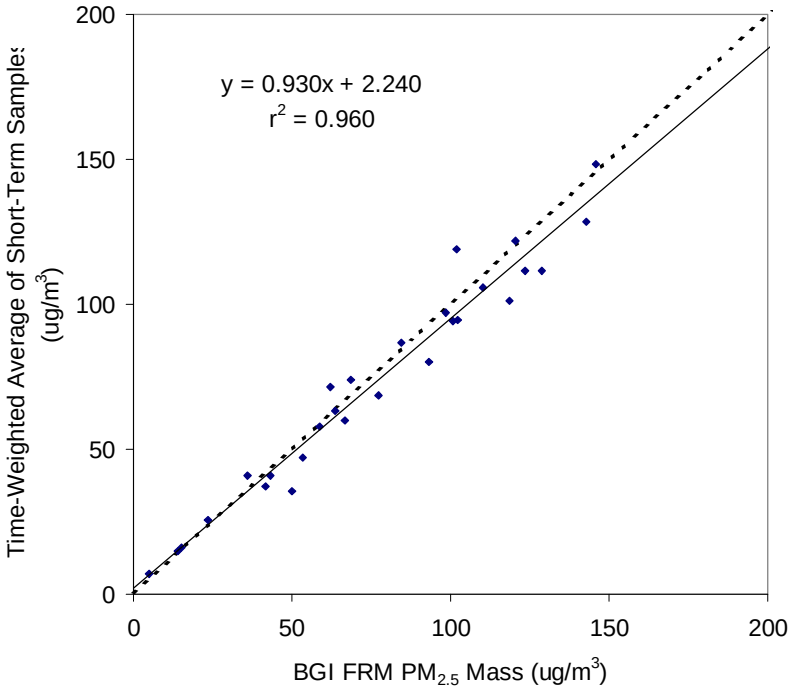

Figure 6-7. Correlation Plot for the Time-Weighted Average of the Short-Term Samples and the $PM_{2.5}$ FRM for Phase II

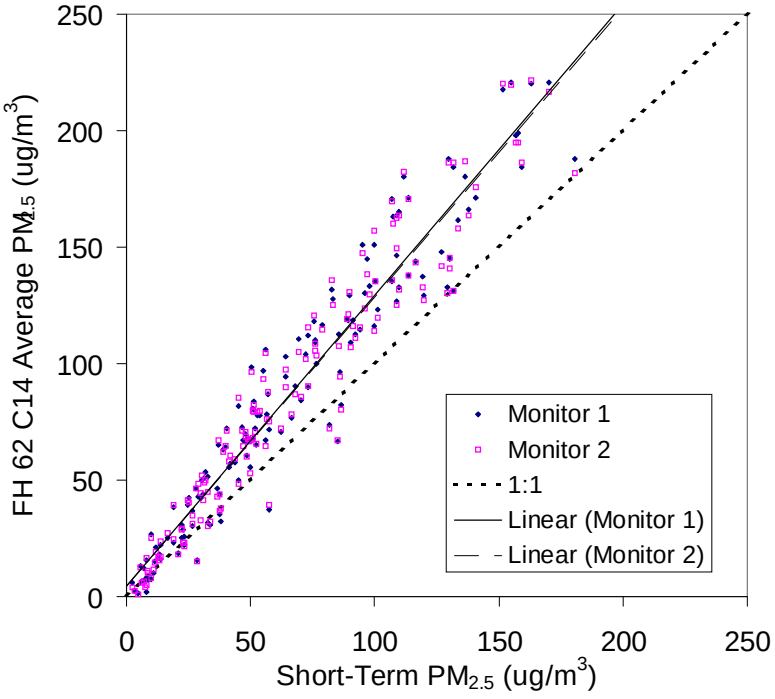

Figure 6-8. Correlation Plot of Short-Term Monitoring Results and the Corresponding Averages from the Duplicate FH 62 C14 Monitors During Phase II of Verification Testing

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Table 6-10. Regression Analysis Results for the Short-Term Monitoring

Short-Term Monitoring Period	Monitor 1			Monitor 2		
	Slope	Intercept ($\mu g/m^3$)	r^2	Slope	Intercept ($\mu g/m^3$)	r^2
All	1.25	5.0	0.931	1.24	4.8	0.927
0000-0500	1.36	7.6	0.943	1.35	7.8	0.942
0500-1000	1.36	2.9	0.930	1.34	2.6	0.937
1000-1300	1.21	1.0	0.962	1.22	-0.5	0.964
1300-1600	1.35	1.8	0.959	1.36	2.2	0.962
1600-2400	1.14	2.1	0.948	1.13	0.9	0.947

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 6-10.

The short-term monitoring results show r^2 values of $\geq$ 0.927 overall and for each of the five short-term monitoring periods for both monitors. The slopes of the regression lines range from 1.14 to 1.36 for Monitor 1 and 1.13 to 1.36 for Monitor 2. The intercepts ranged from 1.0 to 7.6 $\mu g/m^3$ for Monitor 1 and from -0.5 to 7.8 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.) The overall slopes of about 1.25 are consistent with the slopes found in comparison to the 24-hour FRM data (Table 6-8).

6.3 Instrument Reliability/Ease of Use

Approximately 10 days of data were lost at the beginning of Phase I owing to insufficient memory of the two monitors. Other than data loss associated with that cause, 100% data recovery was achieved by each of the FH 62 C14 monitors during Phase I. No operating problems arose during Phase I of testing, and no maintenance was performed on either monitor during this phase. During Phase II of the verification test, 100% data recovery was achieved. No maintenance was performed, and no operating problems arose for either monitor.

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6.4 Shelter/Power Requirements

The FH 62 C14 monitors were installed and operated in outside enclosures during Phase I of verification testing and were operated inside an instrument trailer during Phase II. Both the monitors and their pumps were run on a single 15 amp circuit. Vendor literature indicates a range of operating temperatures from -10°C to 40°C; however these limits were not verified in this test.

6.5 Instrument Cost

The price of the FH 62 C14, as tested, was $15,000.

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Chapter 7
Performance Summary

The FH 62 C14 monitor measures ambient particulate matter concentration on a time scale as short as five minutes. Duplicate FH 62 C14 monitors were evaluated under field test conditions in two separate phases of this verification test. The duplicate monitors were operated side by side in outdoor enclosures during Phase I of verification testing and were operated indoors during Phase II of verification testing. During each phase, the FH 62 C14 monitors were operated with a PM_{10} head and $PM_{2.5}$ SCC 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)

Inter-unit precision of the FH 62 C14 monitors was assessed using both 5-minute data and 24-hour average data. The regression analysis for the 5-minute data shows a slope of 0.565 (0.019), an intercept of 9.5 (1.2) $\mu g/m^3$, and an r^2 of 0.374. These results are undoubtedly affected by daily periods of negative readings, attributed to moisture condensation in the early morning hours. Regression analysis of the 24-hour $PM_{2.5}$ averages showed an r^2 value of 0.875 for these data, with a slope of 0.948 (0.183) and a negative intercept of 1.29 (5.9) $\mu g/m^3$. At the 95% confidence level, the slope was not significantly different from unity, and the intercept was not significantly different from zero. The calculated CV for the 5-minute data was 46.7% and for the 24-hour average data was 20.6%.

Comparisons of the 24-hour averages with $PM_{2.5}$ FRM results showed r^2 values of 0.856 and 0.802 for Monitor 1 and Monitor 2, respectively. The slopes of the regression lines for Monitor 1 and for Monitor 2 were 1.60 (0.35) and 1.56 (0.41), respectively, indicating a positive bias of about 60% relative to the FRM. No statistically significant intercept was observed for either monitor.

The multivariable model analysis of the 24-hour average data ascribed to wind speed, relative humidity, solar radiation, and total precipitation a statistically significant influence on the readings of one of the monitors relative to the FRM values at 90% confidence. Similarly, barometric pressure and total precipitation were ascribed a statistically significant influence on the other monitor. On average these parameters influenced the readings of Monitor 1 by approximately 4% and Monitor 2 by approximately 15%. There was no effect of the measured precursor gases on the results of either monitor relative to the FRM at the 90% confidence level.

Approximately 10 days of data were lost at the beginning of Phase I owing to insufficient memory of the two monitors. Other than data loss associated with that cause, 100% data recovery was achieved by each of the FH 62 C14 monitors during Phase I.

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

Inter-unit regression analysis shows r^2 values of 0.987 and 0.999, respectively, for the 30-minute and 24-hour average data during Phase II. The slopes of the regression lines were 1.002 (0.006) and 1.005 (0.012), respectively, for the 30-minute data and 24-hour averages, and the intercepts were 0.69 (0.65) $\mu g/m^3$ and 0.29 (1.34) $\mu g/m^3$, respectively. The calculated CV for the 30-minute data was 15.4% and for the 24-hour data the CV was 4.4%. A Student's t-test indicates an absolute bias of 0.91 $\mu g/m^3$ between the two monitors for the 30-minute data, and a bias of 0.77 $\mu g/m^3$ between the 24-hour average results. In both cases these biases equal about 1% of the average $PM_{2.5}$ concentration in 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 1.23 (0.10) and 1.22 (0.10), respectively, indicating a positive bias of about 23% relative to the FRM. No statistically significant intercept was observed in either case at the 95% confidence level. The regression results show r^2 values of 0.958 and 0.953 for Monitor 1 and Monitor 2, respectively.

The multivariable model analysis of the 24-hour average data ascribed to relative humidity a statistically significant influence on the readings of one of the monitors relative to the FRM values at a 90% confidence level. However, the magnitude of the influence (about 0.1%) was negligible. There was no effect of the measured precursor gases on the results of either monitor relative to the FRM at the 90% confidence level.

In addition to 24-hour FRM samples, short-term monitoring (3-, 5-, and 8-hour intervals) was performed on a five-sample-per-day basis. The FH 62 C14 results were averaged for each of the sampling periods and compared with the gravimetric results. Linear regression of these data showed slopes of 1.25 and 1.24, respectively, for Monitor 1 and Monitor 2, when all short-term intervals are included. These results indicate a bias of about 25% relative to the short-term reference data, which is consistent with the result noted above from comparison of 24-hour FRM data in Phase II. The intercepts of the regression lines were 5.0 and 4.8 $\mu g/m^3$; respectively, and the r^2 values were 0.931 and 0.927, respectively.

During Phase II of the verification test, 100% data recovery was achieved. No maintenance was performed, and no operating problems arose for either monitor.

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Chapter 8
References

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

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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.