August 2001

Environmental Technology Verification Report

DEKATI LTD.
ELECTRICAL LOW PRESSURE IMPACTOR (ELPI™) PARTICLE MONITOR

Prepared by

Battelle

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Battelle

Under a cooperative agreement with

EPA U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

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ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Continuous Ambient Fine Particle Monitor**
APPLICATION:	**MEASURING FINE PARTICULATE MASS IN AMBIENT AIR**
TECHNOLOGY NAME:	**Electrical Low Pressure Impactor**
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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 Dekati Ltd. electrical low pressure impactor (ELPI™) particle monitor.

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, accuracy and correlation relative to time-integrated reference methods, effect of meteorological conditions, influence of precursor gases, and short-term monitoring capabilities. The ELPI™ 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 ELPI™ measures particle sizes (from 0.03 to 10 micrometers in diameter) and particle concentrations in real time. The ELPI™ sensor measures the electrical current carried by charged particles at 12 impactor stages, using a highly sensitive, multichannel electrometer as the particle impacts the collection plate. Aerosol is sampled through a unipolar corona charger, and the charged particles pass into a low pressure impactor with electrically isolated collection stages. Particle collection into each impactor stage is dependent on the aerodynamic size of the particles. Measured current signals are converted to (aerodynamic) size distribution using particle-size dependent relations describing the properties of the charger and the impactor stages. Particles can be collected on substrates for microscopic analysis or additional measurements of mass or composition. The ELPI™ charger calibration is based on aerosol particle number distribution measurement. Particulate mass is calculated assuming a spherical shape and known density for the particles. $PM_{2.5}$ mass is calculated by integrating the particle mass from ELPI™ stages 1 to 8 from the particle size distribution. The ELPI™ software features a graphical user interface and permits monitoring each stage during loading. Total concentration and particle-size data are updated continuously. Data can be displayed either on a number, volume, area, or mass basis. ELPI™ components are housed in a single unit with a standard RS-232 port for communication with a laptop or PC. The ELPI™ is 570 mm high x 420 mm wide x 260 mm deep.

VERIFICATION OF PERFORMANCE

Inter-Unit Precision: During Phase I, regression analysis showed r^2 values of 0.958 and 0.963, respectively, for the 10-minute data and the 24-hour averages from the duplicate ELPI™ monitors. The slopes of the regression lines were 0.922 (0.006) and 0.958 (0.073), respectively, for the 10-minute data and 24-hour averages, and no statistically significant intercept was observed in either case at the 95% confidence level. The calculated coefficient of variation (CV) for the 10-minute data was 9.2%; and, for the 24-hour data, the CV was 8.8%. During Phase II, regression analysis showed r^2 values of 0.910 and 0.896, respectively, for the 10-minute data and the 24-hour averages. The slopes of the regression lines were 1.237 (0.012) and 1.240 (0.167), respectively, for the 10-minute data and 24-hour averages, indicating a bias between the two monitors. The calculated CV for the 10-minute data was 18.2%; and, for the 24-hour data, the CV was 18.5%.

Comparability/Predictability: During Phase I, comparisons of the 24-hour averages with $PM_{2.5}$ FRM results showed intercepts that were not significantly different from zero and slopes of the regression lines of 1.81 (0.29) and 1.85 (0.31), respectively, for Monitor 1 and Monitor 2. The regression results show r^2 values of 0.871 and 0.862 for Monitor 1 and Monitor 2, respectively. During Phase II, comparison of the 24-hour averages with $PM_{2.5}$ FRM results showed slopes of the regression lines for Monitor 1 and Monitor 2 of 2.13 (0.30) and 2.60 (0.44), respectively. The regression results show r^2 values of 0.897 and 0.843 for Monitor 1 and Monitor 2, respectively.

Meteorological Effects: The multivariable analysis model of the 24-hour average data during Phase I ascribed to horizontal and vertical wind speed, wind direction, total precipitation, and temperature a statistically significant influence on the ELPI™ readings relative to the FRM values, at the 90% confidence level. Multivariable analysis of the 24-hour average data during Phase II ascribed only to barometric pressure a statistically significant influence on the readings of Monitor 1 relative to the FRM values, at 90% confidence. There was no effect of meteorology on the results of Monitor 2 relative to the FRM.

Influence of Precursor Gases: During Phase I, multivariable analysis of the 24-hour average data showed that none of the precursor gases measured had a statistically significant influence on either of the ELPI™ monitors. During Phase II, the multivariable model of the 24-hour average data ascribed to the concentration of carbon monoxide a statistically significant but negligible effect on the readings of Monitor 1 relative to the FRM. None of the measured gases had an effect on Monitor 2.

Short-Term Monitoring: In addition to 24-hour FRM samples, short-term monitoring was performed on a five-sample-per-day basis during Phase II. The ELPI™ results were averaged for each of the short-term sampling periods and compared with the gravimetric reference method results. Considering all short-term results together, linear regression showed slopes of 2.06 and 2.55, respectively, for Monitor 1 and Monitor 2, consistent with the bias found relative to the 24-hour FRM data. The intercept was not significantly different from zero for either regression line, and the r^2 values were 0.882 and 0.850, respectively.

Other Parameters: With the exception of short periods during which impactor plates were replaced and brief power outages, 100% data recovery was achieved by each of the ELPI™ monitors from the time of installation to the end of Phase I sampling. No operating problems arose during Phase I of testing. The only maintenance that was performed on the ELPI™ monitors involved changing the impactor plates. This process took approximately 30 minutes per week for each monitor. During Phase II of the verification test, approximately three days of data were lost for one monitor when its internal memory buffer reached its capacity. As in Phase I, the only maintenance that was performed on the ELPI™ monitors was changing the impactor plates weekly.

Gabor J. Kovacs	Date	Gary J. Foley	Date
Vice President		Director	
Environmental Sector		National Exposure Research Laboratory	
Battelle		Office of Research and Development	
		U.S. Environmental Protection Agency	

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ETV Advanced Monitoring Systems Center

DEKATI LTD.
ELECTRICAL LOW PRESSURE IMPACTOR (ELPI™) PARTICLE MONITOR

by

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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.

Foreword

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

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

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

Acknowledgments

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

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List of Abbreviations

ADQ	audit of data quality
AMS	Advanced Monitoring Systems
CARB	California Air Resources Board
ELPI™	electrical low pressure impactor
CI	confidence interval
cm	centimeter
CO	carbon monoxide
CV	coefficient of variation
DOE	U.S. Department of Energy
DPI	digital pressure indicator
DRI	Desert Research Institute
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FRM	federal reference method
H_2S	hydrogen sulfide
IMPROVE	Interagency Monitoring for Protection of Visual Environments
in.	inch
L/min	liters per minute
mg	milligram
mm	millimeters
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
SFS	sequential filter sampler
SLAMS	state and local air monitoring stations
SO_2	sulfur dioxide
TOR	thermal optical reflectance
TSA	technical systems audit
WINS	well impactor ninety six

Chapter 1
Background

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

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

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

Chapter 2
Technology Description

The following description of the ELPI™ is based on information provided by the vendor.

The ELPI™ measures particle sizes (from 0.01 to 10 micrometers in diameter) and particle concentrations in real time. The ELPI™ sensor measures the electrical current carried by charged particles at 12 impactor stages, using a highly sensitive, multichannel electrometer as the particle impacts the collection plate. Gases are sampled through a unipolar corona charger, and the charged particles pass into a low pressure impactor with electrically isolated collection stages. Particle collection into each impactor stage is dependent on the aerodynamic size of the particles. Measured current signals are converted to (aerodynamic) size distribution using particle-size dependent relations describing the properties of the charger and the impactor stages. Particles can be collected on substrates for microscopic analysis or additional measurements of mass or composition. The ELPI™ is designed for applications where a wide range of particle sizes must be measured and a fast response is required, including combustion aerosol studies, engine emission measurements, filter testing, indoor/outdoor air quality studies, and pharmaceutical research. The ELPI™ charger calibration is based on aerosol particle number distribution measurement. Particulate mass is calculated by assuming a spherical shape and known density to particles. $PM_{2.5}$ mass is calculated by integrating the particle mass from stages 1 through 8 from the particle size distribution.

Figure 2-1. Dekati Ltd. ELPI™ Particle Monitor

The ELPI™ software features a graphical user interface and permits monitoring each stage during loading. Total concentration and particle-size data are updated continuously. Data can be displayed either on a number, volume, area, or mass basis. ELPI™ components are housed in a single unit with a standard RS-232 port for communication with a laptop or PC. The ELPI™ is 570 mm high x 420 mm wide x 260 mm deep.

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 ELPI™ monitors (serial numbers 280101 and 280102) were tested in side-by-side operation during each phase of testing. Collocation of the ELPI™ 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 ELPI™ measures current carried by charged particles that can be converted by various assumptions to $PM_{2.5}$ mass. The results from the ELPI™ were therefore compared with the federal reference method (FRM) for $PM_{2.5}$ mass determination.(2) Additionally, comparisons with a variety of supplemental measurements were made to establish specific performance characteristics. Descriptions of the reference method and supplemental measurements used during the verification test are given below.

3.3.1 $PM_{2.5}$ Mass

The primary comparisons of the ELPI™ readings were made relative to the FRM for $PM_{2.5}$ mass determination, i.e., the 24-hour time-averaged procedure detailed in 40 CFR Part 50.(2) This method involves manual sampling using any of a number of designated commercially available filter samplers, followed by gravimetric analysis of the collected sample. In this method, a size-selective inlet is used to sample only that fraction of aerosol of interest (i.e., < 2.5 µm aerodynamic diameter). The air sample is drawn into the sampler at a fixed rate over 24 hours, and the aerosol is collected on an appropriate filter for gravimetric analysis. After equilibration of the sample and filter in a temperature- and humidity-controlled environment, the sample is weighed on an appropriate microbalance. The particulate sample weight is determined by subtracting the weight of the filter alone, determined prior to sampling after similar equilibration. Protocols for sample collection, handling, and analysis are prescribed by 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), and the $PM_{2.5}$ mass was determined according to the procedures mentioned above. In Phase I, a single BGI FRM sampler (SN 311) was operated daily from noon to noon to collect the FRM samples. During Phase II, two BGI FRM samplers (SN 287 and SN 311) were used and were operated on alternate days to facilitate a midnight-to-midnight sampling schedule.

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

3.3.2 Supplemental Measurements

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

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

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

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

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

3.4 Data Comparisons

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

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

3.5 Site Layout/Instrument Installation

In each phase of testing, the two ELPI™ monitors were installed in Battelle's instrument trailer, which is a converted 40-foot refrigerator semi-trailer. The ELPI™ monitors were placed on a counter top, with each monitor below a 7.6-cm (3") port through the roof of the trailer. The inlet system for each ELPI™ monitor consisted of a flexible plastic tube connected to a rigid metal tube approximately 1 meter in length and 1 cm in diameter. The tube extended from approximately 10 cm below the trailer ceiling to the outside of the trailer and was secured to a polyvinyl chloride cap on the port in the roof. A total suspended particulate head was used with each ELPI™ as a rain cap, and particle size selection was performed by the ELPI™ monitors themselves. Data generated by the ELPI™ 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. This 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 ELPI™ monitors were installed inside the Battelle trailer, and the BGI FRM sampler was installed on the Battelle/ETV platform. A difference in elevation of approximately two meters existed between the inlets of the ELPIs and that of the BGI FRM sampler, with the FRM being lower. A 10-meter (33-foot) meteorological tower was located approximately 25 meters (65 feet) to the north of the DOE/NETL instrument trailer.

3.5.2 Phase II

Phase II of verification testing was conducted at the CARB site on First Street in Fresno. This site is located in a residential/commercial neighborhood about three miles north of the center of Fresno. The two BGR 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

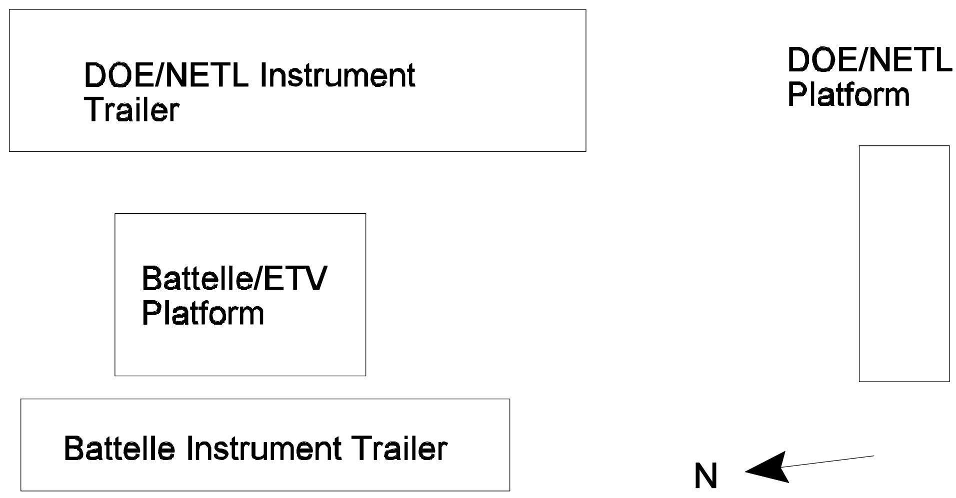

Figure 3-1. Site Layout During Phase I of Verification Testing (not drawn to scale)

verification test also was used during Phase II. For Phase II, the Battelle trailer was located in the parking lot adjacent to the building in which the CARB site is located. The trailer was positioned approximately 25 meters (80 feet) to the south of the building, as shown in Figure 3-2. A difference in elevation of approximately 20 feet existed between the top of the trailer and the roof of the building housing the CARB site. 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. The ELPI™ monitors were located in the Battelle trailer and installed in the same fashion as in Phase I of the verification test.

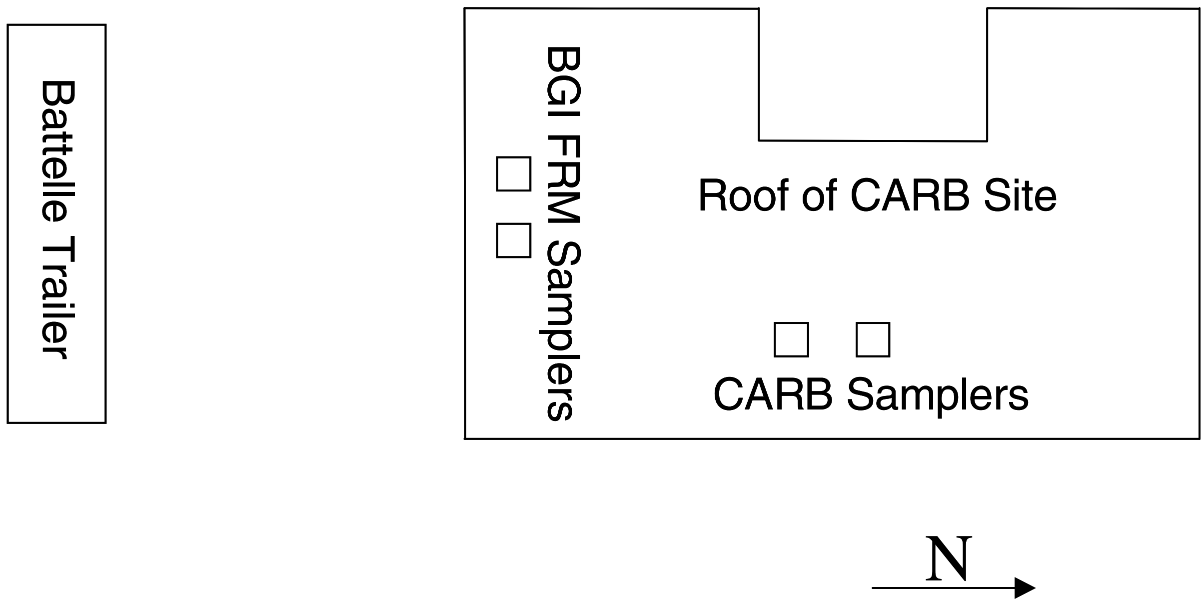

Figure 3-2. Site Layout During Phase II of Verification Testing (not drawn to scale)

Chapter 4
Quality Assurance/Quality Control

4.1 Data Review and Validation

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

Data from the ELPI™ monitors were validated by a representative of Delkati 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 ELPI™ 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 approximately 25 meters to accommodate changes in the overall site layout for Phase II.

4.3 Calibration and Parameter Checks of Reference Sampler

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

4.3.1 Flow Rate Calibration and Verification

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

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

Prior to Phase II of the verification test, single point calibration checks of the duplicate BGI FRM 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.

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

4.4 Collocated Sampling

4.4.1 Phase I—Pittsburgh

To establish the precision of the $PM_{2.5}$ FRM, the BGI FRM sampler was collocated with an R&P FRM sampler for Phase I, including a period of two weeks prior to and one week after Phase I of the verification test. During the sampling periods before and after Phase I, the BGI and R&P

FRM samplers were located on the same platform and within 4 meters of one another. During the Phase I testing period, these samplers were separated by a distance of approximately 25 meters. The samples from the BGI FRM sampler were collected and analyzed by Consol, and the samples from the R&P FRM sampler were collected and analyzed by on-site Mining Safety and Health Administration staff.

Figure 4-1 shows the results of the collocated FRM sampling conducted for Phase I. These data were compared by linear regression; and the calculated slope, intercept, and r^2 values are 0.939 (0.067), 1.28 (1.33) $\mu g/m^3$, and 0.957, respectively, where the values in parentheses are 95% CIs. Despite completely independent operations (i.e., separate sampling staff and weighing facilities), these data show very good agreement between the BGI FRM and the R&P FRM samplers. The data also indicate that, although the humidity in the conditioning/weighing room at Consol was not always within the specified FRM limits, the influence of the elevated humidity was not severe.

4.4.2 Phase II—Fresno

During Phase II of testing, duplicate BGI FRM samplers (SN 287 and SN 311) were used to collect the 24-hour FRM reference samples. These samplers were operated one at a time on alternate days to facilitate midnight-to-midnight sampling. Likewise, an R&P Partisol sampler was used by CARB to collect 24-hour FRM samples. The R&P FRM sampler was located approximately 25 meters from the BGI FRM samplers. The same on-site operators performed the sampling for the two 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 -1.04 (4.7) $\mu g/m^3$ and r^2 value of 0.982, where the numbers in parentheses indicate the 95% CI.

4.4.3 Summary

The results from the collocated FRMs in both Pittsburgh and Fresno show agreement that is consistent with the goals for measurement uncertainty of $PM_{2.5}$ methods run at state and local air monitoring stations (SLAMS). These goals are identified in Appendix A to 40 CFR Part 58, Section 3.5[(4)] which states: "The goal for acceptable measurement uncertainty has been defined as 10 percent coefficient of variation (CV) for total precision and ± 10% for total bias." Since the collocated FRMs in both Pittsburgh and Fresno were operated by independent organizations, a comparison to the SLAMS data quality objectives for $PM_{2.5}$ is an appropriate way to assess whether the measurement systems were producing data of acceptable quality. In both Pittsburgh and Fresno, the results of the collocated sampling meet the data quality objectives for the total bias. In Fresno, the collocated sampling results show a CV of 6.3%, which meets the data quality objectives for precision. In Pittsburgh, the calculated CV was 10.5%.

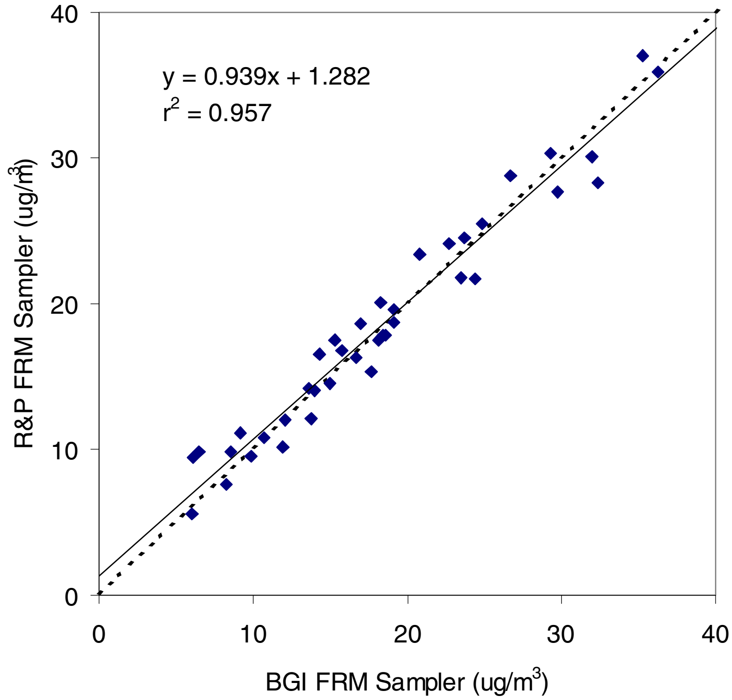

Figure 4-1. Comparison of Collocated $PM_{2.5}$ FRM Samplers for Phase I of Verification Testing

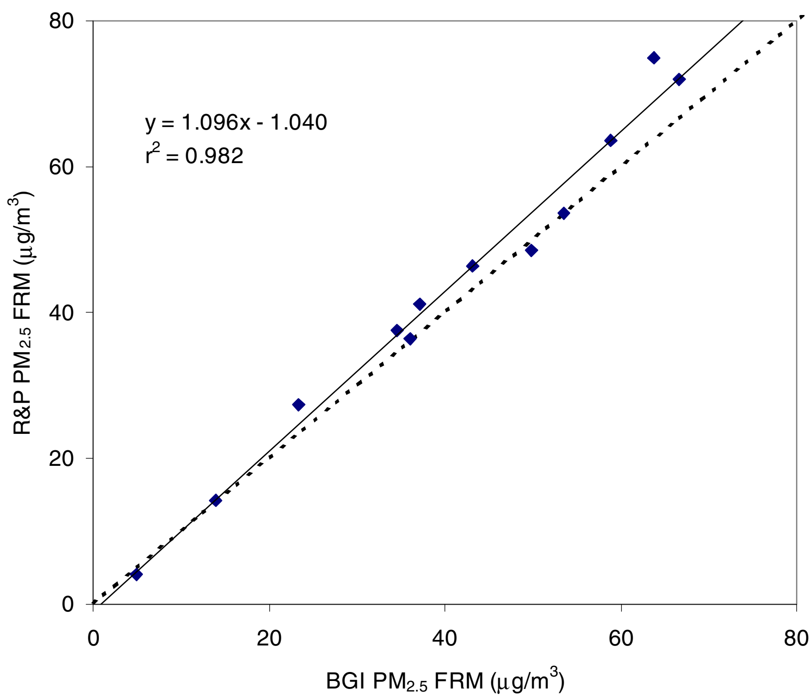

Figure 4-2. Comparison of Collocated $PM_{2.5}$ FRM Samplers for Phase II of Verification Testing

However, this value is driven largely by a single data pair. When this 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 0.0007 mg/m^3, averaging 0.00015 mg/m^3. FRM results for Phase I were not blank corrected.

4.5.2 Phase II—Fresno

Throughout Phase II, at least 10% of the collected reference samples (both the BGI FRM samplers and the DRI sequential filter sampler) were field blanks. The results were added to a database containing historical field blank data. These blanks showed mass differences of 2 µg, with a standard deviation of 8 µg. Assuming a sample volume of 24 m^3 (i.e., FRM value), these blanks account for approximately 0.0001 mg/m^3. Assuming sample volume of 3.6 m^3 (i.e., three-hour short-term sample from sequential filter sampler, these blanks account for approximately 0.0006 mg/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.

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 ELPI™ Monitors

Data from each of the ELPI™ monitors were recorded every 10 minutes in an internal memory buffer throughout each phase of the verification test. The recorded data were downloaded directly onto a floppy disk. These data were converted from measured current to mass using vendor-supplied software. The converted data were saved as text files and imported into Excel for subsequent analysis. Copies of the data were stored by the Verification Test Coordinator on a floppy disk, as well as on a computer hard drive.

4.7 Assessments and Audits

4.7.1 Technical Systems Audit

Phase I—Pittsburgh

The technical systems audit (TSA) ensures that the verification tests are conducted according to the test/QA plan[(1)] and that all activities associated with the tests are in compliance with the ETV pilot QMP.[(3)] The Battelle Quality Manager conducted an internal TSA on August 3, 2000, at the Pittsburgh test site. All findings noted during this TSA were documented and submitted to the Verification Test Coordinator for correction. The corrections were documented by the Verification Test Coordinator and reviewed by Battelle's Quality Manager, Verification Testing Leader, and 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 ELPI™. All corrective actions were completed to the satisfaction of the Battelle Quality Manager and the EPA.

4.7.2 Performance Evaluation Audit

Phase I—Pittsburgh

The reference sampler provided by Battelle for this verification test was audited during Phase I to ensure that it was operating properly. During Phase I of the verification test, the flow rate of the

BGI FRM sampler was audited on August 28, using a dry gas meter (American Meter Company, Battelle asset number LN 275010, calibrated April 17, 2000). The measured flow rate was within the ±4% acceptance criterion with respect to the internal flow meter and within the ±5% acceptance criterion with respect to the nominal flow rate.

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

Phase II—Fresno

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

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

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

4.7.3 Audit of Data Quality

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

Chapter 5
Statistical Methods

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

5.1 Inter-Unit Precision

The inter-unit precision of the ELPI™ 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 ELPI™ monitors were paired, and the behavior of their differences was used to assess precision. For both the 10-minute readings 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 ELPI™ results and the $PM_{2.5}$ FRM was assessed, since the ELPI™ 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 ELPI™ 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 10-minute ELPI™ 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 ELPI™ measurements is used because this is the quantity that is most comparable to the reference sampler measurements.

Comparability is expressed in terms of bias between the ELPI™ 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 ELPI™ 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 ELPI™ 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% CIs for the intercept and slope. Comparability to the FRM was determined independently for each of the two duplicate ELPI™ 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 ELPI™ monitors and the $PM_{2.5}$ FRM reference samplers was evaluated by using meteorological data such as temperature and humidity as parameters in multivariable analyses of the reference/monitor comparison data. The same evaluation was done with ambient precursor pollutant concentrations as the model parameters. The model used is as follows:

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

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

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

5.4 Short-Term Monitoring Capabilities

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

These comparisons were made only after establishing the relationship between the short-term sampling results and the corresponding 24-hour 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 10-minute 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 ELPI™ monitors, and the data from each phase of testing were analyzed separately.

Chapter 6
Test Results

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

Samples were collected daily between August 1 and September 1, 2000, using a $PM_{2.5}$ FRM sampler. During this period, the daily $PM_{2.5}$ concentration as measured by the BGI FRM sampler ranged from 0.0061 mg/m^3 to 0.0362 mg/m^3, with an average daily concentration of 0.0184 mg/m^3. Typically, the $PM_{2.5}$ composition was dominated by sulfate and carbon species. On average, the measured sulfate concentration, determined by ion chromatography, accounted for approximately 47% of the daily $PM_{2.5}$ mass. Total carbon, as measured by the IMPROVE thermal optical reflectance (TOR) method, accounted for approximately 38% of the $PM_{2.5}$ mass, with elemental carbon contributing approximately 22% and organic carbon contributing approximately 77% of the total carbon. Additionally, nitrate contributed about 8.3% of the daily $PM_{2.5}$ concentration.

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

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

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

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

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

6.1.1 Inter-Unit Precision

Current readings on the impactor stages of the two ELPI™ monitors were recorded every 10 minutes during Phase I of the verification test. These 10-minute current readings were converted to mass concentrations using software supplied by the vendor. Figure 6-1a shows the calculated fine particulate mass data from the two ELPI™ monitors for Phase I of the verification test. Breaks in the data indicate episodes during which power outages occurred at the test site (August 6, 7, and 10 through 11), or periods during which the impactor stages were being replaced in the ELPI™ monitors. The two ELPI™ monitors agreed closely with one another throughout this phase of testing. The two traces in Figure 6-1a appear nearly indistinguishable. In Figure 6-1b these same data are plotted against one another to illustrate the correlation between the two monitors.

For comparison with the $PM_{2.5}$ FRM reference measurements, the 10-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. In Figure 6-2a the noon-to-noon averages for Phase I of the verification test are presented for the two ELPI™ monitors. A correlation plot of these data is shown in Figure 6-2b.

These data were analyzed by linear regression, and the results of this analysis are presented in Table 6-3. The CV values for these data were also determined according to Section 5.1, and the calculated CV is shown in Table 6-3. The regression analysis of the 10-minute data shows a coefficient of determination $r^2 = 0.958$ between the duplicate monitors. The results of the regression analysis of the 10-minute data indicate a bias between the two monitors, with Monitor 1 generally reading higher than Monitor 2 [slope = 0.922 (0.006)]. The regression results for the 10-minute data also show that the intercept of the correlation plot includes zero at the 95% confidence interval. Inspection of Figure 6-1b also shows that the scatter in the data increases markedly above about 0.1 mg/m^3, which corresponds to the data from the highest peaks in Figure 6-1a.

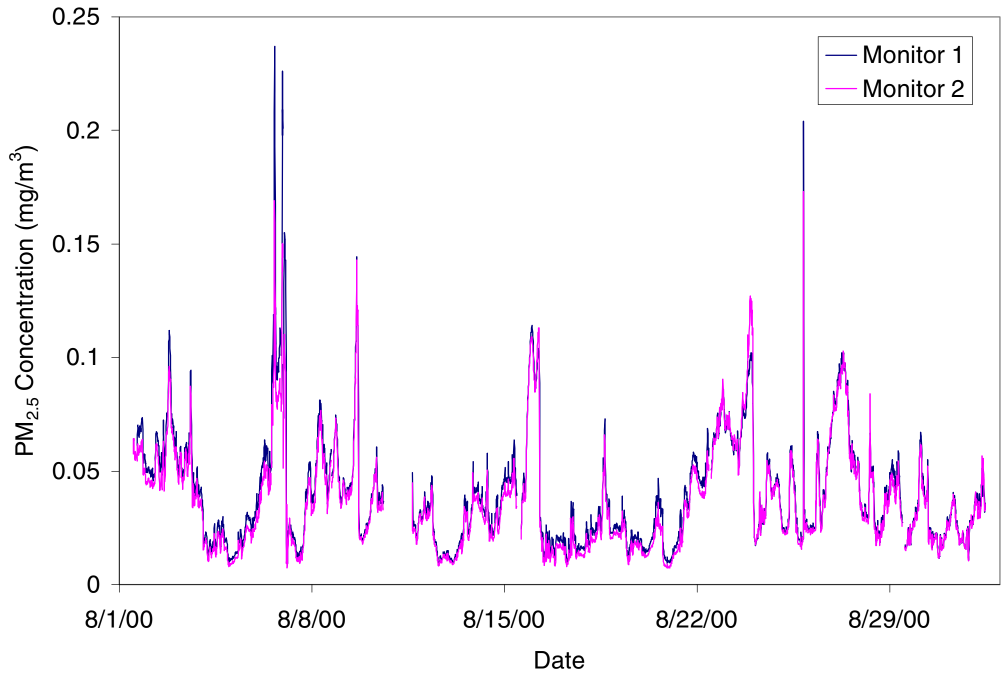

Figure 6-1a. $PM_{2.5}$ Mass Concentration 10-Minute Readings from Duplicate ELPI™ Monitors During Phase I of Verification Testing

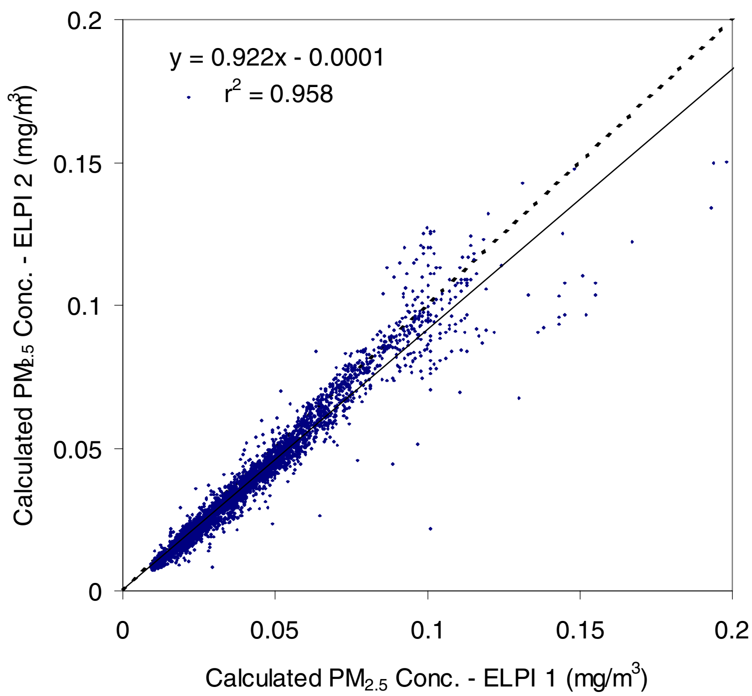

Figure 6-1b. Correlation Plot of the 10-Minute $PM_{2.5}$ Data from Duplicate ELPI™ Monitors During Phase I of Verification Testing

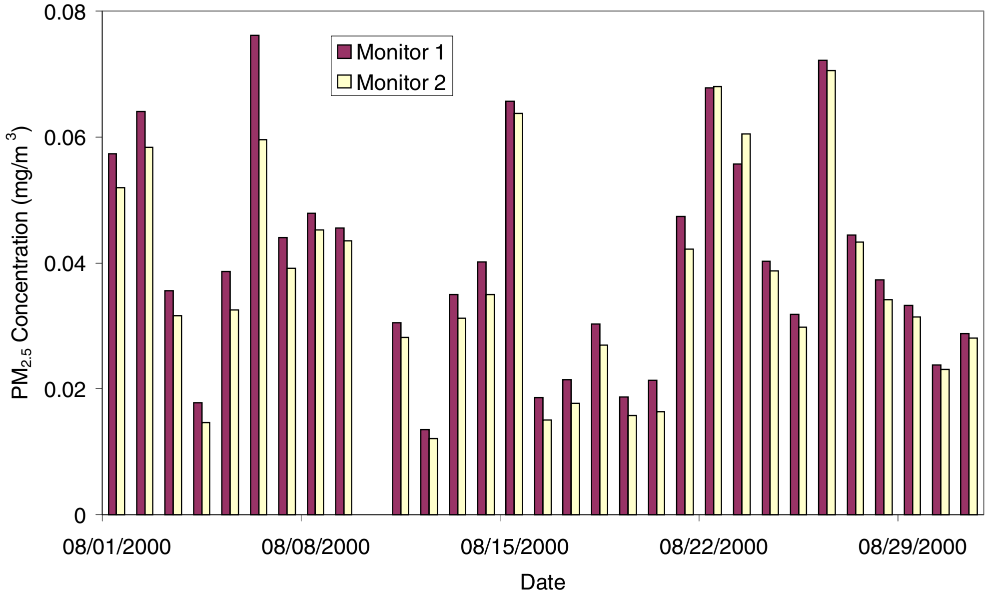

Figure 6-2a. 24-Hour Average PM2.5 Mass Concentrations from Duplicate ELPI™ Monitors During Phase I of Verification Testing

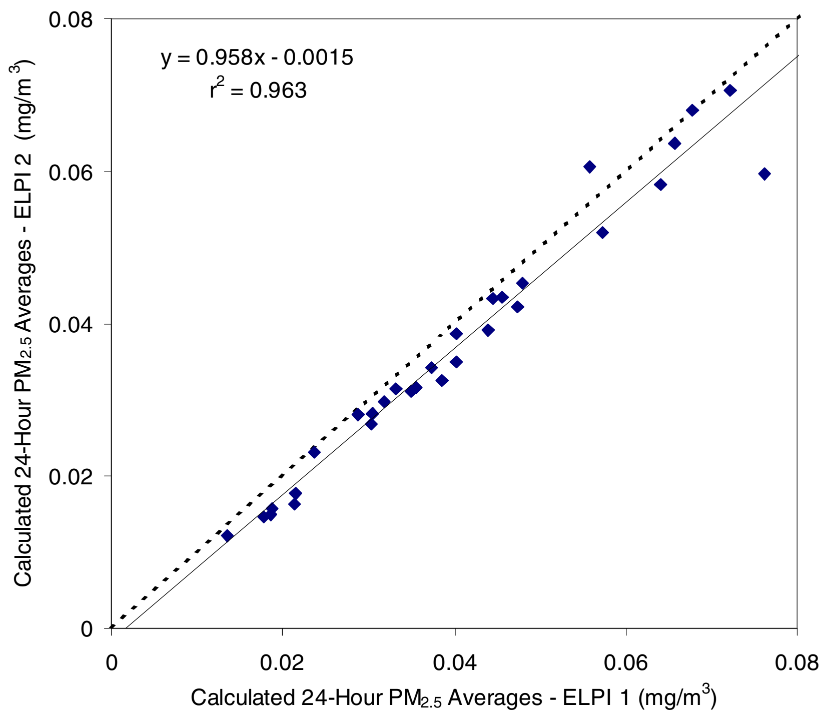

Figure 6-2b. Correlation Plot of 24-Hour $PM_{2.5}$ Concentrations from Duplicate ELPI™ Monitors During Phase I of Verification Testing

Table 6-3. Linear Regression and Coefficient of Variation Results for 10-Minute and 24-Hour Average $PM_{2.5}$ Concentrations During Phase I

Parameter	10-Minute Data	24-Hour Average Data
Slope (95% CI)	0.922 (0.006)	0.958 (0.073)
Intercept (mg/m^3) (95% CI)	-0.0001 (0.0025)	-0.0015 (0.0032)
r^2	0.958	0.963
CV	9.2%	8.8%

The 24-hour average concentration results in Table 6-3 show an r^2 value of 0.963. The calculated CV for the 24-hour averages is 8.8%. The slope of the correlation plot [(0.958 (0.073)] is not statistically different from unity at the 95% confidence level. These data show an intercept of -0.0015 (0.0032) mg/m^3, which is not statistically significant at the 95% confidence level.

6.1.2 Comparability/Predictability

In Figure 6-3a, the noon-to-noon averages of the ELPI™ measurements are shown, along with the $PM_{2.5}$ FRM measurements for Phase I of the verification test. These $PM_{2.5}$ concentration values were analyzed by linear regression according to Section 5.2 to establish the comparability of each of the ELPI™ monitors with the $PM_{2.5}$ FRM sampler. The resulting comparisons are plotted in Figure 6-3b; and the calculated slope, intercept, and r^2 value of the regression analyses are presented in Table 6-4 for each monitor.

The linear regression results show r^2 values of 0.871 and 0.862, respectively for Monitor 1 and Monitor 2. For Monitor 1, the slope of the regression line is 1.81 (0.29), and for Monitor 2 the slope is 1.85 (0.31), where the numbers in parentheses are the respective standard errors. No statistically significant intercept is observed in either case at the 95% confidence level.

The vendor has suggested that the positive bias observed between the ELPI™ and the FRM results may be attributable to volatile components of the ambient aerosol, primarily water. As tested, no sample conditioning was performed for the ELPIs™, and, as such, they were measuring "wet" particles. Since the FRM is based on dry particle mass (i.e., sample equilibration at 20 to 23°C and 30 to 40% relative humidity), the water collected is evaporated during the filter conditioning. The instrument vendor has indicated that sample conditioning can be introduced in the inlet of the ELPI™ which might help remove volatile components of the sampled aerosol, although no assessment of this improvement was made in this test. Alternatively, since the ELPI™ calculates $PM_{2.5}$ mass from the charged particle current measured on multiple stages, errors in the required assumptions about particle shape, particle density, etc., may possibly contribute to the observed bias.

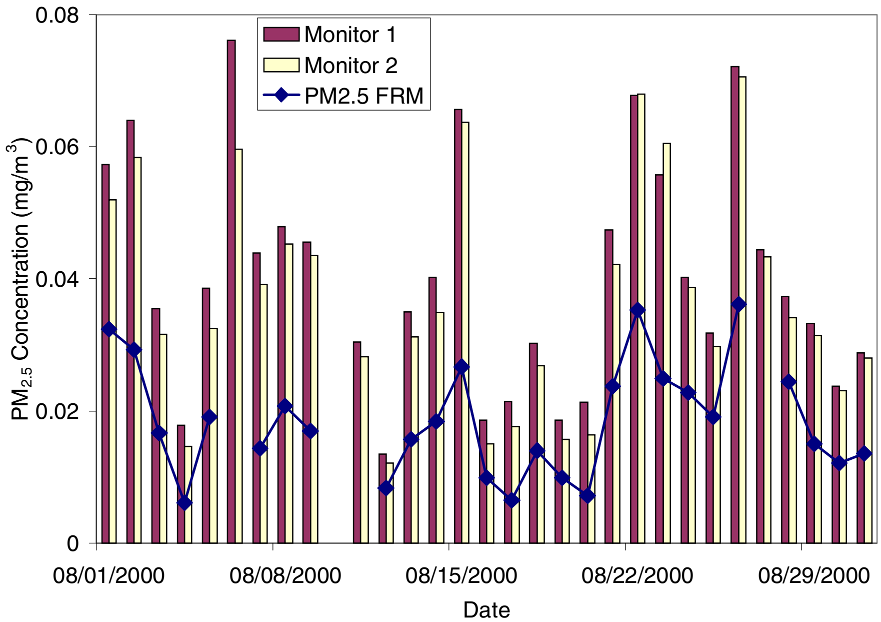

Figure 6-3a. Daily $PM_{2.5}$ FRM Concentrations and the 24-Hour $PM_{2.5}$ Concentrations from Duplicate ELPI™ Monitors During Phase I of Verification Testing

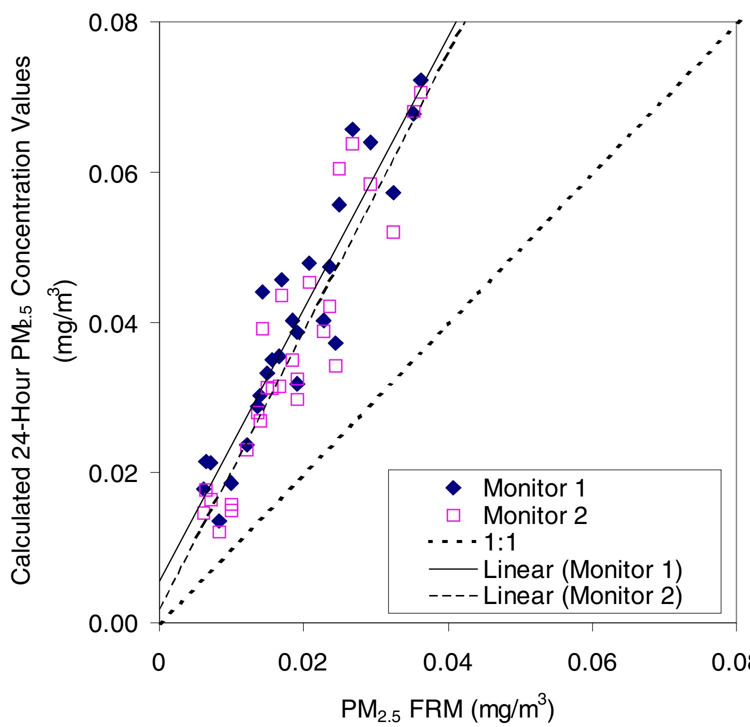

Figure 6-3b. Correlation Plot of the 24-Hour Averages from the Duplicate ELPI™ Monitors and the $PM_{2.5}$ FRM Concentrations During Phase I of Verification Testing

Table 6-4. Comparability of the ELPI™ Monitors with the $PM_{2.5}$ FRM for Phase I

Regression Parameter	Monitor 1	Monitor 2
Slope (95% CI)	1.812 (0.287)	1.850 (0.305)
Intercept (mg/m^3) (95% CI)	0.0055 (0.0058)	0.0020 (0.0062)
r^2	0.871	0.862

6.1.3 Meteorological Effects

A multivariable model, as described in Section 5.3, was used to determine if variability in the readings of the ELPI™ monitor could be accounted for 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. This analysis indicated the following relationship for Monitor 1:

$$\text{Monitor 1} = 1.739*FRM - 0.00276*WS - 0.0352*VWS - 0.00128*T10 + 0.00158*T2 + 0.0099*TP - 2.71 \times 10^{-5}*WDSTD + 0.011 \text{ mg/m}^3$$

where FRM represents the $PM_{2.5}$ values in mg/m^3, WS is the horizontal wind speed in mph, VWS is the vertical wind speed in mph, T10 and T2 are the ambient air temperatures in Fahrenheit at 10 meters and 2 meters, respectively, TP is the total precipitation in inches, and WDSTD is the standard deviation of the wind direction. For Monitor 2, the multivariable analysis shows the following relationship:

$$\text{Monitor 2} = 1.675*FRM + 1.70*10^{-6}*WD - 0.0729*VWS - 0.00219*RH - 1.04*10^{-4}*RAD - 2.28*10^{-5}*WDSTD + 0.216 \text{ mg/m}^3$$

where WD is the wind direction in degrees, RH is the average relative humidity in percent, and RAD is the average daily solar radiation in W/m^2.

The r^2 results in Table 6-4 show that regression against the FRM accounts for about 86 to 87% of the variance in 24-hour ELPI readings in Phase I. The multivariable analysis results above show that the model ascribes the rest of the variability to several meteorological parameters, most of which are different for Monitor 1 than for Monitor 2. These results do not necessarily imply actual cause-and-effect influences on the ELPI monitors. However, the magnitude of the purported effects can be estimated. For example, using the average values for $PM_{2.5}$ and the various meteorological parameters during Phase I (Table 6-1), the equation above would predict an average $PM_{2.5}$ reading of 0.0303 mg/m^3 for Monitor 1:

$$\text{Monitor 1} = 1.739*0.0184 - 0.00276*3.35 - 0.0352*0.09$$
$$- 0.00128*20.0 + 0.00158*16.6 + 0.0099*0.0014$$
$$- 2.71*10^{-5}*34.2 + 0.011$$
$$= 0.0303 \text{ mg/m}^3.$$

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

$$\text{Monitor 1} = 1.812* 0.0184 + 0.0055$$
$$= 0.0388 \text{ mg/m}^3$$

Thus, the multivariable model shows a difference of approximately 22% relative to the linear regression.

Similarly, the multivariable model would predict a $PM_{2.5}$ reading of 0.0288 mg/m^3 for Monitor 2:

$$\text{Monitor 2} = 1.675*0.0184 + 1.70x10^{-6}*196 - 0.0729*0.09$$
$$- 0.00219*89.4 - 0.000104*162.8 + 2.28x10^{-5}*34.2$$
$$+ 0.216$$
$$= 0.0288 \text{ mg/m}^3$$

whereas the linear equation would predict

$$\text{Monitor 2} = 1.850*0.0184+ 0.0020$$
$$= 0.0360 \text{ mg/m}^3.$$

In this case, the multivariable model provides a result that is 20% below the results from the linear equation.

6.1.4 Influence of Precursor Gases

As described in Section 5.3, a multivariable analysis was performed to determine if precursor gases had an influence on the readings of the ELPI™ 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 none of the gases that were measured (ozone, carbon monoxide, hydrogen sulfide, nitrogen oxides, nitrogen dioxide, nitric oxide, sulfur dioxide) had a statistically significant influence on the results of either ELPI™ monitor relative to the FRM at the 90% confidence interval.

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

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

Table 6-5 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

As in Phase I, ion current readings were recorded every 10 minutes by the duplicate ELPI™ monitors. These ion current readings were subsequently converted to mass concentration values.

The 10-minute mass concentration readings from the two ELPI™ monitors for Phase II of the verification test are shown in Figure 6-4a. In Figure 6-4b, these data are plotted against one another to illustrate the correlation between the two monitors. As was the case in Phase I, the two ELPI™ monitors gave nearly indistinguishable readings of $PM_{2.5}$ mass. However, close inspection of Figure 6-4a shows that, in some periods, one ELPI™ monitor read higher than the other; and, in other periods, the opposite was true. These periods were sharply defined, as is evident from Figure 6-4b, in which the changing relationship between Monitor 1 and Monitor 2 readings produced different linear groupings of data points. The cause of the transitions from one such period to another appears to coincide with ELPI™ impactor plate changes, and may indicate the presence of a leak. Those changes took place on December 22, at 18:00, December 29 (18:00), January 6 (12:00), and January 12 (15:00).

For comparison with the $PM_{2.5}$ FRM reference measurements, the 10-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 midnight-to-midnight averages for Phase II of the verification test are presented for the two ELPI™ monitors. A correlation plot of these data is shown in Figure 6-5b.

The results of a linear regression analysis of these data are presented in Table 6-7. The CV for the 10-minute and the midnight-to-midnight average values were also calculated and are shown in Table 6-7.

Table 6-7. Linear Regression and Coefficient of Variation Results for 10-Minute and 24-Hour Average $PM_{2.5}$ Concentrations During Phase II

Parameter	10-Minute Data	24-Hour Average Data
Slope (95% CI)	1.237 (0.012)	1.240 (0.167)
Intercept (mg/m^3) (95% CI)	-0.0118 (0.0023)	-0.0126 (0.0291)
r^2	0.910	0.896
CV	18.2%	18.5%

The 10-minute data from the duplicate monitors show a coefficient of determination $r^2 = 0.910$. The regression results show a significant bias between the two monitors, with Monitor 2 typically reading higher than Monitor 1 [slope = 1.237 (0.012)]. This bias is also indicated by a Student's t-test, which shows Monitor 2 reading 0.026 mg/m^3 higher than Monitor 1 on average for the 10-minute data. The calculated CV for the 10-minute data is 18.2%. Much of the calculated CV can be attributed to the bias between the duplicate monitors rather than to random differences between the two monitors.

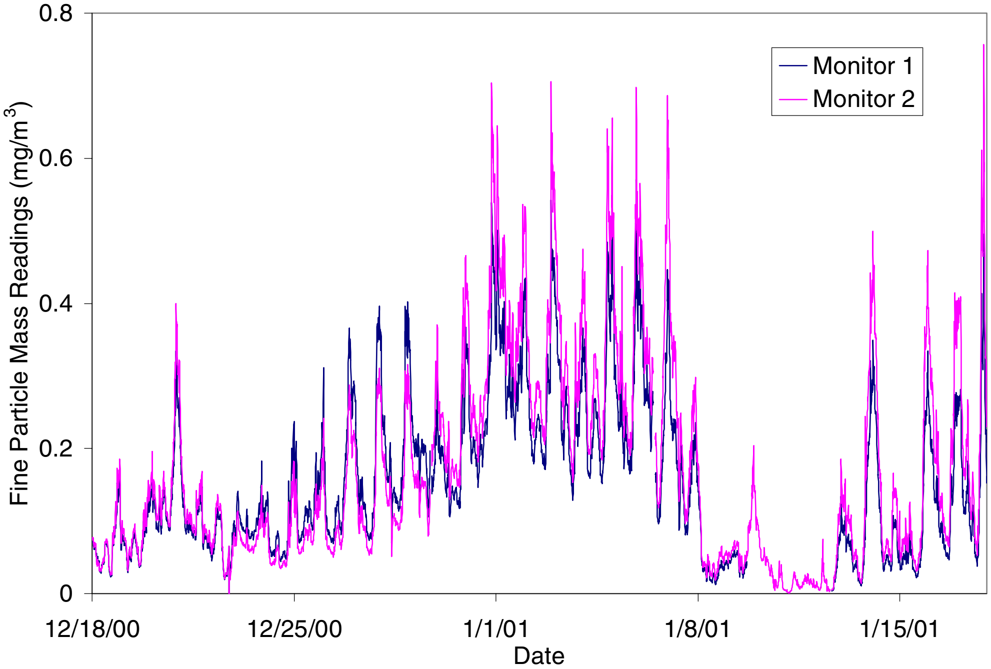

Figure 6-4a. $PM_{2.5}$ 10-Minute Concentrations from Duplicate ELPI™ Monitors During Phase II of Verification Testing

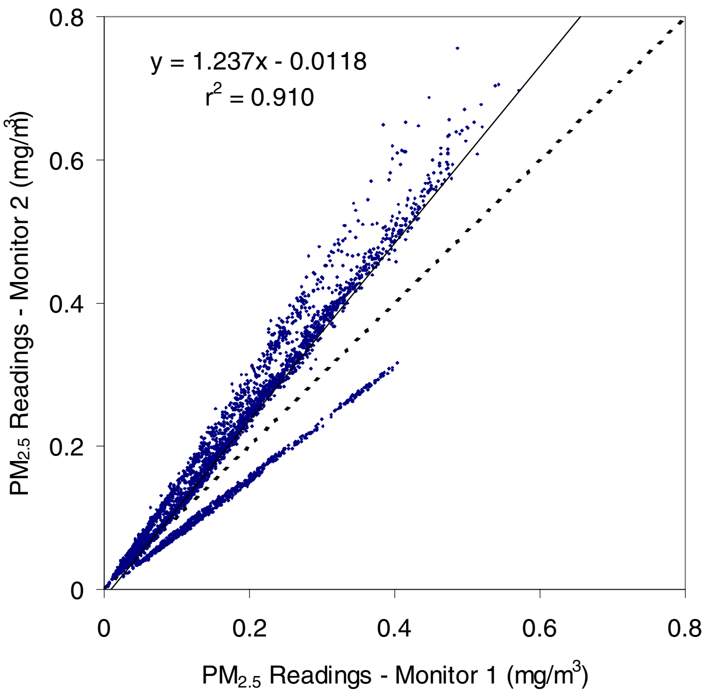

Figure 6-4b. Correlation Plot of 10-Minute $PM_{2.5}$ Measurements from Duplicate ELPI™ Monitors During Phase II of Verification Testing

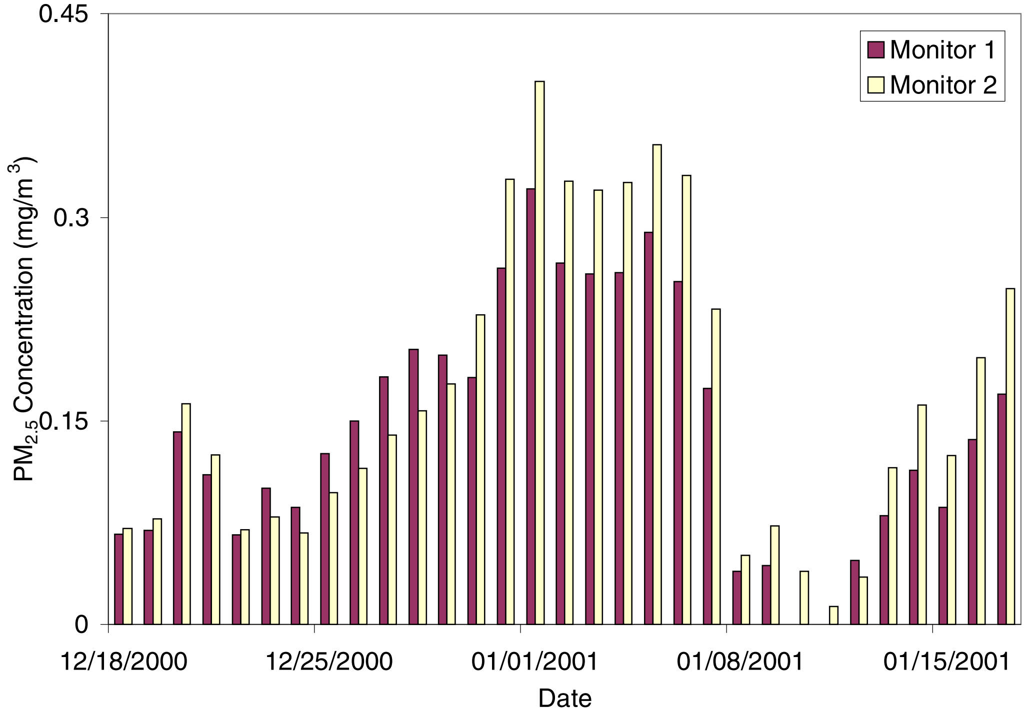

Figure 6-5a. Midnight-to-Midnight $PM_{2.5}$ Concentrations from Duplicate ELPI™ Monitors During Phase II of Verification Testing

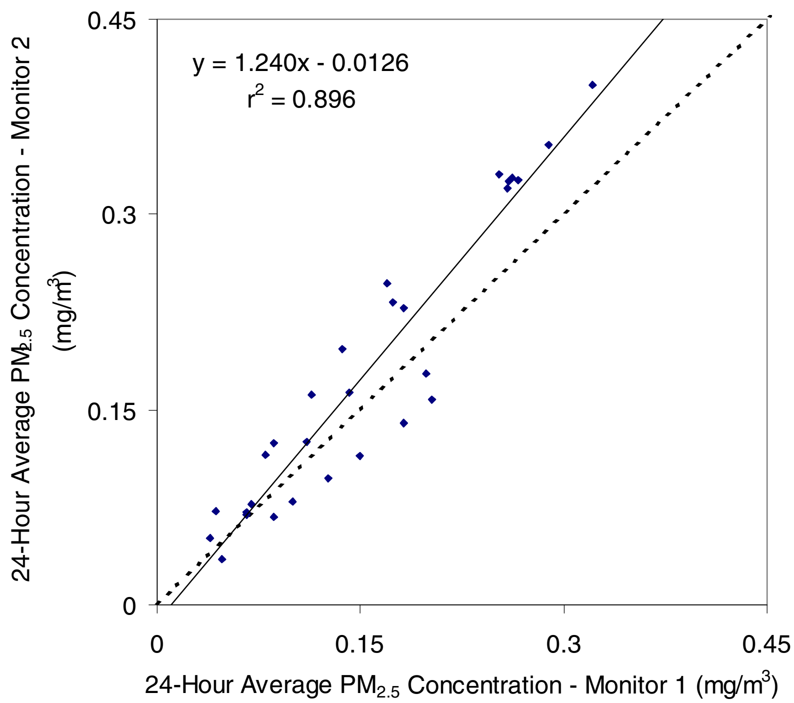

Figure 6-5b. Correlation Plot of 24-Hour Average $PM_{2.5}$ Concentrations from Duplicate ELPI™ Monitors During Phase II of Verification Testing

The 24-hour average concentration results for the duplicate monitors show an r^2 value of 0.896. As with the 10-minute data, the regression results of the 24-hour averages show a statistically significant bias between the monitors [slope= 1.240 (0.167)]. A Student's t-test indicates a bias for the 24-hour averages, with Monitor 2 reading 0.024 mg/m^3 higher than Monitor 1 on average.

6.2.2 Comparability/Predictability

In Figures 6-6a and 6-6b, the midnight-to-midnight averages of the ELPI™ measurements are shown, along with the $PM_{2.5}$ FRM measurements for Phase II of the verification test. It is apparent from Figure 6-6a that the ELPI™ averages followed the same temporal pattern as the FRM data; but, in general, the ELPI™ averages exceeded the FRM values by as much as a factor of two. A correlation plot of these 24-hour data is shown in Figure 6-6b. These $PM_{2.5}$ concentration values were analyzed by linear regression according to Section 5.2 to establish the comparability of each of the ELPI™ 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 ELPI™ Monitors with the $PM_{2.5}$ FRM for Phase II

Regression Parameter	Monitor 1	Monitor 2
Slope (95% CI)	2.132 (0.297)	2.598 (0.443)
Intercept (mg/m^3) (95% CI)	-0.012 (0.0262)	-0.022 (0.038)
r^2	0.897	0.843

The r^2 values of the regression analyses were 0.897 for Monitor 1 and 0.843 for Monitor 2. Both Monitors 1 and 2 showed a substantial positive bias relative to the FRM results. The slopes of the regression lines were 2.13 (0.30) and 2.60 (0.44), respectively. The intercepts of the regression lines were not statistically different from zero at the 95% confidence level.

As with the Phase I results, the ELPIs™ both show a significant positive bias relative to the FRM results. This difference may result from errors in the assumptions used to convert ELPI™ impactor current into $PM_{2.5}$ mass. Or, as suggested by the vendor, this bias may be attributable to volatile components of the aerosol that are measured by the ELPIs™ but not reflected in the FRM results. If sample conditioning of the aerosol were performed prior to ionization in the ELPIs™, it is possible that the agreement between the ELPI™ and the FRM could be improved, although this was not evaluated in this verification test.

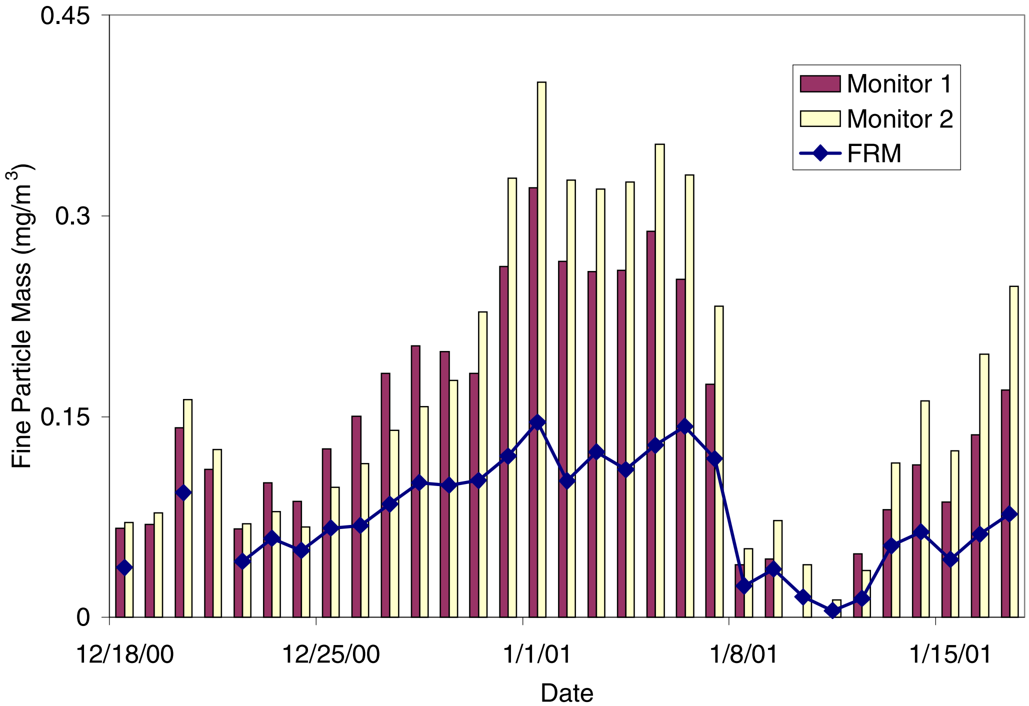

Figure 6-6a. Midnight-to-Midnight Average Concentrations from Duplicate ELPI™ Monitors and the $PM_{2.5}$ FRM Results During Phase II of Verification Testing

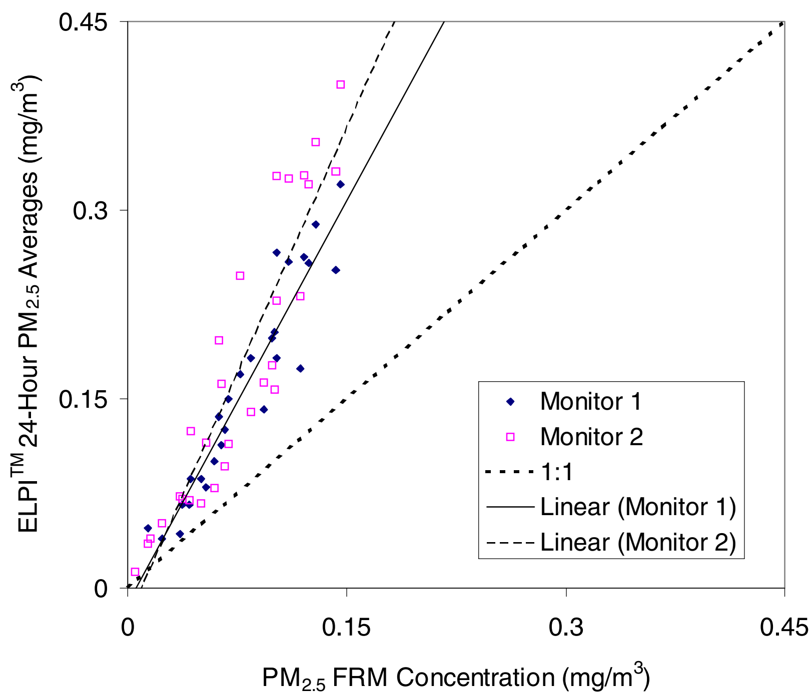

Figure 6-6b. Correlation Plot of the 24-Hour Average Concentrations from Duplicate ELPI™ Monitors and the $PM_{2.5}$ FRM During Phase II of Verification Testing

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 ELPI™ 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 meteorological effects on Monitor 2 relative to the FRM at the 90% confidence level. However, the model ascribed to barometric pressure a statistically significant influence on the readings of Monitor 1 relative to the FRM values at the 90% confidence level. The regression analysis indicates a relationship of the form:

$$\text{Monitor 1} = 2.07*\text{FRM} + 4.24 \times 10^{-3}*\text{BP} - 3.216 \text{ mg/m}^3$$

where FRM represents the measured $PM_{2.5}$ FRM values in mg/m^3, and BP represents the average barometric pressure in mmHg. Typically the average barometric pressure was near 750 mmHg and the contribution from the pressure canceled out the large intercept.

Using the average barometric pressure and $PM_{2.5}$ concentration during Phase II, the multivariable equation above would predict an average value of 0.1435 mg/m^3, whereas the linear equation would predict 0.1458 mg/m^3. The 1.6% difference between these values shows that, although a statistically significant effect is indicated, the overall effect is of little practical importance.

6.2.4 Influence of Precursor Gases

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

$$\text{Monitor 1} = 1.816*\text{FRM} + 0.0215*\text{CO} - 0.030 \text{ mg/m}^3$$

was observed, where the concentration of carbon monoxide is reported in ppm. Assuming the average $PM_{2.5}$ concentration and the average carbon monoxide concentration, this equation would predict an average $PM_{2.5}$ reading of 0.1452 mg/m^3 for Monitor 1 and the linear equation would predict a value of 0.1458. The 0.4% difference between these values shows that, although a statistically significant effect is indicated, the overall effect is of little practical importance.

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 sum of the short-term measurements from the sequential filter

Table 6-9. Summary of $PM_{2.5}$ Levels During Phase II of Verification Testing

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

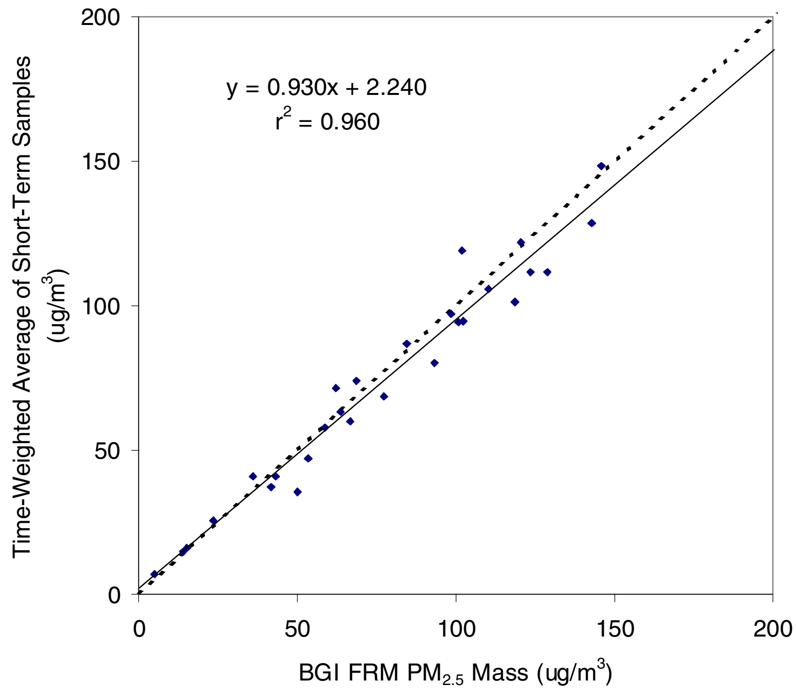

Figure 6-7. Correlation Plot of the Time-Weighted Averages for the Short-Term Samples and the $PM_{2.5}$ FRM

sampler and the 24-hour FRM measurements. The slope and intercept of the regression line are 0.930 (0.077), and 2.2 µg/m^3 (6.6), respectively, with an r^2 value of 0.960, where the numbers in parentheses are 95% CIs.

In Figure 6-8, the averages of the ELPI™ readings for all the short-term monitoring periods are plotted versus the corresponding $PM_{2.5}$ concentration values from the sequential filter sampler. Linear regression analysis of these data was performed separately for each ELPI™ monitor, and the results are presented in Table 6-10. Regression analyses were also performed separately for each of the five time periods during which the short-term samples were collected (i.e., 0000-0500, 0500-1000, 1000-1300, 1300-1600, and 1600-2400). These regression results are also presented in Table 6-10.

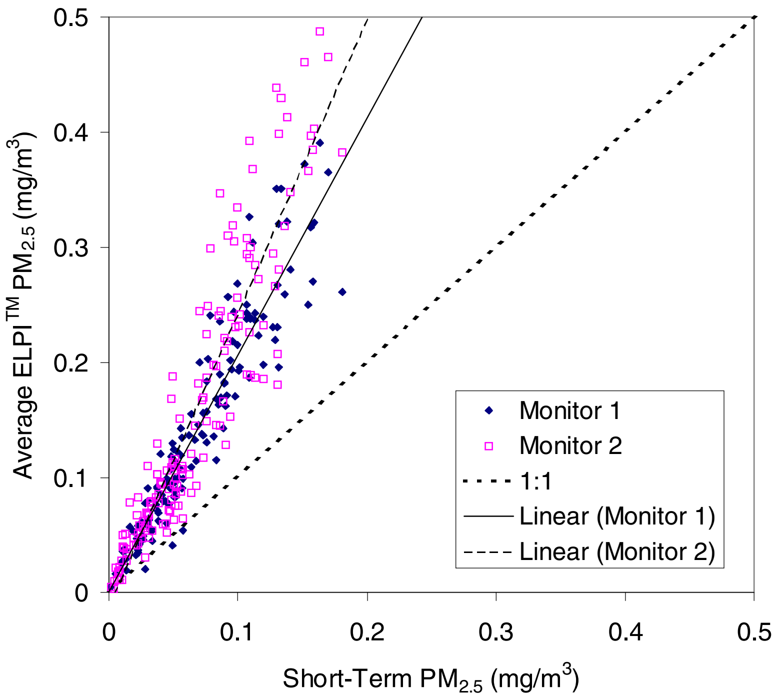

Figure 6-8. Correlation Plot of Short-Term Monitoring Results and the Corresponding Averages from Duplicate ELPI™ Monitors During Phase II of Verification Testing

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

Short-Term Monitoring Period	Monitor 1			Monitor 2		
	Slope	Intercept (mg/m^3)	r^2	Slope	Intercept (mg/m^3)	r^2
All	2.06	0.001	0.882	2.55	-0.011	0.850
0000-0500	2.24	-0.008	0.836	2.87	-0.030	0.852
0500-1000	2.44	-0.006	0.865	2.99	-0.016	0.829
1000-1300	1.98	0.003	0.948	2.37	-0.007	0.903
1300-1600	1.86	0.004	0.959	2.22	-0.005	0.927
1600-2400	2.03	-0.008	0.862	2.43	-0.009	0.790

The short-term monitoring results indicate that the ELPI™ monitors show similar degrees of correlation with the reference measurements overall and for each of the five short-term monitoring periods. When all the sampling periods are included, the regression results show r^2 values of 0.882 for Monitor 1 and 0.850 for Monitor 2. The r^2 values for the individual sampling periods range from 0.836 to 0.959 for Monitor 1 and from 0.790 to 0.927 for Monitor 2. The regression results show a slope of 2.06 (0.13) for Monitor 1 and 2.55 (0.17) for Monitor 2 when all sampling periods are included. For both Monitor 1 and Monitor 2, the agreement with the reference measurements was best (i.e., the slopes were closest to 1.0) for the shortest sampling periods (i.e., 1000-1300 and 1300-1600). The r^2 values also were highest for these shortest periods. The slopes of the regression lines range from 1.86 to 2.44 for Monitor 1 and 2.22 to 2.99 for Monitor 2.

These short-term results are consistent with the 24-hour FRM comparisons shown in Sections 6.1.2 and 6.2.2, in that the ELPI™ results are biased high relative to the FRM. As noted in those sections, possible reasons for the bias include errors in the assumptions needed to convert ELPI™ current to $PM_{2.5}$ mass readings, and differing measurement of volatile material in the ELPI™ and reference methods. The instrument vendor has suggested that during these short mid-day sampling periods, the levels of volatile components are possibly lowest, and, therefore, agreement with the reference measurements is best. No evaluation of this hypothesis was conducted in this verification test. (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.).

6.3 Instrument Reliability/Ease of Use

With the exception of short periods during which impactor plates were replaced and brief power outages, 100% data recovery was achieved by each of the ELPI™ monitors from the time of installation to the end of Phase I sampling. No operating problems arose during Phase I of testing. The only maintenance that was performed on the ELPI™ monitors involved changing the impactor plates. This process took approximately 30 minutes per week for each monitor.

During Phase II of the verification test, approximately three days of data were lost for one monitor when its internal memory buffer reached its capacity. As in Phase I, the only maintenance that was performed on the ELPI™ monitors was changing the impactor plates weekly.

6.4 Shelter/Power Requirements

The ELPI™ monitors were installed and operated inside an instrument trailer during each phase of testing and were run on a single 15 A circuit. Vendor-supplied literature indicates a range of operating temperatures of 5 to 40°C; however, these limits were not verified in this test.

6.5 Instrument Cost

The price of the ELPI™ as tested is approximately $80,000.

Chapter 7
Performance Summary

The ELPI™ monitor is a semi-continuous particle monitor designed to provide indications of the ambient particulate matter size distribution and concentration at time periods as short as several seconds. Duplicate ELPI™ monitors were evaluated under field test conditions in two separate phases of this verification test. The duplicate monitors were operated side by side. The results from each phase of this verification test are summarized below.

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

In current data were collected from the duplicate ELPI™ monitors every 10-minutes during Phase I. These data were converted to mass concentrations and averaged to obtain 24-hour PM_{25} concentrations. Regression analysis of these data showed r^2 values of 0.958 and 0.963, respectively, for the 10-minute readings and 24-hour averages. The slopes of the regression lines were 0.922 (0.006) and 0.958 (0.073), respectively, for the 10-minute data and 24-hour averages; the intercept was not significantly different from zero in either case at the 95% confidence level. The calculated CV for the 10-minute data was 9.2%; and, for the 24-hour averages, the CV was 8.8%.

Comparisons of the 24-hour averages with $PM_{2.5}$ FRM results showed intercepts indistinguishable from zero and slopes of the regression lines of 1.81 (0.29) and 1.85 (0.31), respectively, for Monitor 1 and Monitor 2. The regression results show r^2 values of 0.871 and 0.862 for Monitor 1 and Monitor 2, respectively.

Multivariable analysis of the 24-hour average data showed that most of the measured meteorological parameters had a statistically significant influence on the ELPI™ readings relative to the FRM values at the 90% confidence level.

Multivariable analysis of the 24-hour average data showed that none of the ambient precursor gases measured had a statistically significant influence on either of the ELPI™ monitors.

No operating problems arose during Phase I of testing. The only maintenance that was performed on the ELPI™ monitors involved changing the impactor plates. This process took approximately 30 minutes per week for each monitor.

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

Regression analysis showed r^2 values of 0.910 and 0.896, respectively, for 10-minute and 24-hour average data for Phase II. The slopes of the regression lines were 1.237 (0.012) and 1.240 (0.167), respectively, for the 10-minute data and 24-hour averages, indicating a bias between the two monitors. The calculated CV for the 10-minute data was 18.2%; and, for the 24-hour averages, the CV was 18.5%.

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 2.13 (0.30) and 2.60 (0.44), respectively, indicating a bias between the ELPI™ monitors and the FRM. The regression results show r^2 values of 0.897 and 0.843 for Monitor 1 and Monitor 2, respectively.

Multivariable analysis of the 24-hour average data showed that barometric pressure had a statistically significant influence on the readings of Monitor 1 relative to the FRM values at 90% confidence. However, this effect was small and of little practical importance. There was no effect of meteorology on the results of Monitor 2 relative to the FRM.

Multivariable analysis of the 24-hour average data indicated that the presence of carbon monoxide influenced the readings of Monitor 1 relative to the FRM. However, this effect was small and of little practical importance. None of the measured precursor gases had an effect on Monitor 2.

In addition to 24-hour FRM samples, short-term monitoring was performed on a five-sample-per-day basis in Phase II. The ELPI™ results were averaged for each of the sampling periods and compared with the gravimetric results. Linear regression of these data showed slopes of 2.06 and 2.55, respectively, for Monitor 1 and Monitor 2, consistent with the positive bias seen relative to the 24-hour FRM results. Intercepts for both regression lines were indistinguishable from zero and the r^2 values were 0.882 and 0.850, respectively.

During Phase II of the verification test, approximately three days of data were lost for one monitor when its internal memory buffer reached its capacity. As in Phase I, the only maintenance that was performed on the ELPI™ monitors was changing the impactor plates weekly.

Chapter 8
References

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

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

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

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