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Effectiveness of the $PM_{2.5}$ Federal Reference Method to Differentiate Fine and Coarse Mode Aerosol

A Response to Section 6102(e) of the Transportation Equity Act for the 21st Century

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Effectiveness of the $PM_{2.5}$ Federal Reference Method to Differentiate Fine and Coarse Mode Aerosol

A Response to Section 6102(e) of the Transportation Equity Act for the 21st Century

Prepared by

Thomas Peters, Jeff Antley, Robert Vanderpool, and Sanjay Natarajan
P.O. Box 12194
Research Triangle Institute
Research Triangle Park, NC 27709-2194

Gary Norris, Frank McElroy, Paul Solomon, David Gemmill,
Michael Tolocka, and Russell Wiener
U.S. EPA
National Exposure Research Laboratory
Research Triangle Park, NC 27711

Notice

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Abstract

This report is submitted in response to Section 6102(e) of the Transportation Equity Act for the 21st Century, which states:

> "The Administrator shall conduct a field study of the ability of the $PM_{2.5}$ Federal Reference Method to differentiate those particles that are larger than 2.5 micrograms [sic] in diameter. This study shall be completed and provided to the Committee on Commerce of the House of Representatives and the Committee on Environment and Public Works of the United States Senate no later than 2 years from the date of enactment of this Act."

While the concern about the ability of the Federal Reference Method to function as asserted is understandable, extensive data from multiple laboratory and field tests have established that the Federal Reference Method effectively differentiates between particles larger and smaller than 2.5 micrometers in aerodynamic diameter.

Extensive laboratory tests, conducted by the U.S. EPA and independent researchers, demonstrated that the reference method primary size separation hardware, the WINS impactor, provides selection of particles less than 2.5 micrometers in aerodynamic diameter. Furthermore, these evaluations showed conclusively the ability of the WINS to eliminate coarse particle intrusion when clean and after becoming dirty during routine field use. Three intensive field studies corroborated the laboratory findings.

Additional field studies are ongoing, in which existing and new or potentially superceding fractionation technologies are being challenged against a variety of ambient environmental conditions in an effort to more fully characterize sampler behavior.

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Acronyms and Abbreviations

APS	Aerodynamic Particle Sizer
ATD	Arizona test dust
CFR	Code of Federal Regulations
D_{ae}	Particle diameter (aerodynamic equivalent)
DFPSS	Dual fine particle sequential sampler
DOS	Dioctyl sebacate
D_p	Particle diameter
EDXRF	Energy dispersive x-ray fluorescence
FRM	Federal Reference Method (specifically, for $PM_{2.5}$)
HEPA	High-efficiency particulate air filter
HSL	Health and Safety Laboratory (UK)
MASS	Mass Aerosol Speciation Sampler (URG)
MST	Marple, Spengler, and Turner sampler
NAAQS	National Ambient Air Quality Standards
NERL	National Exposure Research Laboratory
OAR	Office of Air and Radiation
ORD	Office of Research and Development
PM	Particulate matter
$PM_{2.5}$	Particulate matter smaller than 2.5 micrometers in aerodynamic diameter

PM_{10}	Particulate matter smaller than 10 micrometers in aerodynamic diameter
PSL	Polystyrene latex (microspheres)
PTFE	Polytetrafluoroethylene
R&P	Rupprecht and Patashnick Co., Inc., Albany, NY
RAAS	Reference Ambient Aerosol Sampler (Andersen Instruments, Inc.)
RTP	Research Triangle Park
SASS	Spiral Aerosol Speciation Sampler (Met One Instruments, Inc.)
SCC	Sharp-cut cyclone
URG	University Research Glassware, Chapel Hill, NC
VAPS	Versatile Air Pollution Sampler (URG)
VOAG	Vibrating orifice aerosol generator
WINS	Well impactor ninety-six

Chapter 1
Introduction

Section 6102(e) of the Transportation Equity Act for the 21st Century states:

> "The Administrator shall conduct a field study of the ability of the $PM_{2.5}$ Federal Reference Method to differentiate those particles that are larger than 2.5 micrograms (sic) in diameter. This study shall be completed and provided to the Committee on Commerce of the House of Representatives and the Committee on Environment and Public Works of the United States Senate no later than 2 years from the date of enactment of this Act."

While the concern about the ability of the $PM_{2.5}$ Federal Reference Method (FRM) to function as designed is understandable, extensive data from multiple laboratory and field tests establish that the FRM effectively differentiates between particles larger and smaller than 2.5 micrometers in diameter.

This report addresses the concerns of Section 6102(e) by presenting laboratory and field evaluations that have been conducted to ascertain the ability of the FRM to separate $PM_{2.5}$ from the environment. The studies presented in this report answer the question raised by this section of the act. In addition, they are among the many EPA programs designed to foster a greater understanding of fine particulate matter in the environment through: (1) the development of state-of-the-art and emerging measurement technologies, (2) the analysis of measurements made by ongoing particulate matter (PM) monitoring networks, and (3) the integration of chemical speciation with $PM_{2.5}$ mass concentration networks.

The introductory chapter of this report provides background material essential to understanding how PM exists in the environment and how this material can be sampled representatively from the atmosphere. Furthermore, this section describes the current FRM for $PM_{2.5}$. Chapter 2 provides descriptions and results of rigorous laboratory evaluations performed by the U.S. EPA on the ability of the FRM to accurately separate particles by size as asserted. Additionally, this chapter presents the results of similar tests conducted by an independent organization to confirm the U.S. EPA test results. Chapter 3 presents a brief description and pertinent results from several extensive field tests involving the FRM. Last, Chapter 4 contains conclusions that can be drawn from this research.

Ambient Particulate Matter

Ambient PM may vary significantly in composition, size distribution, and morphology as a function of emissions, formation processes, time of day, time of year, and location. Field

studies from literature establish the typical presence of multiple "modes" of aerosol mass concentrations as a function of particle size in the ambient air (Lundgren, 1970; Whitby, 1978; Burton and Lundgren, 1987; Jaenicke, 1993; Lundgren et al., 1996). "Fine" mode aerosol is generally composed of submicrometer particles formed by combustion processes, condensation, coagulation, and gas-to-particle conversions resulting from chemical conversion of anthropogenic and natural precursor emissions (Hering and Friedlander, 1982; John et al., 1990; Meng and Seinfeld, 1994). Fine particles are primarily composed of sulfate, nitrate, ammonium ions, elemental carbon, and organic components and may remain suspended in the atmosphere for days to weeks (U.S. EPA, 1998a).

"Coarse" mode aerosol is typically composed of supermicrometer particles broken down by mechanical processes (grinding, crushing, and abrasion [Lundgren and Paulus, 1975]), wind, agricultural practices, and vehicular traffic on unpaved roads. Coarse particles are primarily composed of crustal elements (Si, Al, Mg, etc.), fly ash, biological material (pollen, spores, etc.), and sea salt (U.S. EPA, 1998a). These particles generally deposit more rapidly than fine mode particles due to gravitational settling and, therefore, are less uniform in concentration across an area.

Based on a review of previous ambient size distribution measurements, Vanderpool et al. (2000) numerically constructed three idealized, bimodal particle size distributions to represent a range of atmospheric aerosols that can occur in the U.S. Lognormal plots of the fine and coarse particle size distributions (refer to Figure 1) show two distinct modes in a typical ambient distribution. Typical ambient aerosol mass distributions exhibit a minimum between 1.0 and 3.0 micrometers (Seinfeld and Pandis, 1998). The mass median diameters and mass concentrations of the fine and coarse aerosol modes may appear similar to Figure 2 when the ambient air is dominated by fine particles, or similar to Figure 3 when dominated by coarse particles. Note, however, that Figures 2 and 3 represent extreme situations.

Measurement of Fine Mode Atmospheric Particulate Matter

Many methods are used to measure the mass concentration of fine mode atmospheric PM. All methods must incorporate technologies to contend with the multimodal and multicompositional nature of atmospheric particles. The most common and historically accepted measurement technique relies on the aspiration of a representative atmospheric sample, followed by removal of coarse mode aerosol by inertial means, and subsequent collection of the remaining aerosol on a sample collection filter. The mass concentration is then determined by dividing the mass gained on the filter during the sampling event by the volume of air sampled. The mass

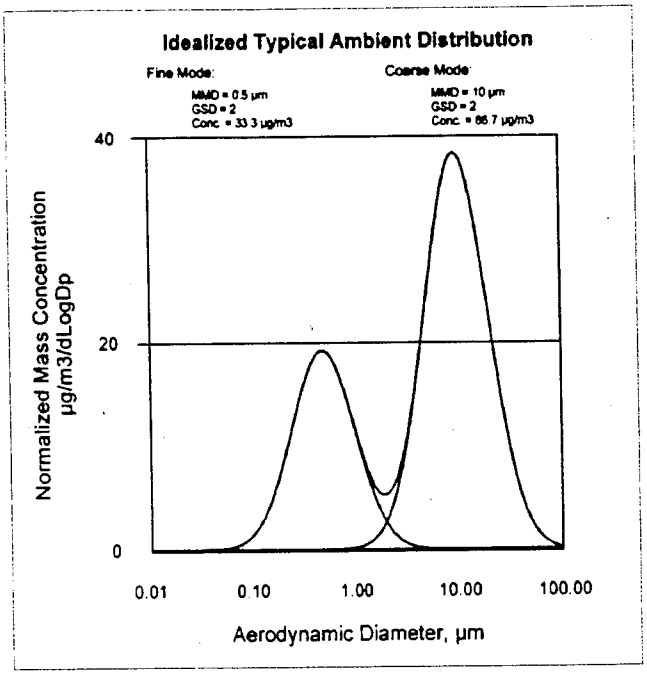

Figure 1. Idealized Typical Ambient Bimodal Distribution

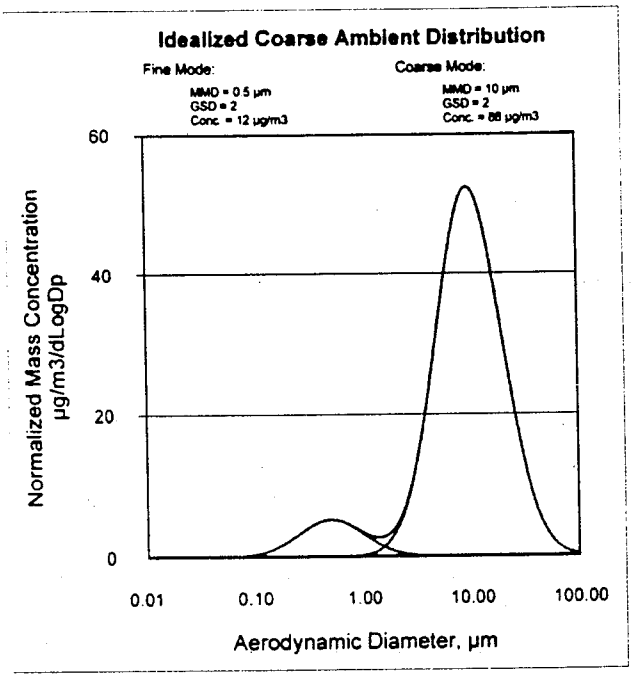

Figure 3. Idealized Coarse Bimodal Ambient Distribution: Aerosol is Dominated by the Coarse Mode

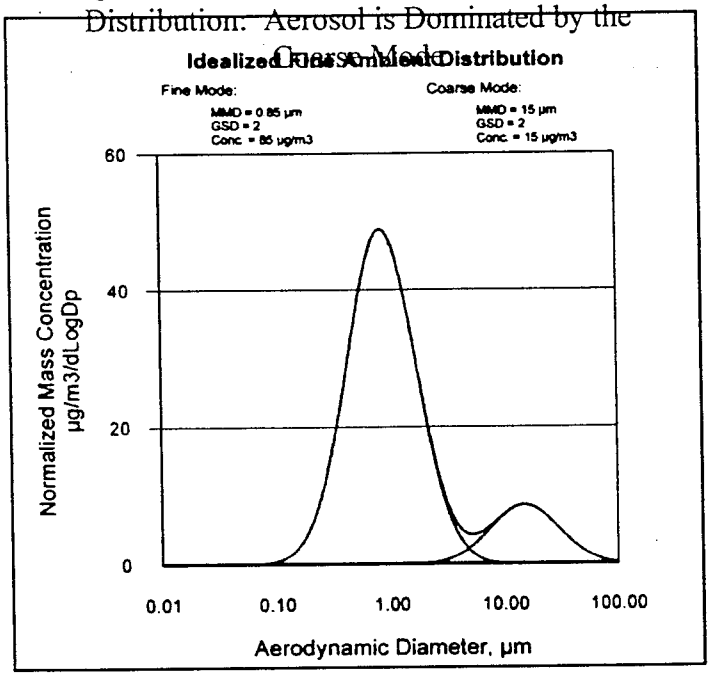

Figure 2. Idealized Fine Ambient Bimodal Distribution: Aerosol is Dominated by the Fine Mode

concentration measured by a given fine mode aerosol collection method is, therefore, a function of the properties of the atmospheric aerosol, both chemistry and size distribution, and the ability of the sampler to representatively aspirate, separate, transport, and collect this aerosol.

Devices that provide inertial separation of aerosols are well documented and include conventional impactors (Marple and Willeke, 1976), virtual impactors (Loo and Cork, 1988), and cyclones (John and Reischl, 1980). Although the construction and operation details of these devices differ, the size separation in any inertial separator is achieved when larger particles are removed from the airstream because of their inertia in a curvilinear flow field. The criteria by which particles are separated include particle physical diameter (D_p), density, and shape; these are generally normalized into a single parameter, "aerodynamic diameter," defined as the diameter of a spherical particle with a density of 1 g/cm^3 with equivalent aerodynamic properties. All mentions of particle diameter in this report, unless otherwise stated, are implied to mean a particle's equivalent aerodynamic diameter ("D_{ae}").

The efficiency with which all inertial separators remove particles from the incident airstream is never absolute. Stating that a separator "cuts" at a nominal 2.5 micrometers is equivalent to stating that it has a 50-percent cutpoint at 2.5 micrometers; or, approximately 50 percent of 2.5-micrometer particles will be removed and 50 percent will not (ref. Figure 4). Particles increasingly larger or smaller than 2.5 micrometers are removed increasingly more and less efficiently, respectively, as described by the separator's penetration curve. Particle size separation depends on how close the efficiency curve is to the ideal step function (i.e., how

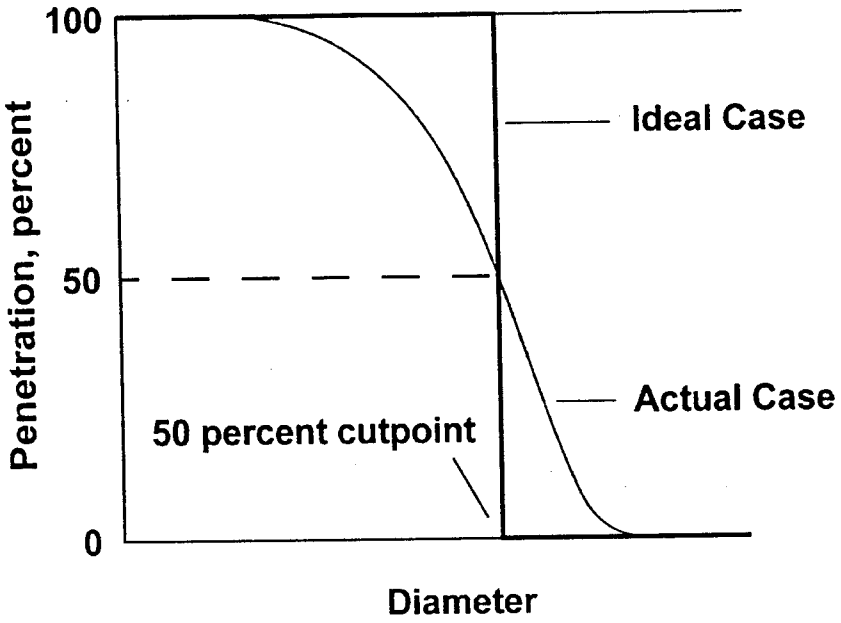

Figure 4. Ideal vs. Actual Separator Penetration Curves

"sharp" the slope is), and whether the penetration curve becomes altered over time as a result of routine use (Marple and Willeke, 1976). Due to internal flow dynamics, the characteristic penetration curve of an inertial separator can approach, but never achieve, the perfectly vertical separation curve identified as "ideal" on Figure 4.

The $PM_{2.5}$ Federal Reference Method

On July 18, 1997, new primary and secondary NAAQSs for fine PM, measured as $PM_{2.5}$ (defined as the mass concentration of fine PM having an aerodynamic diameter less than or equal to a nominal 2.5 micrometers in ambient air) were promulgated. EPA selected $PM_{2.5}$ as the appropriate indicator for fine PM on the basis of "consistency with the community health studies, the limited potential for intrusion of coarse fraction particles in the fine fraction, and availability of monitoring technology" (62 FR 38668, July 18, 1997). The FRM for $PM_{2.5}$ defines the manner by which a $PM_{2.5}$ sample is representatively aspirated from the atmosphere, separated from the total aerosol, transported to the sample collection filter, and subsequently analyzed for mass concentration. A $PM_{2.5}$ FRM sampler "...draws ambient air at a constant volumetric flow rate into a specially shaped inlet and through an inertial particle size separator where the suspended PM in the $PM_{2.5}$ size range is separated for collection onto a polytetrafluoroethylene (PTFE) filter over the specified sampling period" (40 CFR 50, Appendix L, Section 2.1). Filters stabilized at a constant temperature and relative humidity, as defined in the CFR, are weighed before and after sampling to determine net mass gain from collected PM, and the mass concentration of $PM_{2.5}$ in ambient air is obtained by dividing this net mass gain by the total volume of air sampled.

The "specially shaped inlet" and the "inertial particle size separator (impactor)" of an FRM, shown in Figure 5, are specified in engineering drawings L-2 through L-18 and L-20 through L-24, respectively (40 CFR 50, Appendix L). The inlet (a modified version of the one historically used for the dichotomous virtual impactor and several other commercial samplers) representatively aspirates an atmospheric sample and then removes particles greater than a nominal 10 micrometers in diameter from the sampled air volume (Tolocka et al., 2000b).

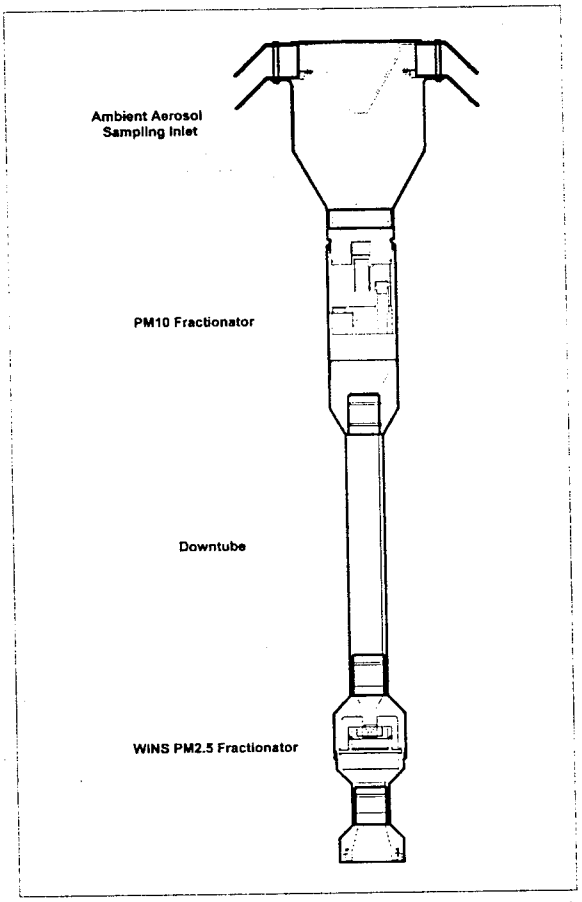

Figure 5. $PM_{2.5}$ Federal Reference Method (FRM) Design Components

The impactor serves as the final separator in the FRM sampling train and, therefore, it follows that its performance is critical. A special impactor, the EPA well impactor ninety-six (WINS), shown in Figure 6, was specifically developed to serve as the final separator for the FRM (Peters et al., 2000a). For design simplicity and ease of construction, the aerosol in the WINS is separated by a single-stage, single-jet, round-hole impactor. The design flow rate of the WINS is 16.7 Lpm and the diameter of the impaction nozzle is 0.391 cm. Particles greater than 2.5 micrometers in aerodynamic diameter have sufficient inertia to be impacted upon a circular glass fiber filter 37 mm in diameter. This filter is immersed in 1 mL of a very low volatility oil, which improves particle retention greatly, minimizes substrate overloading, and prevents subsequent particle bounce that may occur in conventional impactors.

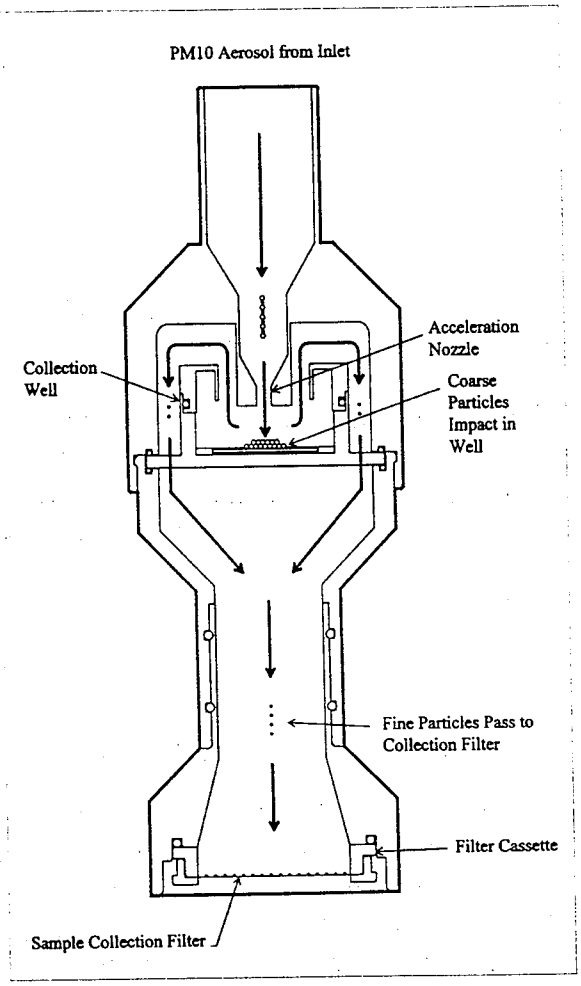

Figure 6. $PM_{2.5}$ WINS Separator and Sample Collection Filter

Chapter 2
Laboratory Evaluations

Prior to promulgation of the FRM for $PM_{2.5}$, the U.S. EPA conducted rigorous laboratory tests to assess the performance of the WINS in relation to other conventional inertial separators. These tests established the shape and position of the penetration curve of the WINS under ideal (clean) conditions as well as after periods of exposure to high particulate concentrations. Since promulgation, laboratory tests conducted by the U.S. EPA and by independent researchers have continued to corroborate the accurate performance of the $PM_{2.5}$ WINS.

Prepromulgation Research

Determination of Penetration

The apparatus used to determine the performance of the WINS, shown in Figure 7, has been described by Peters et al. (2000b). The challenge aerosol consisted of spherical monodisperse aerosol created with the vibrating orifice aerosol generator (VOAG, TSI, Inc., St. Paul, MN) or by nebulizing polystyrene latex (PSL) microspheres with a density of 1.05 g/m^3. The VOAG aerosols were composed of solid ammonium fluorescein with a known density of 1.35 g/cm^3. The particles were charge-neutralized, dried *via* residence in a 10-L chamber with 500 g of silica gel, and diluted with dry, filtered, compressed air.

The number concentration of the particles downstream and upstream of the separator was measured with an Aerosizer (Aerosizer LD, TSI, Inc, St. Paul, MN). The Aerosizer was used to verify the aerodynamic particle size distribution of the challenge aerosol as well. Penetration for a given size was calculated by dividing the number concentration of the particles penetrating through the separator by the number concentration of those bypassing the separator. An entire penetration curve was then developed by stepping through discrete particle sizes until an adequate number of sizes were evaluated to describe the cutpoint diameter and the shape of the curve. It should be noted that this method correctly accounts for any impactor jet and interstage losses and thus characterizes the overall performance of the entire separator. The WINS was developed and evaluated using solid, ammonium fluorescein aerosols. A more rapid manner of aerosol generation relying on nebulization of suspensions containing multiple sizes of PSL microspheres was adopted to conduct the postloading tests.

The EPA WINS penetration curve, as presented in Figure 8, was created by fitting a mathematical function to the penetration determined for nine sizes of monodisperse VOAG

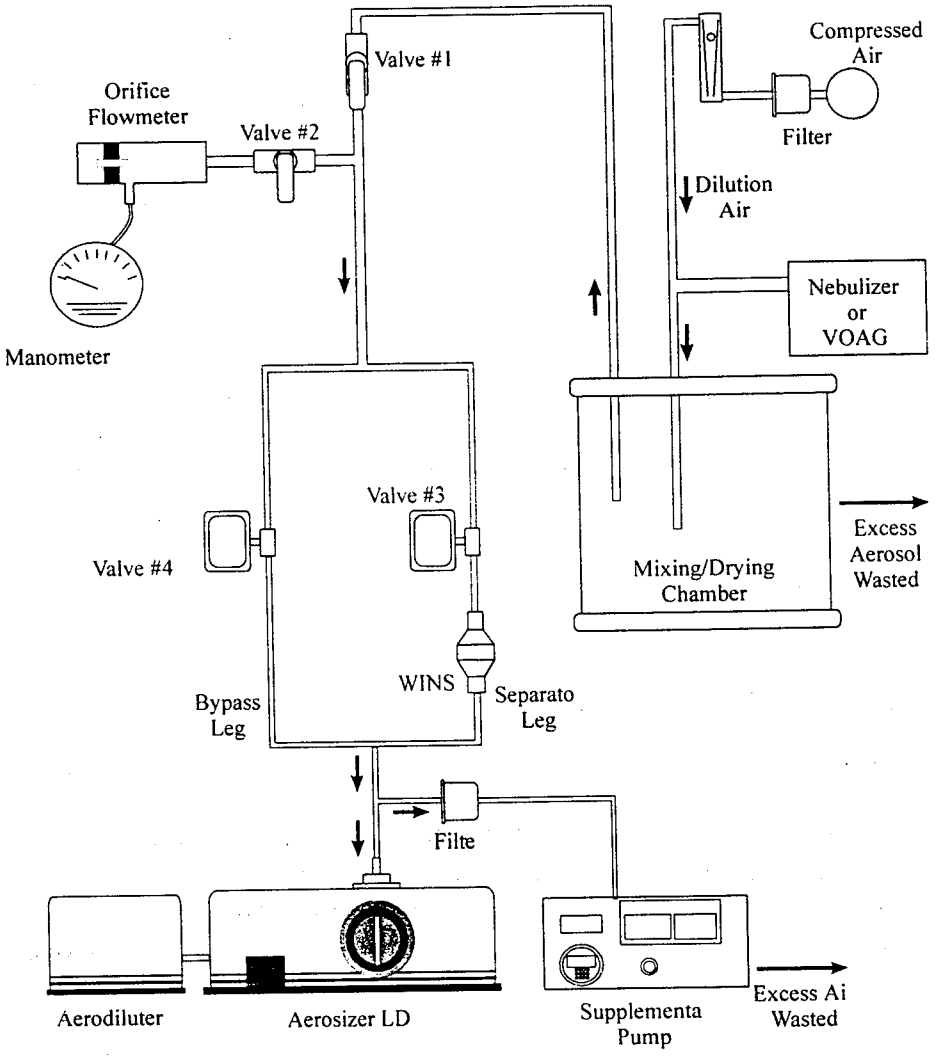

Figure 7. U.S. EPA's Laboratory Apparatus for Determining Separator Penetration

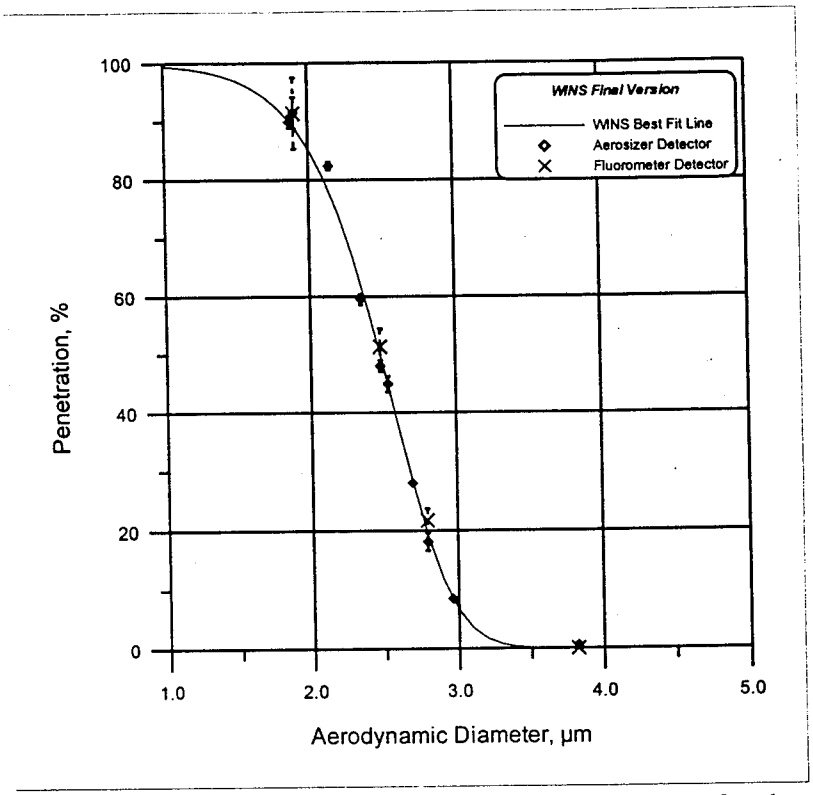

Figure 8. Penetration Versus Aerodynamic Diameter for the Final WINS Design

aerosol. The equation, an asymmetric sigmoid, fits these data well (r-squared greater than 0.99) and predicts a 50-percent cutpoint for a clean WINS of 2.48 micrometers. The "sharpness" of the WINS penetration curve compares favorably to other inertial separators that operate at 16.7 Lpm, as discussed in detail later in this chapter.

Penetration of a Loaded WINS

Laboratory tests were performed to determine how the penetration curve of a WINS would be affected during extended periods of sampling. A specially designed low-velocity, aerosol wind tunnel was constructed to simulate environments of coarse mode aerosol with particulate concentrations greatly exceeding the $PM_{2.5}$ standard (Vanderpool et al., 2000). The WINS performance was evaluated after various periods of exposure to this environment. These test results were used to establish WINS cleaning schedules in addition to defining performance of the WINS as a function of loading.

The aerosol used during the loading tests was Arizona test dust (ATD), fractionated to less than 10 micrometers in diameter via aerodynamic classification by the manufacturer (Powder Technology, Inc., Burnsville, MN). ATD is representative of crustal particulate common to geographic regions dominated by coarse mode aerosol. The ATD was aerosolized by a venturi nozzle, charge-neutralized, diluted to a known concentration, and injected into the loading tunnel

(Figure 9). Air flow through the tunnel was driven by a high-volume blower, metered to be approximately 100 m^3/hr.

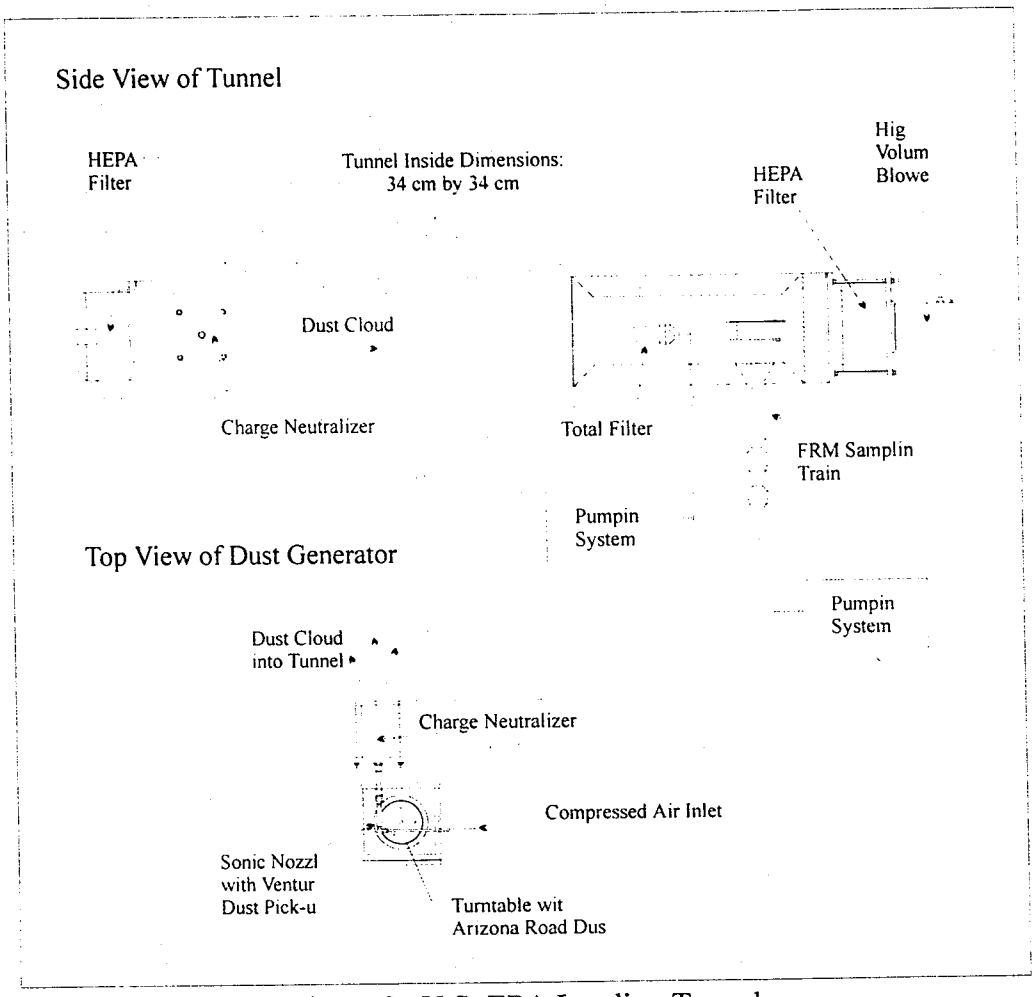

Figure 9. U.S. EPA Loading Tunnel

The FRM sampling train, comprising a PM_{10} sampler inlet, a WINS, and a filter assembly, was operated at its design flow rate of 16.7 Lpm. The aspiration section of the PM_{10} inlet was situated so that it sampled air exclusively from within the tunnel. Loading tests were performed over three 24-hour periods. The mass concentration of the ATD aerosol averaged 332 micrograms/m^3, with a $PM_{2.5}/PM_{10}$ ratio of 0.19 (i.e., dominated by coarse mode aerosol). Note that this concentration is appreciably higher than is typically encountered during most $PM_{2.5}$ compliance measurements. After each 24-hour test, the penetration curve for the WINS was re-evaluated using PSL aerosols, as mentioned in the previous section.

The WINS penetration as a function of loading, illustrated in Figure 10, indicates that the performance curve shifts to slightly smaller sizes. The WINS design successfully eliminates the coarse particle bounce problem that is common to conventional impactors because the oil in the well wicks through the previously deposited particles and presents a continuously wetted surface to the incoming aerosol. The 50-percent cutpoint after the three successive 24-hour periods was determined to be 2.39, 2.29, and 2.21 micrometers, respectively. In contrast, a greased conventional impactor becomes ineffective for particles above its cutpoint diameter after several monolayers of particles are deposited (Tsai and Cheng, 1995). Experimental data from Tsai and Cheng (1995), shown superimposed on Figure 10, have been adapted to illustrate this phenomenon. The impactor studied by these researchers had a cutpoint of 2.0 micrometers when clean; therefore, all data points for the overloaded data presented in Figure 10 were shifted by 0.5 micrometers to provide direct comparison to the WINS results.

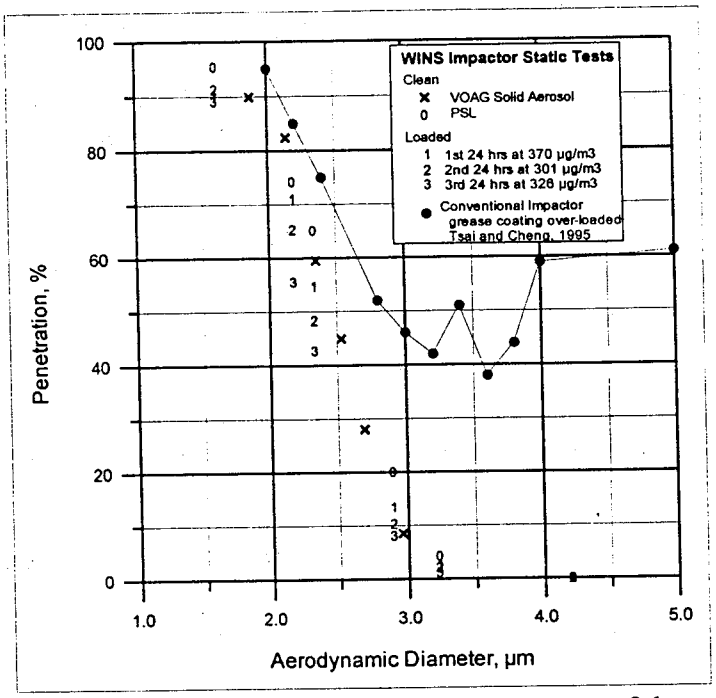

Figure 10. Results of the U.S. EPA's Tests of the WINS After Loading, Compared to a Greased Conventional Impactor

It is possible to estimate the expected measured mass concentration for extremely fine, typical, and extremely coarse mode ambient aerosols by integrating the penetration curve with the assumed ambient distributions depicted in Figures 1 through 3 using the procedures outlined in 40 CFR Part 53, Subpart F, and Vanderpool et al. (2000). The bias relative to a clean WINS can then be calculated by dividing the difference in estimated mass concentration between the loaded WINS and the clean WINS by the estimated mass concentration for the clean WINS.

The biases for the lowest 50-percent cutpoint, D_{50} = 2.21 micrometers, in relation to a clean WINS were calculated to be -3.8 percent, -2.6 percent, and -5.3 percent for the fine, typical, and coarse distribution, respectively. Since the effect of substrate loading for any given aerosol is primarily a function of deposited mass, this same change in WINS performance would be expected to occur in the case of sampling of a mean 200 $\mu g/m^3$ total aerosol mass concentration composed of particles in the 2.5-micrometer to 10-micrometer size range for 5 consecutive days.

To minimize losses of collected volatile and semivolatile $PM_{2.5}$ aerosols following their collection in reference method samplers, the CFR requires that samples be retrieved within 96 hours after sampling. Since this step requires the site operator to service the sampler every 5 sample days, it was considered prudent to replace the WINS well on this frequency. Results of the laboratory loading tests confirmed that this cleaning frequency is adequate to minimize measurement bias associated with the substrate's overloading in all but unusually extreme atmospheres of high concentration coarse mode aerosols. It is expected that this bias will occur only when concentrations are 20 or more times greater than the current $PM_{2.5}$ standard.

To summarize, these tests showed that the WINS is capable of preventing large particle bounce, reentrainment of previously impacted particles, or overloading between the 5-day maintenance periods. The WINS is unlike conventional impactors in that the performance curve of overloaded separators shifts to slightly smaller particle sizes. Use of the WINS in the field will not result in overestimation of mass concentrations due to sampling of coarse particles.

Postpromulgation Research

Since promulgation, both the U.S. EPA and independent researchers have performed laboratory and field tests to gauge the performance of the WINS both clean (or ideal) and after periods of loading. In all cases, the U.S. EPA's prepromulgation findings have been verified. Test results conducted at the Health and Safety Laboratory follow.

Studies Conducted at the Health and Safety Laboratory, Sheffield, U.K.

In 1998, Dr. Lee Kenny of the Health and Safety Laboratory evaluated the performance of the WINS in comparative tests with other established and prototype inertial separators (Kenny, 1998; Kenny et al., 2000). The experimental methods used to test the penetration curve of the WINS were similar to those used by the U.S. EPA, and are fully described by Maynard and Kenny (1995). The test medium was an aerosol consisting of glass microspheres with physical diameters of up to 25 micrometers (density of 2.95 g/cm^3), a mass median diameter of 8 micrometers, and a number median diameter of approximately 2 micrometers. The aerosol was injected into a test chamber with a cross-sectional area of 1 m^2. Two vertical test lines sampled the aerosol from near the center of the test chamber at flow rates of 16.7 Lpm, with the test separator on one of the two lines. An Aerodynamic Particle Sizer (APS, TSI, Inc., St. Paul, MN) was used to analyze five 60-second samples alternately from each line, and the penetration curve was developed by taking the ratio of the measured aerosol distributions from the two lines.

In the laboratory, severely high coarse mode aerosol concentrations were simulated by injecting aerosolizing aluminum oxide grinding powder (Aloxite F1200) into the test chamber. The aerosolized dust is known to have a mass median aerodynamic diameter around 6 micrometers and a geometric standard deviation of around 1.4, meaning that almost all of the particle mass is contained within an aerodynamic particle size range of 3 to 9 micrometers. In these tests, the WINS sampled directly from the test environment without the PM_{10} inlet present. The performance curve was determined for the WINS using the procedures specified in the previous paragraph after sampling of the aloxite dust for varying time periods. Filters downstream of the separators had weight gains indistinguishable from laboratory blanks, indicating that all aerosolized material was retained within the WINS well. The loading levels ranged from 0.4 mg to 4.5 mg.

In addition to the artificial loading performed in the laboratory, Kenny et al. (2000) loaded a WINS separator by operating several FRM $PM_{2.5}$ instruments in the field continuously, without cleaning the WINS, over a period of 5 weeks. Two reference method samplers were operated in a suburban garden during summer months, while a third FRM instrument was operated without its PM_{10} inlet inside a parking garage. The performance curve of the WINS after laboratory and field loading was determined using the procedures described at the beginning of this section.

The evaluation of the clean WINS, depicted in Figure 11, showed very good agreement with the U.S. EPA results (labeled as "Ideal WINS" in Figure 11). Results of both the laboratory loading tests and the field loading tests, presented in Figure 12, showed that the penetration curve shifted to smaller diameters and the lowest 50-percent cutpoint was observed to be 2.15 micrometers. The calculated bias in the measurement of $PM_{2.5}$ by a dirty WINS compared to a clean WINS was between -2 percent (for a typical aerosol distribution) and -6 percent (for a coarse aerosol distribution), which is similar to what the U.S. EPA predicted prior to promulgation.

U.S. EPA Penetration Tests of the WINS After Field Operation

Further research conducted by the U.S. EPA involved evaluating the WINS performance after operation in various locations around the U.S. The WINS wells were retrieved and archived during two intensive fine particulate method intercomparison studies, identified as the 4-City Study and the Atlanta-99 "Supersite" Study (study details and selected results are provided in Chapter 4). The FRM samplers were operated for a period of 5 days and then the WINS wells were sent back to a U.S. EPA laboratory for evaluation of the WINS penetration curve. Evaluations were performed by the U.S. EPA using the same testing protocols and laboratory facilities as described above for prepromulgation tests. In all, 13 wells were evaluated. PM_{10} measurements were made with collocated reference method samplers. The ambient distributions at Rubidoux (CA) and Phoenix (AZ) were primarily coarse mode aerosol (mean $PM_{2.5}/PM_{10}$ ratios of 0.47), while distributions at Philadelphia (PA) and Research Triangle Park (RTP, NC) were dominated by the fine mode (mean $PM_{2.5}/PM_{10}$ ratios of 0.82 and 0.76, respectively).

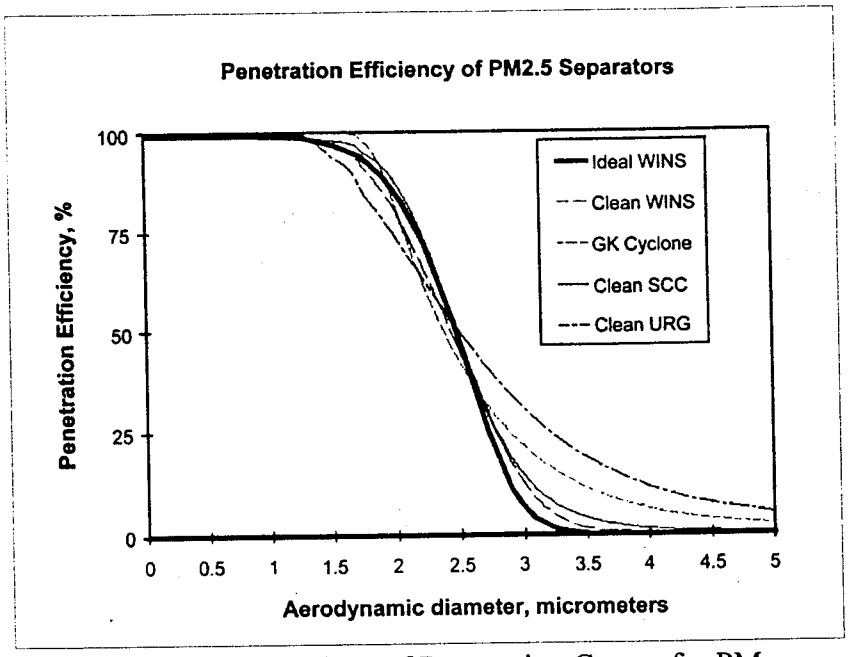

Figure 11. Comparison of Penetration Curves for $PM_{2.5}$ Separators Performed by the Health and Safety Laboratory, from Kenny (1998). Ideal WINS Indicates U.S. EPA Results, GK Indicates Gussman-Kenny, SCC Indicates a Sharp-Cut Cyclone, and URG is a URG Corporation Device.

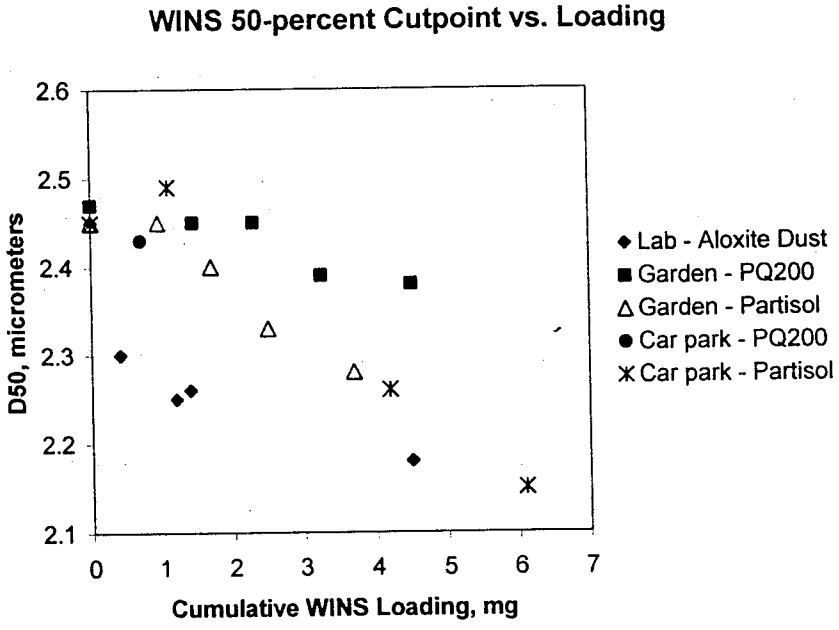

Figure 12. Results of Tests of WINS Penetration After Cumulative Loading Performed by the Health and Safety Laboratory, from Kenny (1998)

The results of the penetration curve evaluations for the field-loaded WINS wells from these studies are illustrated in Figure 13. The mean 50-percent cutpoint was measured to be 2.41 ± 0.05 micrometers (one standard deviation), with low and high values of 2.32 micrometers and 2.51 micrometers. Integrating the loaded penetration curves with the fine, average, and coarse ambient distributions from Figures 1 through 3 resulted in average biases in measured mass concentrations of -0.9 percent, -0.4 percent, and -0.6 percent, respectively, compared to a clean, unloaded WINS. These results of evaluations of penetration curves of field-loaded WINS wells reinforce the findings of prepromulgation studies.

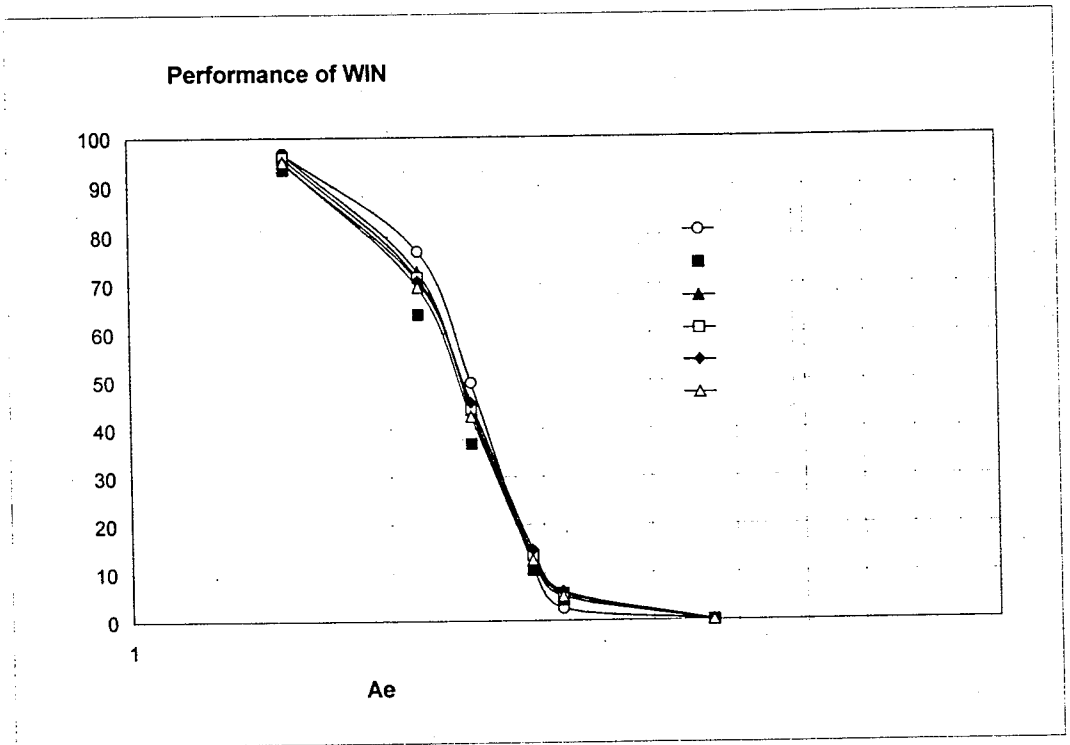

Figure 13. Results of EPA Penetration Tests on WINS Separators Loaded During Field Operation at Five U.S. Cities (Rubidoux, Phoenix, Philadelphia, Research Triangle Park, and Atlanta)

Comparison of the WINS to Other Inertial Separators

It is important to compare the performance of the WINS to other inertial separators for $PM_{2.5}$. Many conventional impactors have been designed to separate fine mode aerosol from total aerosol. Tsai and Cheng (1995) demonstrated that a flat greased plate in a conventional impactor can overload after only a few monolayers of material are deposited. Unlike the WINS, which prevents coarse particles from penetrating to the sample collection filter even after becoming loaded, conventional impactors typically allow coarse particles to bounce off of the overloaded impaction substrate and continue on to the sample collection filter (Markowski, 1984; Pak et al., 1992).

One approach to solving this problem is to use an oil-soaked, sintered metal disk as the impaction substrate (Reischl and John, 1978). Marple et al. (1987) used this type of substrate in the MST impactor to reduce or eliminate particle bounce in a microenvironmental $PM_{2.5}$ impactor designed for indoor air studies. It was further used in personal samplers (Marple et al., 1989). The penetration curve of this impactor, shown in Figure 14, provides a sharper cut than the WINS; however, this impaction surface has to be cleaned daily, a serious drawback. Virtual impactors also have been used to defeat the particle-bounce problem. The penetration curve for the dichotomous virtual impactor, as shown in Figure 14, was determined by Loo and Cork (1988) to be somewhat less steep than for the WINS.

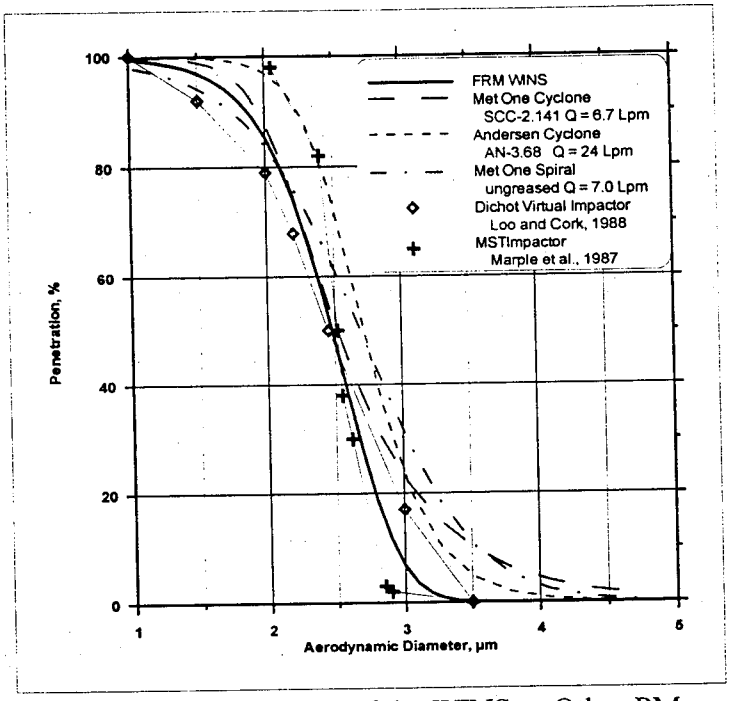

Figure 14. Comparison of the WINS to Other $PM_{2.5}$ Separators

Many separators rely on a cyclone-type design to achieve $PM_{2.5}$ separation. The separation characteristics of the URG $PM_{2.5}$ cyclone (Figure 11) were shown by Kenny et al. (2000) to be significantly less steep than for the WINS, with the penetration curve tailing well into the coarse particle mode. These researchers determined the penetration curves of two other cyclones, the GK cyclone and the 16.7 Lpm sharp-cut cyclone (SCC). Figure 11 shows that the SCC is steeper than the WINS below 2.5 micrometers, but somewhat less steep above 2.5 micrometers. The penetration curve of the GK cyclone is steeper than, but similar to, the URG cyclone.

Several new methods for $PM_{2.5}$ sampling were developed to support the EPA's speciation trends network. Peters et al. (2000c) determined the penetration curves for the final $PM_{2.5}$ separators employed in these devices, shown in Figure 14. The Andersen cyclone, AN-3.68, provided a sharp cut similar to the WINS, but possessed a 50-percent cutpoint of

2.7 micrometers. The penetration curve of the Met One-Spiral was determined to be less steep than for the WINS. Similarly, the Met One SCC-2.141 (a smaller variation of the 16.7 Lpm SCC) penetration curve was steeper than for the Spiral, but had a slightly larger tail for particles above 2.5 micrometers.

The predicted bias in mass concentration from the WINS for a variety of these $PM_{2.5}$ separators is provided in Table 1 for the assumed fine, typical, and coarse mode ambient size distributions. The bias for all separators was calculated to be within ± 5 percent for the fine and typical distributions. Although the steepness of the penetration curve varied greatly between the dichotomous virtual impactor and the MST impactor, the predicted bias for the coarse distribution was calculated to be within ± 5 percent because both separators have cutpoints of 2.5 micrometers and penetration curves that are fairly symmetric above and below their cutpoint diameters. The Met One SASS-SCC 2.141 and the URG cyclones possess cutpoint diameters of 2.5 micrometers, but they have asymmetric separation curves that caused the calculated bias to exceed 5 percent for the coarse aerosol. The calculated coarse bias for the SCC 2.141 was only slightly greater than 5 percent, at 6.1 percent; however, it was significantly greater for the URG cyclone, 10.5 percent. The Andersen RAAS cyclone had the sharpest penetration slope of the cyclones presented, but yielded a calculated coarse bias of 7.4 percent resulting from the separator's cutpoint diameter being greater than 2.7 micrometers. The Met One-Spiral coarse bias was calculated to be slightly greater than 5 percent.

Table 1. Bias in mass concentration from the ideal FRM, estimated for various $PM_{2.5}$ separators.

Separator	Estimated Bias from Ideal FRM (%)		
	Fine	Typical	Coarse
Met One SASS Cyclone SCC 2.141 Q = 6.7 Lpm[a]	1.4	2.3	6.1
Andersen RAAS Cyclone AN 3.68 Q = 24 Lpm [a]	2.7	2.6	7.4
Met One SASS Spiral Q = 7.0 Lpm [a]	0.0	1.4	6.1
Dichotomous Virtual Impactor [b]	-1.2	0.4	3.2
MST Impactor [c]	2.1	1.0	1.8
URG PM2.5 Cyclone [d]	-1.1	2.7	10.5
Perfect Step Function at 2.5 micrometers	1.9	0.6	0.5

[a] Penetration curve obtained from Peters et al. (2000c).
[b] Penetration curve obtained from Loo and Cork (1988).
[c] Penetration curve obtained from Marple et al. (1987).
[d] Penetration curve obtained from Kenny et al. (2000).

Laboratory Evaluation of Crystallized DOW 704 on WINS Performance

Subsequent to the 1997 promulgation of the Federal Reference Method for $PM_{2.5}$, the USEPA received reports that the DOW 704 diffusion oil used in the method's WINS separator had been occasionally observed to crystallize during field use. While the frequency of occurrence and the conditions under which crystallization occurs have not yet been determined, concerns have been raised that crystallization of the DOW 704 oil during a given sampling event may adversely affect the event's data quality. In particular, concerns were expressed that the measured $PM_{2.5}$ concentration may be artificially high during a crystallization event due to possible particle bounce from the crystallized impaction surface.

In response to these concerns, the USEPA designed and conducted a specialized series of laboratory tests to determine the influence of crystallized DOW 704 oil on the size-selective performance of the WINS separator. The experimental setup previously presented in Figure 7 was modified to use dry ice to artificially induce crystallization of the diffusion oil under controlled conditions. Standard size-selective performance tests of the WINS separator were then conducted using primary calibration aerosols to determine the influence of the crystallized oil on the position and shape of the WINS separation curve. Test results showed that neither the position nor the shape of the WINS separation curve was substantially influenced by the crystallization of the DOW 704 oil. No large particle bounce from the crystallized impaction surface was observed. In addition to these tests conducted with unloaded WINS filters, tests conducted with filters previously collected in Rubidoux, CA showed no substantial performance difference between crystallized WINS deposits versus non-crystallized deposits.

In conjunction with the laboratory tests of the crystallized DOW 704, EPA has also been reviewing alternative oils with properties such that the oil would not be expected to crystallize under typical operating conditions. Laboratory and field tests of dioctyl sebacate (DOS), possessing a freezing point of -48 C (-54 F), indicated that it represents a promising replacement oil at sampling sites which occasionally experience crystallization of the DOW 704 oil. Laboratory tests show that WINS separators equipped with DOS oil possess identical size-selective performance to those equipped with DOW 704 oil. Field sampling at RTP, NC , Rubidoux, CA, and Phoenix, AZ during spring and summer 2000 showed that mass concentrations obtained with DOS-equipped samplers were virtually identical to collocated samplers equipped with DOW 704 oil. For the total 45 collocated field tests conducted at the three field sites, the slope, intercept, and R^2 values for the DOS versus DOW 704 $PM_{2.5}$ concentrations were 0.995, -0.006 $\mu g/m^3$, and 0.999, respectively.

Chapter 3
Field Evaluations

The FRM was designed to measure $PM_{2.5}$ mass concentration at sites throughout the U.S. For this reason, robust field evaluations at a variety of geographic locations are necessary to confirm proper operation of all reference method hardware components. Due to the complexities in collecting and measuring particulate matter, there is no absolute knowledge of $PM_{2.5}$ in the atmosphere and, therefore, a reference method measurement cannot be directly compared to a true value. For this reason, this chapter presents field intercomparison studies that allow measurements made with reference method samplers to be compared with similar measurements made by other methods for $PM_{2.5}$. The three studies highlighted in this chapter demonstrate clearly that the FRM is capable of preventing coarse particle intrusion that can lead to an overestimation of $PM_{2.5}$ mass concentration.

National Particulate Matter Research Monitoring

As a result of issues arising from recent epidemiological observations, specifically PM associations with mortality and morbidity, EPA's Office of Research and Development (ORD) developed a research strategy which identified and prioritized the research needed to address the potential risk and uncertainties surrounding PM exposures and effects. This strategy identified the collection of daily PM size and composition data in major metropolitan areas as one of ORD's highest-priority research needs. In response to this need, ORD's National Exposure Research Laboratory (NERL) at RTP, NC established research monitoring platforms in residential neighborhoods in three U.S. metropolitan areas with widely differing PM size and composition characteristics: Phoenix, AZ; Baltimore, MD; and Fresno, CA. These monitoring platforms were operated with the cooperation and involvement of EPA's regional offices, the State and/or local environmental agency where the platform was located, and other interested parties such as industry representatives and university researchers. The operation of these platforms has now been discontinued as other programs are being put in place to provide similar information, namely the supersite and chemical speciation monitoring programs instituted by EPA's Office of Air and Radiation (OAR).

The Phoenix site allowed for a unique comparison of the URG cyclone and the WINS at a site where PM is composed of a large fraction of crustal material, or soil. Chow et al. (1991) reported that PM_{10} in Phoenix was 43 percent soil in previous studies. Daily, integrated 24-hour samples were collected on 37 mm diameter Teflon and quartz filters for fine particle mass and species measurements using a dual fine particle sequential sampler (DFPSS, URG, Chapel Hill, NC). The DFPSS has two separate channels, each with separate, Teflon-coated URG cyclone inlets through which samples are collected simultaneously at a flow rate of 16.7 Lpm. Teflon

filter samples were used for mass and energy dispersive x-ray fluorescence (EDXRF) analysis (elemental concentrations from Al to Pb). The elemental concentrations that were measured with EDXRF were used to construct soil concentrations by accounting for the oxides of the elements associated with soil (Al, Si, Ca, Fe, Ti; Malm et al., 1994). Elemental sulfur was assumed to be in the form of ammonium sulfate (Malm et al., 1994).

The $PM_{2.5}$ URG cyclone on the Phoenix DFPSS was replaced with a WINS separator on 12/20/96 to be more compatible with the $PM_{2.5}$ FRM prototype. As shown in Figure 11, the shape of the penetration curve for the WINS is sharper than that for the URG cyclone. Ammonium sulfate and soil were compared for the two time periods with the different separators. Ammonium sulfate particles typically have an aerodynamic diameter between 0.1 micrometer and 1 micrometer (John et al., 1990; Hering and Friedlander, 1982) and, therefore, no difference should be found for the two separators. On the other hand, a predominant fraction of soil particles have aerodynamic diameters larger than 2.5 micrometers. Therefore, soil concentrations measured with the WINS, which has a relatively sharper cut, should be lower than those measured by the sampler with the URG cyclone separator.

Both ammonium sulfate and soil concentrations can be compared for the URG cyclone (02/01/95 – 12/19/96) and the WINS (12/20/96 – 06/30/98) separators. Ammonium sulfate concentrations (Figure 15) showed no change in concentration, while soil concentrations (Figure 16) were markedly reduced with the WINS. The average ammonium sulfate percent concentrations measured by the sampler employing the URG cyclone and WINS separators were 17 and 19 percent, respectively. In contrast, the average percent soil concentrations measured by the sampler employing the URG cyclone and WINS separators were 21 and 12 percent, respectively.

These results are consistent with the bias calculations presented in the previous chapter. These bias calculations predicted that the URG cyclone would collect fine mode aerosol in a manner similar to the WINS, whereas a coarse mode aerosol would be positively biased toward the URG cyclone because of the significant tail of its penetration curve into the coarse mode. This comparison provides a "real-world" demonstration that the WINS impactor is capable of differentiating coarse mode aerosol more sharply than one type of cyclone separator, namely the URG $PM_{2.5}$ cyclone. Since this comparison was based on a single instrument over separate time periods, some of the decrease in the soil concentration may have been due to factors other than the separator performance; however, the change in concentration clearly occurred with the change in separator, and these results are consistent with those found in the 4-City Study, presented in the following section.

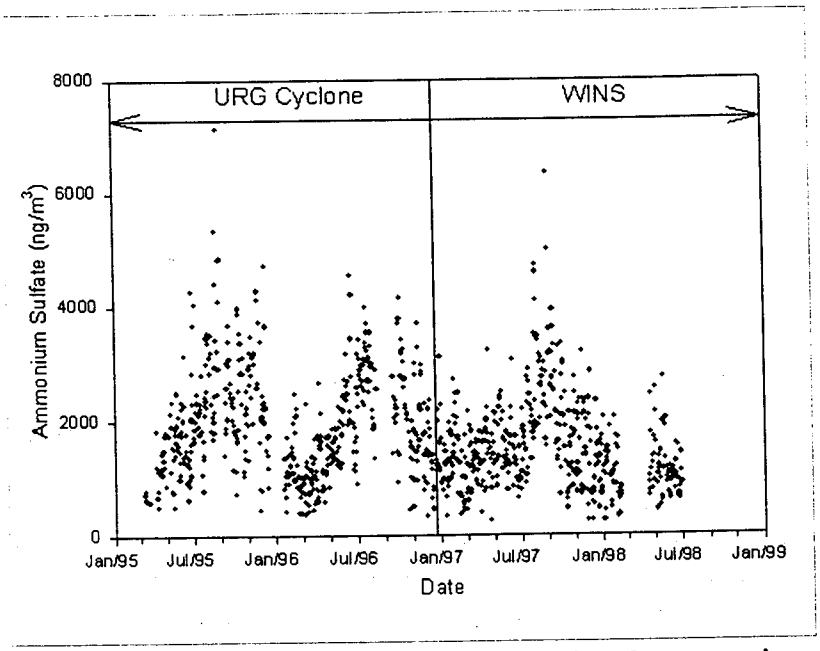

Figure 15. Comparison of Ammonium Sulfate Concentrations Measured Using the URG Cyclone and the WINS

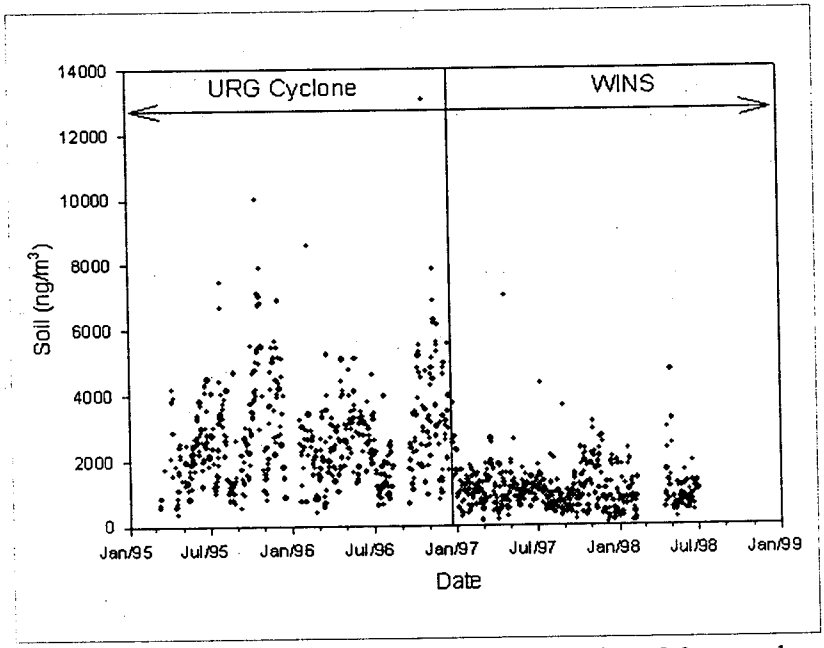

Figure 16. Comparison of Soil Concentrations Measured Using the URG Cyclone and the WINS

The 4-City Study

Four sites in the U.S., namely Philadelphia, PA; Phoenix, AZ; Rubidoux, CA; and RTP, NC, were identified as appropriate sites to challenge methods of fine aerosol collection, owing to individual differences in chemical atmospheres (Tolocka et al., 2000a). The prominent objective of the 4-City Study was to compare a variety of prototype chemical speciation samplers (Andersen-RAAS, URG-MASS, and Met One-SASS) and the FRM $PM_{2.5}$ samplers.

All samplers were unique with respect to their design and method of operation. The FRM sampler employed the hardware presented in the CFR as detailed in Chapter 1. Aspiration in the Andersen-RAAS speciation sampler was achieved using a FRM design inlet with the interior impaction section removed and operated at a flow rate of 54 Lpm, of which 6 Lpm were used for cooling purposes. The remaining 48 Lpm flow bifurcated into two identical AN 3.68 cyclones operated at 24 Lpm. The fine aerosol exiting each cyclone passed to a manifold from which the airflow was directed to two sample collection filters. During the 4-City Study, the Met One-SASS used five parallel Spiral separators to aspirate and separate the fine mode aerosol from the environment. The URG-MASS employed two standard $PM_{2.5}$ FRM hardware sampling trains, each operated at the FRM design flow rate of 16.7 Lpm specified in 40 CFR Part 50, Appendix L; therefore, the results from this sampler are not presented in this section. The performance curves of the AN 3.68 cyclone and the Spiral separators are presented in Figure 14.

This study was conducted during the period January through March, 1999. Chemical analysis results from the FRM and the other samplers operated at the four sites indicated that the criteria for varied chemical atmospheres was satisfied: Philadelphia, high sulfate; Phoenix, high carbon and crustal material; Rubidoux, high nitrate; and RTP, all low concentrations (Tolocka et al., 2000a). Note that the WINS wells were changed on a 5-day sampling schedule.

A summary of selected results from the 4-City Study, presented in Table 2, provides a comparison of $PM_{2.5}$ mass, sulfate, and crustal material concentrations measured by the FRM, the Andersen-RAAS, and the Met One-SASS (with the Spiral) at all four cities. Crustal components are defined as oxides of Si, Fe, and Ca. The mass of these oxides were estimated empirically based on atmospheric XRF measurements of these three elements. The mass, sulfate, and crustal material concentrations measured with the FRM agreed closely with those measured with the Andersen-RAAS speciation sampler in all cities. This result indicates that the WINS has separation characteristics similar to those of the AN 3.68 cyclone.

The mean sulfate concentration measured with the Met One-SASS was similar to the other methods in all cases, indicating proper aspiration and collection of the fine mode aerosol. In contrast, the mean mass concentration measured with the Met One-SASS was greater than that measured by the FRM at all sites. In RTP and in Philadelphia, this difference, although slight, may be attributed to an increased magnitude of coarse mode aerosol reaching the sample collection filter. This difference was markedly more pronounced at the Phoenix and Rubidoux sites, where the mean mass concentration was 2.0 and 1.4 times greater than for the FRM, respectively.

Table 2. Comparison between FRM and speciation samplers for $PM_{2.5}$ mass, sulfate, and crustal material concentrations observed in the Four-City Study (Jan – Mar '99).

RTP, (Mean ± Std. Dev), μg/m³			
Sampler Separator	**Mass**	**Sulfate**	**Crustal**
FRM WINS	10.8 ± 5.1	3.1 ± 1.6	0.26 ± 0.20
Andersen AN 3.68	10.7 ± 5.2	3.1 ± 1.7	0.25 ± 0.18
Met One Spiral	11.8 ± 5.9	3.2 ± 1.8	0.36 ± 0.29

Philadelphia, (Mean ± Std. Dev), μg/m³			
Sampler Separator	**Mass**	**Sulfate**	**Crustal**
FRM WINS	17.2 ± 8.8	3.9 ± 2.0	0.30 ± 0.19
Andersen AN 3.68	16.9 ± 8.8	3.6 ± 2.1	0.32 ± 0.2
Met One Spiral	17.7 ± 9.9	3.9 ± 2.1	0.54 ± 0.43

Phoenix, (Mean ± Std. Dev) μg/m³			
Sampler Separator	**Mass**	**Sulfate**	**Crustal**
FRM WINS	15.9 ± 7.1	0.85 ± 0.42	1.1 ± 0.58
Andersen AN 3.68	15.7 ± 6.8	0.75 ± 0.38	1.3 ± 0.61
Met One Spiral	31.9 ± 18.4	0.97 ± 0.42	4.8 ± 2.6

Rubidoux, (Mean ± Std. Dev) μg/m³			
Sampler Separator	**Mass**	**Sulfate**	**Crustal**
FRM WINS	26.0 ± 19.5	1.5 ± 1.5	0.89 ± 0.57
Andersen AN 3.68	25.6 ± 21.6	1.4 ± 1.6	0.95 ± 0.68
Met One Spiral	36.3 ± 25.5	1.5 ± 1.5	3.3 ± 3.0

A bias of this magnitude was not predicted based on the laboratory measured performance curve for the clean Spiral (Figure 14). Once again, the difference can be attributed to the coarse mode particle intrusion as evidenced in the mean concentration of crustal material observed on the sample collection filter. Because of these issues, Met One subsequently modified the separator design to a more traditional cyclone design (the SCC 2.141).

In summary, the $PM_{2.5}$ measured with the FRM was similar to that measured with the Andersen-RAAS sampler, indicating that the WINS and the AN 3.68 cyclone separate the aerosol in a similar manner. The intrusion of the coarse mode into the Met One-SASS sampler can be attributed to particle bounce and offers field confirmation that the WINS is capable of preventing coarse particle bounce in the presence of elevated concentrations of coarse mode aerosol.

The Atlanta-99 "Supersite" Study

The Atlanta-99 "Supersite" Study, conducted in August 1999, was operated by the Southern Oxidants Study program under an agreement between NERL and Georgia Institute of Technology. This study was conducted in a manner similar to the 4-City Study, but it was greatly expanded to include emerging and state-of-the-art samplers. An alternate-day sampling schedule was chosen with 24-hour measurements commencing at 0700 AM and ending at 0700 AM of the following day. In all, 15 sampling periods were successfully accomplished. WINS wells were changed every 5 sample days as recommended by the Quality Assurance Guidance Document (U.S. EPA, 1998b).

Reference method measurements were once again compared with other methods for measuring fine mode aerosol. Design corrections were made in the Met One sampler by substituting the SCC 2.141 $PM_{2.5}$ cyclone in place of the earlier Spiral separator. Two other samplers, namely the R&P dichotomous sampler employing a virtual impactor and the R&P speciation sampler employing a conventional greased impactor, were collocated with the other speciation samplers (Andersen-RAAS, Met One-SASS, and URG-MASS). The characteristic performance curves for each of the $PM_{2.5}$ separators can be found in Figure 14 for all of the samplers, excluding the R&P greased conventional impactor. The penetration curve for the R&P impactor was not available at the time this report was being prepared.

A summary of selected results, presented in Figures 17, 18, and 19, shows method comparisons of mass, sulfate, and crustal material concentrations, respectively. Good agreement was observed for all methods in measuring sulfate concentrations (Figure 18) indicating that they collect fine mode aerosol in a similar manner. As an indicator of coarse mode aerosol collection, measured crustal material concentrations, shown in Figure 19, were similar for all samplers, excluding the R&P speciation sampler. Because this sampler was positively biased, it is likely that the greased conventional impactor suffered from particle bounce. The mass concentration, shown in Figure 17, measured by the FRM and the Andersen was very similar. The Met One-SASS showed very slightly elevated values of mass concentration when compared with the FRM and the Andersen-RAAS. The URG-MASS, which employs hardware similar to that used in the FRM, was also slightly elevated. This result could not be explained by the sulfate or the crustal material concentrations, which were similar to those for the FRM.

In brief, this study demonstrated that FRM provides measurements of $PM_{2.5}$ similar to those for several other methods of fine particle collection. Most importantly to this presentation, this study demonstrated again that the WINS is capable of preventing coarse particle intrusion that can lead to an overestimate of $PM_{2.5}$ mass concentration. Furthermore, the position and shape of the WINS provides $PM_{2.5}$ measurements that are comparable to separators relying on other techniques of inertial separation.

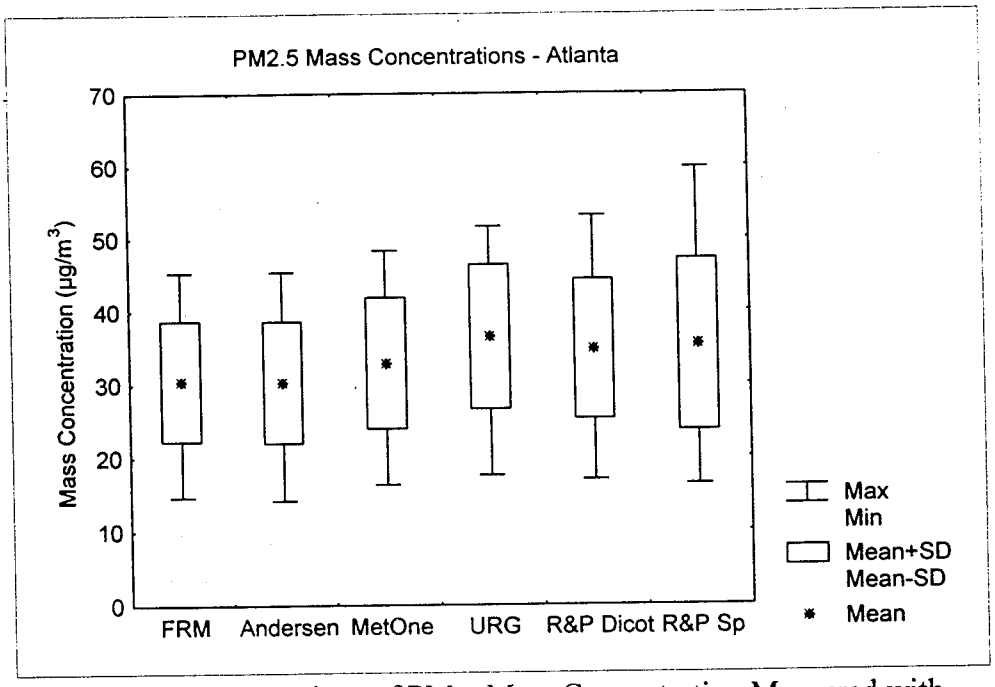

Figure 17. Comparison of $PM_{2.5}$ Mass Concentration Measured with Various Samplers in Atlanta During August 1999

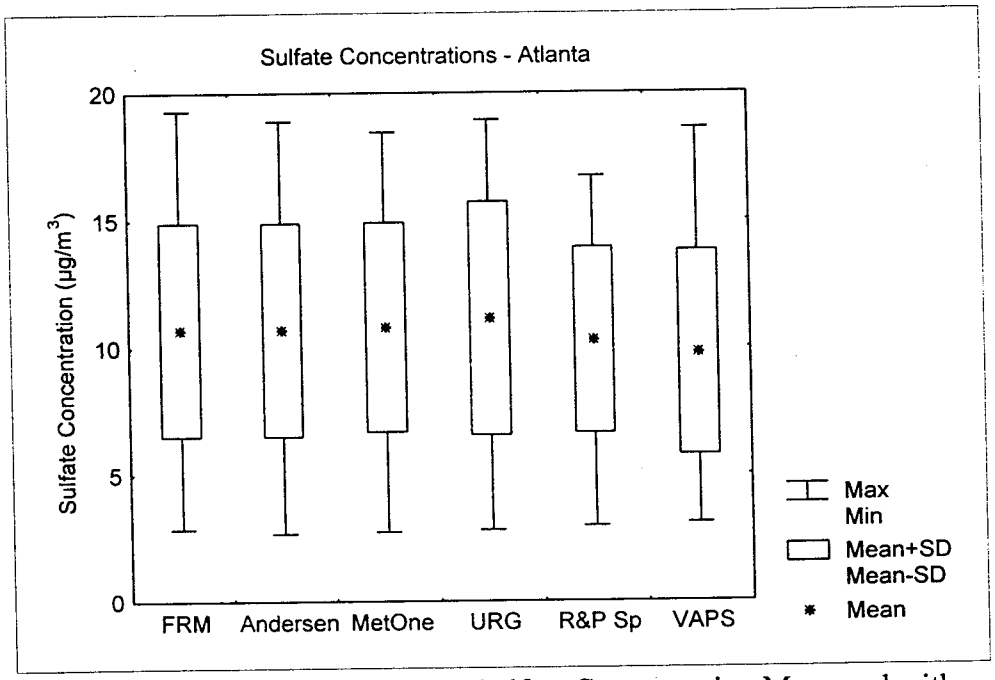

Figure 18. Comparison of $PM_{2.5}$ Sulfate Concentration Measured with Various Samplers in Atlanta During August 1999

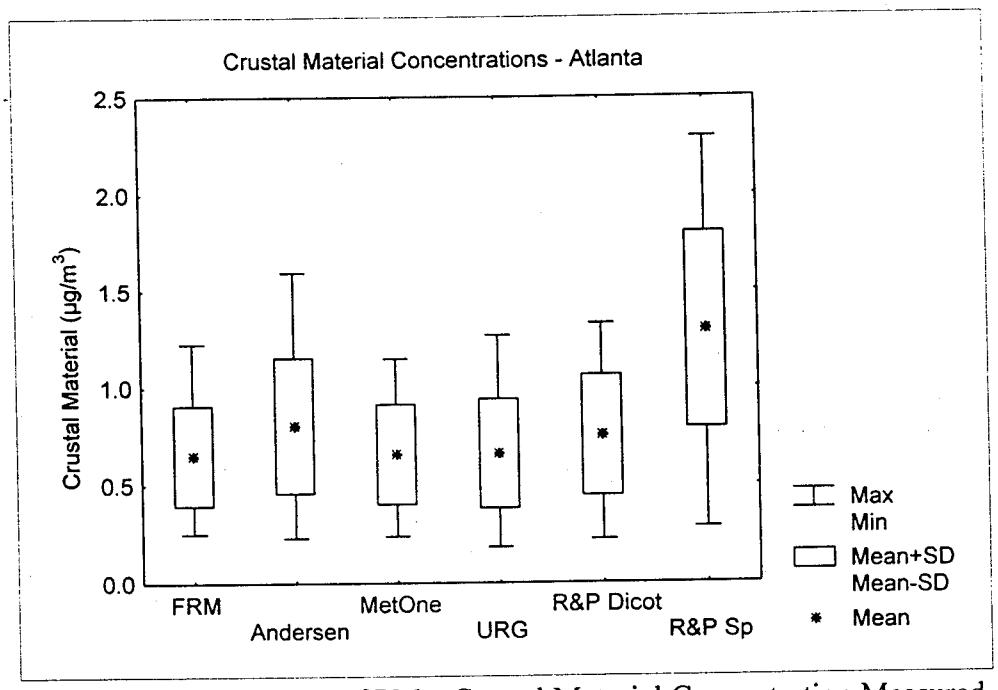

Figure 19. Comparison of $PM_{2.5}$ Crustal Material Concentration Measured with Various Samplers in Atlanta During August 1999

Future Evaluations

In addition to the results of these focused field studies, additional field evaluations of the $PM_{2.5}$ reference method are ongoing. As part of EPA's continuing commitment to improve particulate reference methods, this information will be released once the studies are completed and the resulting data is fully validated and interpreted. EPA will also continue to solicit feedback from the various site operators regarding the reference method itself as well as problems associated with designated FRM sampler designs. Any problems noted will be evaluated and appropriate research will be conducted in order to properly address these concerns. Results of this research will be collated and disseminated to state and local agencies with particular emphasis on improving procedures to optimize the quality of compliance data.

Future studies will also be conducted to both ascertain information regarding field performance of the current fine particle FRM as well as to assist in the development of future aerosol reference methods. Of specific concern are issues of accuracy and precision of PM networks as well as analysis of specific and varied aerosol chemical components. The performance of the FRM will be evaluated under network conditions with emphasis placed on characterizing the method under sampling conditions which vary seasonally as well as geographically.

Chapter 4
Conclusions

This report addresses concerns regarding Section 6102(e) of the Transportation Equity Act for the 21st Century. Extensive laboratory and field tests have established that the FRM effectively differentiates between particles larger and smaller than 2.5 micrometers in diameter. Extensive laboratory tests, conducted by the U.S. EPA and independent researchers, demonstrated that the reference method primary size separation hardware, the WINS impactor, provides selection of particles less than 2.5 micrometers in diameter. Furthermore, these evaluations showed conclusively the ability of the WINS to eliminate coarse particle intrusion when clean and after becoming dirty during routine field use. Three intensive field studies corroborated the laboratory findings.

The laboratory evaluations of the FRM presented in Chapter 2 support the following conclusions:

- Evaluations by U.S. EPA and independent researchers have shown that the penetration curve of the WINS impactor has a 50-percent cutpoint of 2.5 ± 0.1 micrometers when clean, and that the penetration curve may be described as "sharp" in comparison to other, existing separators.

- The U.S. EPA's laboratory loading tests demonstrated that the design of the WINS overcomes the particle bounce problem common to conventional impactors. These tests showed that the impactor's penetration curve tends to shift to slightly smaller particle sizes with increased loading. The 50-percent cutpoint of the WINS, which is approximately 2.5 micrometers when clean, was determined to be 2.2 micrometers after several days of exposure to extremely high concentrations of coarse Arizona test dust. Thus, when heavily loaded, the WINS becomes slightly more efficient in rejecting particles that are larger than 2.5 micrometers in diameter.

- The U.S. EPA's postsampling evaluations of the WINS after 5 days of operation at various locations throughout the U.S. confirmed the laboratory assessment of the WINS performance after extended operation.

- Independent research into the effects of loading, both in the laboratory and in the field, corroborated the U.S. EPA's findings that the design of the WINS eliminates particle bounce and, hence, coarse particle intrusion when clean and after extended periods of operation.

- The U.S. EPA's laboratory tests of crystallized DOW 704 oil showed that the oil represents an effective impaction substrate even in the crystallized state. Thus, the crystallization phenomenon occasionally observed in the field is not predicted to adversely affect the performance of the WINS separator nor alter the $PM_{2.5}$ mass concentration measured during the crystallization event.

Field evaluations of the FRM offer "real-world" confirmation of laboratory tests results. These tests have shown that the reference method for $PM_{2.5}$ provides aspiration, separation, and transport of particles that is as good as - or, in some cases, better than - other methods for fine particle collection. The following specific conclusions are supported by the field tests presented in Chapter 3:

- Field results from the National Monitoring Platform operated in Phoenix, AZ, indicated that the WINS impactor provided a sharper separation of particles greater than 2.5 micrometers than one type of commercially available cyclonic separation device.

- The 4-City Study fine particulate method intercomparison study demonstrated that the reference method was able to measure $PM_{2.5}$ in a manner similar to a system relying on a cyclone-type separator. This study also verified the ability of the WINS to prevent coarse particle intrusion.

- The Atlanta-99 "Supersite" Study provided additional method intercomparisons that verified the ability of the FRM to sharply separate $PM_{2.5}$ from the atmosphere in a manner similar to other methods of fine particle collection and to prevent particles substantially larger than 2.5 micrometers from passing to the sample collection filter.

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15. Supplementary Notes

16. Abstract

This report is submitted in response to Section 6102(e) of the Transportation Equity Act for the 21st Century, which states:

> "The Administrator shall conduct a field study of the ability of the $PM_{2.5}$ Federal Reference Method to differentiate those particles that are larger than 2.5 micrograms [sic] in diameter. This study shall be completed and provided to the Committee on Commerce of the House of Representatives and the Committee on Environment and Public Works of the United States Senate no later than 2 years from the date of enactment of this Act."

While the concern about the ability of the Federal Reference Method to function as asserted is understandable, extensive data from multiple laboratory and field tests have established that the Federal Reference Method effectively differentiates between particles larger and smaller than 2.5 micrometers in aerodynamic diameter.

Extensive laboratory tests, conducted by the U.S. EPA and independent researchers, demonstrated that the reference method primary size separation hardware, the WINS impactor, provides selection of particles less than 2.5 micrometers in aerodynamic diameter. Furthermore, these evaluations showed conclusively the ability of the WINS to eliminate coarse particle intrusion when clean and after becoming dirty during routine field use. Three intensive field studies corroborated the laboratory findings.

Additional field studies are ongoing, in which existing and new or potentially superceding fractionation technologies are being challenged against a variety of ambient environmental conditions in an effort to more fully characterize sampler behavior.

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