LESSON 4

Introduction to $PM_{2.5}$ and PM_{10} Monitoring

Goal

To introduce you to basic concepts and principles of $PM_{2.5}$ and PM_{10} monitoring.

Objectives

After completion of this lesson you should be able to:

1. describe the components of a PM sampler.
2. define differences, similarities, and uses of Federal Reference Methods and Equivalent Methods.
3. describe the three types of deployable PM sampling methodologies and the siting strategies appropriate to those methodologies.
4. list measurement method uncertainties and evaluate them in the context of spatial and temporal variations imposed by a limited number of sampling sites and sporadic sampling frequencies.
5. describe characteristics and uses of transport, background, and special purpose monitors.

Reading Assignment Topics

- Components of a particulate sampler
- Types of PM Samplers
- Types of PM Samples
- Siting Strategies

Procedure

1. Read sections 2.4.2 through 2.4.6 (pages 2-24 through 2-28) of *Guidance for the Network Design and Optimum Site Exposure for $PM_{2.5}$ and PM_{10}.*
2. Read the excerpts from 40 CFR 50, Appendix L located on pages 26 through 39 in this manual.

3. Read the excerpts from *Guidelines for Speciated Particulate Monitoring* located in pages 40 through 64 in this manual
4. Complete the review exercise.
5. Check your answers against the answer key in Appendix A.
6. Review the pages from any material you missed.
7. Continue to Lesson 5

Excerpts of 40 CFR 50 Appendix L

Appendix L – Reference Method For the Determination of Fine Particulate Matter as $PM_{2.5}$ in the Atmosphere

1.0 *Applicability.*

1.1 This method provides for the measurement of the mass concentration of fine particulate matter having an aerodynamic diameter less than or equal to a nominal 2.5 micrometers ($PM_{2.5}$) in ambient air over a 24-hour period for purposes of determining whether the primary and secondary national ambient air quality standards for fine particulate matter specified in § 50.6 of this part are met. The measurement process is considered to be nondestructive, and the $PM_{2.5}$ sample obtained can be subjected to subsequent physical or chemical analyses. Quality assessment procedures are provided in part 58, Appendix A of this chapter and quality assurance guidance are provided in references 1, 2, and 3 in section 13.0 of this appendix.

1.2 This method will be considered a reference method for purposes of part 58 of this chapter only if:

(a) The associated sampler meets the requirements specified in this appendix and the applicable requirements in part 53 of this chapter, and

(b) The method and associated sampler have been designated as a reference method in accordance with part 53 of this chapter.

$PM_{2.5}$ samplers that meet nearly all specifications set forth in this method but have minor deviations and/or modifications of the reference method sampler will be designated as "Class 1" equivalent methods for $PM_{2.5}$ in accordance with part 53 of this chapter.

2.0 *Principle.*

2.1 An electrically powered air sampler draws ambient air at a constant volumetric flow rate into a specially shaped inlet and through an inertial particle size separator (impactor) where the suspended particulate matter in the $PM_{2.5}$ size range is separated for collection on a polytetrafluoroethylene (PTFE) filter over the specified sampling period. The air sampler and other aspects of this reference method are specified either explicitly in this appendix or generally with reference to other applicable regulations or quality assurance guidance.

2.2 Each filter is weighed (after moisture and temperature conditioning) before and after sample collection to determine the net gain due to collected $PM_{2.5}$. The total volume of air sampled is determined by the sampler from the measured flow rate at actual ambient temperature and pressure and the sampling time. The mass concentration of $PM_{2.5}$ in the ambient air is computed as the total mass of collected particles in the $PM_{2.5}$ size range divided by the actual volume of air sampled, and is expressed in micrograms per cubic meter of air ($\mu g/m^3$). 3.0 *$PM_{2.5}$ Measurement Range*

3.1 *Lower concentration limit.* The lower detection limit of the mass concentration measurement range is estimated to be approximately 2 $\mu g/m^3$, based on noted mass changes in field blanks in conjunction with the 24 m^3 nominal total air sample volume specified for the 24 hour sample.

3.2 *Upper concentration limit.* The upper limit of the mass concentration range is determined by the filter mass loading beyond which the sampler can no longer maintain the operating flow rate within specified limits due to increased pressure drop across the loaded filter. This upper limit cannot be specified precisely because it is a complex function of the ambient particle size distribution and type, humidity, the individual filter used, the capacity of the sampler flow rate control system, and perhaps other factors. Nevertheless, all samplers are estimated to be capable of measuring 24-hour $PM_{2.5}$ mass concentrations of at least 200 $\mu g/m^3$ while maintaining the operating flow rate within the specified limits.

3.3 *Sample period* The required sample period for $PM_{2.5}$ concentration measurements by this method shall be 1,380 to 1500 minutes (23 to 25 hours). However, when a sample period is less than 1,380 minutes, the measured concentration (as determined by the collected $PM_{2.5}$ mass divided by the actual sampled air volume), multiplied by the actual number of minutes in the sample period and divided by 1,440, may be used as if it were a valid concentration measurement for the specific purpose of determining a violation of the NAAQS. This value assumes that the $PM_{2.5}$ concentration is zero for the remaining portion of the sample period and therefore represents the minimum concentration that could have been measured for the full 24 hour sample period. Accordingly, if the value thus calculated is high enough to be an exceedance, such an exceedance would be a valid exceedance for the sample period. When reported to AIRS, this data value should receive a special code to identify it as not to be commingled with normal concentration measurements or used for other purposes.

4.0 *Accuracy.*

4.1 Because the size and volatility of the particles making up ambient particulate matter vary over a wide range and the mass concentration of particles varies with particle size, it is difficult to define the accuracy of $PM_{2.5}$ measurements in an absolute sense. The accuracy of $PM_{2.5}$ measurements is therefore defined in a relative sense, referenced to measurements provided by this reference method. Accordingly, accuracy shall be defined as the degree of agreement between a subject field $PM_{2.5}$ sampler and a collocated $PM_{2.5}$ reference method audit sampler operating simultaneously at the monitoring site location of the subject sampler and includes both random (precision) and systematic (bias) errors. The requirements for this field sampler audit procedure are set forth in part 58, Appendix A of this chapter.

4.2 Measurement system bias. Results of collocated measurements where the duplicate sampler is a reference method sampler are used to assess a portion of the measurement system bias according to the schedule and procedure specified in part 58, Appendix A of this chapter.

4.3 Audits with reference method samplers to determine system accuracy and bias. According to the schedule and procedure specified in part 58, Appendix A of this chapter, a reference method sampler is required to be located at each of selected $PM_{2.5}$ SLAMS sites as a duplicate sampler. The results from the primary sampler and the duplicate reference method sampler are used to calculate accuracy of the primary sampler on a quarterly basis, bias of the primary sampler on an annual basis, and bias of a single reporting organization on an annual basis. Reference 2 in section 13.0 of this appendix provides additional information and guidance on these reference method audits.

4.4 Flow rate accuracy and bias. Part 58, Appendix A of this chapter requires that the flow rate accuracy and bias of individual $PM_{2.5}$ samplers used in SLAMS monitoring networks be assessed periodically via audits of each sampler's operational flow rate. In addition, part 58, Appendix A of this chapter requires that flow rate bias for each reference and equivalent method operated by each reporting organization be assessed quarterly and annually. Reference 2 in section 13.0 of this appendix provides additional information and guidance on flow rate accuracy audits and calculations for accuracy and bias.

5.0 *Precision.* A data quality objective of 10 percent coefficient of variation or better has been established for the operational precision of $PM_{2.5}$ monitoring data.

5.1 Tests to establish initial operational precision for each reference method sampler are specified as a part of the requirements for designation as a reference method under § 53.58 of this chapter.

5.2 Measurement System Precision. Collocated sampler results, where the duplicate sampler is not a reference method

sampler but is a sampler of the same designated method as the primary sampler, are used to assess measurement system precision according to the schedule and procedure specified in part 58, Appendix A of this chapter. Part 58 Appendix A of this chapter requires that the collocated sampler measurements be used to calculate quarterly and annual precision estimates for each primary sampler and for each designated method employed by each reporting organization. Reference 2 in section 13.0 of this appendix provides additional information and guidance on this requirement.

6.0 *Filter for $PM_{2.5}$ Sample Collection.* Any filter manufacturer or vendor who sells or offers to sell filters specifically identified for use with this $PM_{2.5}$ reference method shall certify that the required number of filters from each lot of filters offered for sale as such have been tested as specified in this section 6.0 and meet all of the following design and performance specifications.

6.1 *Size.* Circular, 46.2 mm diameter ±0.25 mm.

6.2 *Medium.* Polytetrafluoroethylene (PTFE Teflon), with integral support ring.

6.3 *Support ring.* Polymethylpentene (PMP) or equivalent inert material, 0.38 ±0.04 mm thick, outer diameter 46.2 mm ± 0.25 mm, and width of 3.68 mm (±0.00, -0.51 mm).

6.4 *Pore size.* 2 mm as measured by ASTM F 316-94.

6.5 *Filter thickness.* 30 to 50 μm.

6.6 *Maximum pressure drop (clean filter).* 30 cm H_2O column @ 16.67 L/min clean air flow.

6.7 *Maximum moisture pickup.* Not more than 10 g weight increase after 24 hour exposure to air of 40 percent relative humidity, relative to weight after 24-hour exposure to air of 35 percent relative humidity.

6.8 *Collection efficiency.* Greater than 99.7 percent, as measured by the DOP test (ASTM D 2986-91) with 0.3 km particles at the sampler's operating face velocity.

6.9 *Filter weight stability.* Filter weight loss shall be less than 20 μg, as measured in each of the following two tests specified in sections 6.9.1 and 6.9.2 of this appendix. The following conditions apply to both of these tests: Filter weight loss shall be the average difference between the initial and the final filter weights of a random sample of test filters selected from each lot prior to sale. The number of filters tested shall be not leas than 0.1 percent of the filters of each manufacturing lot, or 10 filters, whichever is greater. The filter shall be weighed under laboratory conditions and shall have had no air sample passed through them, i.e., filter blanks. Each test procedure must include initial conditioning and weighing, the test, and final conditioning and weighing. Conditioning and weighing shall be in accordance with sections 8.0 through 8.2 of this appendix and general guidance provided in reference 2 of section 13.0 of this appendix.

6.9.1 *Test for loose, surface particle contamination.* After the initial weighing, install each test filter, in turn, in a filter cassette (Figures L-27, L –28, and L-29 of this appendix) and drop the cassette from a height of 25 cm to a flat hard surface, such as a particle-free wood bench Repeat two times, for a total of three drop tests for each test filter. Remove the test filter from the cassette and weigh the filter. The average change in weight must be less than 20 μg.

6.9.2 *Test for temperature stability.* After weighing each filter, place the test filters in a drying oven set at 40 °C : ±2 °C for no less than 48 hours. Remove, condition, and reweigh each test filter. The average change in weight must be less than 20 μg.

6.10 *Alkalinity.* Less than 25 microequivalents/gram of filter, as measured by the guidance given in reference 2 in section 13.0 of this appendix.

6.11 *Supplemental requirements.* Although not required for determination of $PM_{2.5}$ mass concentration under this reference method, additional specifications for the filter must be developed by users who intend to subject $PM_{2.5}$ filter samples to subsequent chemical analysis. These supplemental specifications include background chemical contamination of the filter and any other filter parameters that may be required by the method of chemical analysis. All such supplemental filter specifications must be compatible with and secondary to the primary filter specifications given in this section 6.0 of this appendix.

7.0 *$PM_{2.5}$ Sampler.*

7.1 *Configuration.* The sampler shall consist of a sample air inlet, downtube, particle size separator (impactor), filter holder assembly, air pump and flow rate control system, flow rate measurement device, ambient and filter temperature monitoring system, barometric pressure measurement system, timer, outdoor environmental enclosure, and suitable mechanical, electrical, or electronic control capability to meet or exceed the design and functional performance as specified in this section 7.0 of this appendix. The performance specifications require that the sampler:

(a) Provide automatic control of sample volumetric flow rate and other operational parameters.

(b) Monitor these operational parameters as well as ambient temperature and pressure.

(c) Provide this information to the sampler operator at the end of each sample period in digital form, as specified in Table L-1 of section 7.4.19 of this appendix.

7.2 *Nature of specifications.* The $PM_{2.5}$ sampler is specified by a combination of design and performance requirements. The sample inlet, downtube, particle size discriminator, filter cassette, and the internal configuration of the filth holder assembly are specified explicitly by design figures and associated mechanical dimensions, tolerances, materials, surface finishes, assembly instructions, and other necessary specifications. All other aspects of the sampler are specified by required operational function and performance, and the design of these diner aspects (including the design of the lower portion of the filter holder assembly) is optional, subject to acceptable operational performance. Test procedures to demonstrate compliance with both the design and performance requirements are set forth in subpart E of part 53 of this chapter.

7.3 *Design specifications.* Except as indicated in this section 7.3 of this appendix, time components must be manufactured or reproduced exactly as specified, in an ISO 9001-registered facility, with registration initially approved and subsequently maintained during the period of manufacture. See § 53.1(t) of this chapter for the definition of an ISO-registered facility. Minor modifications or variances to one or more components that clearly would not affect the aerodynamic performance of the inlet, downtube, impactor, or filter cassette will be considered for specific approval. Any such proposed modifications shall be described and submitted to the EPA for specific individual acceptability either as part of a reference or equivalent method application under part 53 of this chapter or in writing in advance of such an intended application under part 53 of this chapter.

7.3.1 *Sample inlet assembly.* The sample inlet assembly, consisting of the inlet, downtube, and impactor shed be configured and assembled as indicated in Figure L-l of this appendix and shall meet all associated requirements. A portion of this assembly shall also be subject to the maximum overall sampler leak rate specification under section 7.4.6 of this appendix.

7.3.2 *Inlet.* The sample inlet shall be fabricated as indicated in Figures L-2

through L-18 of this appendix and soul meet all associated requirements.

7.3.3 *Downtube.* The downtube shall be fabricated as indicated in Figure I -I9 of this appendix and shall meet all associated requirements.

7.3.4 *Impactor.*

7.3.4.1 The impactor (particle size separator) shall be fabricated as indicated in Figures L-20 through L-24 of this appendix and shall meet all associated requirements. Following the manufacture and finishing of each upper impactor housing (Figure L-21 of this appendix), the dimension of the impaction jet must be verified by the manufacturer using Class ZZ go/no-go plug gauges that are traceable to NIST.

7.3.4.2 Impactor filter specifications:

(a) Size. Circular, 35 to 37 mm diameter.

(b) Medium. Borosilicate glass fiber, without binder.

(c) Pore size. 1 to 1.5 micrometer, as measured by ASTM F 316-80.

(d) Thickness. 300 to 500 micrometers.

7.3.4.3 Impactor oil specifications:

(a) Composition. Tetramethyltetraphenyltrisiloxane, single-compound diffusion oil.

(b) Vapor pressure. Maximum 2 x 10^{-8} mm Hg at 25 °C.

(c) Viscosity. 36 to 40 centistokes at 25 °C.

(d) Density. 1.06 to 1.07 g/cm3 at 25 °C.

(e) Quantity. 1 mL ±0.1 mL

7.3.5 *Filter holder assembly.* The sampler shall have a sample filth holder assembly to adapt and seal to the down tube and to hold and seal the specified filter, under section 6.0 of this appendix, in the sample air stream in a horizontal position below the downtube such that the sample air stream downward through the filter at a uniform face velocity. The upper portion of this assembly shall be fabricated as indicated in Figures L-25 and L-26 of this appendix and shall accept and seal with the filter cassette, which shall be fabricated as indicated in Figures L-27 through L-29 of this appendix.

(a) The lower portion of the filter holder assembly shall be of a design and construction that:

(1) Mates with the upper portion of the assembly to complete the filter holder assembly,

(2) Completes both the external air seal and the internal filter cassette seal such that all seals are reliable over repeated filter changing, and

(3) Facilitates repeated changing of the filter cassette by the sampler operator.

(b) Leak-test performance requirements for the filter holder assembly are included in section 7.4.6 of this appendix.

(c) If additional or multiple filters are stored in the sampler as part of an automatic sequential sample capability, all such filters, unless they are currently and directly installed in a sampling channel or sampling configuration (either active or inactive), shall be covered or (preferably) sealed in such a way as to:

(1) Preclude significant exposure of the filter to possible contamination or accumulation of dust, insects, or other material that may be present in the ambient air, sampler, or sampler ventilation air during storage periods either before or after sampling; and

(2) To minimize loss of volatile or semi-volatile PM sample components during storage of the filter following the sample period.

7.3.6 *Flow rate measurement adapter.* A flow rate measurement adapter as specified in Figure L30 of this appendix shall be furnished with each sampler.

7.3.7 *Surface finish.* All internal surfaces exposed to sample air prior to the filter shall be treated electrolytically in a sulfuric acid bath to produce a clear, uniform anodized surface finish of not less than 1000 mg/ft^2 (1.08 mg/cm^2) in accordance with military standard specification (mil. spec.) 8625F, Type II, Class I in reference 4 of section 13.0 of this appendix. This anodic surface coating shall not be dyed or pigmented. Following anodization, the surface shall be sealed by immersion in boiling deionized water for not less than 15 minutes. Section 53.51(d)(2) of this chapter should also be consulted.

7.3.8 Sampling height. The sampler shall be equipped with legs, a stand, or other means to maintain the sampler in a stable, upright position and such that the center of the sample air entrance to the inlet, during sample collection, is maintained in a horizontal plane and is 2.0 ±0.2 meters above the floor or other horizontal supporting surface. Suitable bolt holes, brackets, tie-downs, or other means should be provided to faciliteste mechanically securing the sample to the supporting surface to prevent toppling of the sampler due to wind.

7.4 *Performance specifications.*

7.4.1 *Sample flow rate* Proper operation of the impactor requires that specific air velocities be maintained through the device. Therefore, the design sample air flow rate through the inlet shall be 16.67 L/min (1.000 m^3/hour) measured as actual volumetric flow rate at the temperature and pressure of the sample air entering the inlet.

7.4.2 *Sample airflow rate control system.* The sampler shall have a sample air flow rate control system which shall be capable of providing a sample air volumetric flow rate within the specified range, under section 7.4.1 of this appendix, for the specified filter. under section 6.0 of this appendix, at any atmospheric conditions specified, under section 7.4.7 of this at a filter pressure drop equal to that of a clean filter plus up to 75 cm water column (55 mm Hg). and over the specified range of supply line voltage. under section 7.4.15.1 of this appendix. This flow control system shall allow for operator adjustment of the operational flow rate of the sampler over a range of at least ±15 percent of the flow rate specified in section 7.4.1 of this appendix.

7.4.3 *Sample flow* rate *regulation.* The sample flow rate shall be regulated such that for the specified filter, under section 6.0 of this appendix, at any atmospheric conditions specified, under section 7.4.7 of this appendix, at a filter pressure drop equal to that of a clean filter plus up to 75 cm water column (55 mm Hg), and over the specified range of supply line voltage, under section 7.4.15.1 of this appendix, the flow rate is regulated as follows:

7.4.3.1 The volumetric flow rate, measure or averaged over intervals of not more than 5 minutes over a 24-hour period, shall not vary more than ±5 percent from the specified 16.67 L/min flow rate over the entire sample period.

7.4.3.2 The coefficient of variation (sampl standard deviation divided by the mean) of the flow rate, measured over a 24-hour period, shall not be greater than 2 percent.

7.4.3.3 The amplitude of short-term flow rate pulsations, such as may originate from some types of vacuum pumps, shall be attenuated such that they do not cause significant flow measurement error or affect the collection of particles on the particle collection filter.

7.4.4 *Flow rate cut off* The sampler's sample air flow rate control system shall terminate sample collection and stop all sample flow for the remainder of the sample period in the event that the sample flow rate deviates by more than 10 percent from the sampler design flow rate specified in sectior 7.4.1 of this appendix for more than 60 seconds. However, this sampler cut-off provision shall not apply during periods wh the sampler is inoperative due to a temporar power interruption, and the elapsed time of

the inoperative period shall not be included in the total sample time measured and reported by the sampler, under section 7.4.13 of this appendix.

7.4.5 *Flow* rate *measurement.*

7.4.5.1 The sampler shawl provide a means to measure and indicate the instantaneous sample air flow rate, which shall be measured as volumetric flow rate at the temperature and pressure of the sample air entering the inlet, with an accuracy of ±2 percent. The measured flow rate shall be available for display to the sampler operator at any time in either sampling or standby modes, and the measurement shall be updated at least even 30 seconds. The sampler shall also provide a simple means by which the sampler operator can manually start the sample flow temporarily during nonsampling modes of operation, for the purpose of checking the sample flow rate or the flow rate measurement system.

7.4.5.2 During each sample period, the sampler's flow rate measurement system shall automatically monitor the sample volumetric flow rate, obtaining flow rate measurements at intervals of not greater than 30 seconds.

(a) Using these interval flow rate measurements, the sampler shall determine or calculate the following flow-related parameters, scaled in the specified engineering units:

(1) The instantaneous or interval-average flow rate, in L/min.

(2) The value of the average sample flow rate for the sample period, in L/min.

(3) The value of the coefficient of variation (sample standard deviation divided by the average) of the sample flow rate for the sample period, in percent.

(4) The occurrence of any time interval during the sample period in which the measured sample flow rate exceeds a range of ±5 percent of the average flow rate for the sample period for more than 5 minutes, in which case a warning flag indicator shall be set.

(5) The value of the integrated total sample volume for the sample period, in m^3.

(b) Determination or calculation of these values shall properly exclude periods when the sampler is inoperative due to temporal interruption of electrical power, under section 7.4.13 of this appendix, or flow rate cut off, under section 7.4.4 of this appendix.

(c) These parameters shall be accessible to the sampler operator as specified in Table L–1of section 7.4.19 of this appendix. In addition, it is strongly encouraged that the flow rate for each 5 minute interval during the sample period be available to the operator following the end of the sample period.

7.4.6 *Leak test capability.*

7.4.6.1 *External leakage.* The sampler shall include an external air leak-test capability consisting of components, accessory hardware, operator interface controls, a written procedure in the associated Operation/Instruction Manual, under section 7.4.18 of this appendix, and all other necessary functioned capability to permit and faciliteste the sampler operator to conveniently carry out a leak test of the sampler at a field monitoring site without additional equipment. The sampler components to be subjected to this leak test include all components and their interconnections in which external air leakage would or could cause an error in the sampler's measurement of the total volume of sample air that passes through the sample filter.

(a) The suggested technique for the operator to use for this leak test is as follows:

(1) Remove the sampler inlet and installs the flow rate measurement adapter supplied with the sampler, under section 7.3.6 of this appendix.

(2) Close the valve on the flow rate measurement adapter and use the sampler air pump to draw a partial vacuum in the sampler, including (at least) the impactor, filter holder assembly (filter in place), flow measurement device, and interconnections between these devices, of at least 55 mm Hg (75 cm water column), measured at a location downstream of the filter header assembly.

(3) Plug the flow system downstream of these components to isolate the components under vacuum from the pump, such as with a built-in valve.

(4) Stop the pump.

(5) Measure the trapped vacuum in the sampler with a built-in Erasure measuring device.

(6) (i) Measure the vacuum in the sampler with the built-in pressure measuring device again at a later time at least 10 minutes after the first pressure measurement.

(ii) **Caution**: Following completion of the test the adaptor valve should be opened slowly to limit the flow rate of air into the sampler. Excessive air flow rate may blow oil out of the impactor.

(7) Upon completion of the test, open the adaptor valve, remove the adaptor and plugs, and restore the sampler to the normal operating configuration.

(b) The associated leak test procedure shall require that for successful passage of this test, the difference between the two pressure measurements shall not be greater then the number of mm of Hg specified for the sampler by the manufacturer, based on the actual interned volume of the sampler, that indicates a leak of less than 80 mL/min.

(c) Variations of the suggested technique or an alternative external leak test technique may be required for samplers whose design or configuration would make the suggested technique impossible or impractical. The specific proposed external leak test procedure, or particularly an alternative leak test technique, proposed for a particular candidate sampler may be described and submitted to the EPA for specific individual acceptability either as part of a reference or equivalent method application under part 53 of this chapter or in writing in advance of such an intended application under part 53 of this chapter.

7.4.6.2 *Internal filter bypass leakage.* The sampler shall include an internal, filth bypass leak-check capability consisting of components, accessory hardware, operator interface controls, a written procedure in the Operation/Instruction Manual, and all other necessary functional capability to permit and faciliteste the sampler operator to conveniently carry out a test for internal filter bypass leakage in the sampler at a field monitoring site without additional equipment. The purpose of the test is to determine that any portion of the sample flow rate that leaks past the sample filter without passing through the filter is insignificant relative to the design flow rate for the sampler.

(a) The suggested technique for the operator to use for this leak test is as follows:

(1) Card out an external leak test as provided under section 7.4.6.1 of this appendix which indicates successful passage of the prescribed external leak test.

(2) Install a flow-impervious membrane material in the filter cassette, either with or without a filter, as appropriate, which effectively prevents air flow through the filter.

(3) Use the sampler air pump to draw a partial vacuum in the sampler, downstream of the filter holder assembly, of at least.55 mm Hg (75 cm water column).

(4) Plug the flow system downstream of the filter holder to isolate the components under vacuum from the pump, such as with a built-in valve.

(5) Stop the pump.

(6) Measure the trapped vacuum in the sampler with a built-in pressure measuring device.

(7) Measure the vacuum in the sampler with the built-in pressure measuring device again at a later time at least 10 minutes after the first pressure measurement.

(8) Remove the flow plug and membrane and restore the sampler to the normal

operating configuration.

(b) The associated leak test procedure shall require that for successful passage of this test, the difference between the two pressure measurements shall not be greater than the number of mm of Hg specified for the sampler by the manufacturer, based on the actual internal volume of the portion of the sampler under vacuum, that indicates a leak of less than 80 mL/min.

(c) Variations of the suggested technique or an alternative internal, filter bypass leak test technique may be required for samplers whose design or configuration would make the suggested technique impossible or impractical. The specific proposed interned leak test procedure, or particularly an alternative internal leak test technique proposed for a particular candidate sampler may be described and submitted to the EPA for specific individual acceptability either as part of a reference or equivalent method application under part 53 of this chapter or in writing in advance of such intended application under part 53 of this chapter.

7.3.5 *Filter holder assembly.* The sampler shall have a sample filter holder assembly to adapt and seed to the down tube and to hold and seed the specified filter, under section 6.0 of this appendix, in the sample air stream in a horizontal position below the downtube such that the sample air passes downward through the filter at a uniform face velocity. The upper portion of this assembly shall be fabricated as indicated in Figures L-25 and 26 of this appendix and shall accept and seal with the filter cassette, which shall be fabricated as indicated in Figures L-27 through L-29 of this appendix.

(a) The lower portion of the filter holder assembly shall be of a design and construction that:

(1) Mates with the upper portion of the assembly to complete the filter header assembly,

(2) Completes both the external air seal and the internal filter cassette seal such that all seals are reliable over repeated filter changings, and

(3) Facilitates repeated changing of the filter cassette by the sampler operator.

(b) Leak test performance requirements for the filter holder assembly are included in section 7.4.6 of this appendix.

(c) If additional or multiple filters are stored in the sampler as part of an automatic sequential sample capability, all such filters, unless they are currently and directly installed in a sampling channel or sampling configuration (either active or inactive), shall be covered or (preferably) sealed in such a way as to:

(1) Preclude significant exposure of the filter to possible contamination or accumulation of dust, insects, or other material that may be present in the ambient air, sampler, or sampler ventilation air during storage periods either before or after sampling; and

(2) To minimize loss of volatile or semi-volatile PM sample components during storage of the filter following the sample period.

7.3.6 *Flow rate measurement adapter.* A flow rate measurement adapter as specified in Figure L–30 of this appendix shall be furnished with each sampler.

7.3.7 *Surface Amish* All internal surfaces exposed to sample air prior to the filter shall be treated electrolytically in a sulfuric acid bath to produce a clear, uniform anodized surface finish of not less than 1000 mg/ft^2 (1.08 mg/cm^2) in accordance with military standard specification (mil. spec.) 8625F, Type II, Class I in reference 4 of section 13.0 of this appendix. This anodic surface coating shall not be dyed or pigmented. Following anodization, the surfaces shall be seeded by immersion in boiling deionized water for not less than 15 minutes. Section 53.51(d)(2) of this chapter should also be consulted.

7.3.8 *Sampling height.* The sampler shall be equipped with legs, a stand, or other means to maintain the sampler in a stable, upright position and such that the center of the sample air entrance to the inlet, during sample collection, is maintained in a horizontal plane and is 2.0 ±0.2 meters above the floor or other horizontal supporting surface. Suitable bolt holes, brackets, tie-downs, or other means should be provided to faciliteste mechanically securing the sample to the supporting surface to prevent toppling of the sampler due to wind.

7.4 *Performance specifications.*

7.4.1 *Sample flow rate.* Proper operation of the impactor requires that specific air velocities be maintained through the device. Therefore the design sample air flow rate through the inset shall be 16.67 L/min (1.000 m^3/hour) measured as actual volumetric flow rate at the temperature and pressure of the sample air entering the inlet.

7.4.2 *Sample airflow rate control system.* The sampler shall have a sample air flow rate control system which shall be capable of providing a sample air volumetric flow rate within the specified range, under section 7.4.1 of this appendix, for the specified filter, under section 6.0 of this appendix, at any atmospheric conditions specified, under section 7.4.7 of this appendix, at a filth pressure drop equal to that of a clean filter plus up to 75 cm water column (55 mm Hg). and over the specified range of supply line voltage, under section 7.4.15.1 of this appendix. This flow control system shall allow for operator adjustment of the operation flow rate of the sampler over a range of at least ±l5 percent of the flow rate specified in section 7.4.1 of this appendix.

7.4.3 *Sample flow rate regulation.* The sample flow rate shall be regulated such that for the specified filter, under section 6.0 of this appendix, at any atmospheric conditions specified, under section 7.4.7 of this appendix, at a filter pressure drop equal to that of a clean filter plus up to 75 cm water column (55 mm Hg), and over the specified range of supply line voltage, under section 7.4.15.1 of this appendix, the flow rate is regulated as follows:

7.4.3.1 The volumetric flow rate, measured or averaged over intervals of not more than 5 minutes over a 24-hour period, shall not vary more than ±5 percent from the specified 16.67 L/min flow rate over the entire sample period.

7.4.3.2 The coefficient of variation (sample standard deviation divided by the mean) of the flow rate, measured over a 24-hour period, shall not be greater than 2 percent.

7.4.3.3 The amplitude of short-term flow rate pulsations, such as may originate from some types of vacuum pumps, send be attenuated such that they do not cause significant flow measurement error or affect the collection of particles on the particle collection filter.

7.4.4 *Flow rate cut off.* The sampler's sample air flow rate control system shall terminate sample collection and stop all sample flow for the remainder of the sample period in the event that the sample flow rate deviates by more than 10 percent from the sampler design flow rate specified in section 7.4.1 of this appendix for more than 60 seconds. However, this sampler cut-off provision shall not apply during periods when the sampler is inoperative due to a temporary power interruption, and the elapsed time of the inoperative period shall not be included in the total sample time measured and reported by the sampler, under section 7.4.13 of this appendix.

7.4.5 *Flow rate measurement.*

7.4.5.1 The sampler shall provide a means to measure and indicate the instantaneous sample air flow rate, which shall be measured as volumetric flow rate at the temperature and pressure of the sample air entering the inlet, with an accuracy of ±2 percent. The measured flow rate shall be available for display to the sampler operator at any time in either sampling or standby modes, and the measurement shall be updated at least even

30 seconds. The sampler shall also provide a simple means by which the sampler operator can manually start the sample flow temporarily during non-sampling modes of operation, for the purpose of checking the sample flow rate or the flow rate measurement system.

7.4.5.2 During each sample period, the sampler's flow rate measurement system shall automatically monitor the sample volumetric flow rate, obtaining flow rate measurements at intervals of not greater than 30 seconds.

(a) Using these internal flow rate measurements, the sampler shall determine or calculate the following flow-related parameters, scaled in the specified engineering units:

(1) The instantaneous or internal-average flow rate, in L/min.

(2) The value of the average sample flow rate for the sample period, in L/min.

(3) The value of the coefficient of variation (sample standard deviation divided by the average) of the sample flow rate for the sample period, in percent.

(4) The occurrence of any time internal during the sample period in which the measured sample flow rate exceeds a range of ±5 percent of the average flow rate for the sample period for more than 5 minutes, in which case a warning flag indicator shall be set.

(5) The value of the integrated total sample volume for the sample period, in m^3.

(b) Determination or calculation of these values shall properly exclude periods when the sampler is inoperative due to temporal interruption of electrical power, under section 7.4.13 of this appendix, or flow rate cut off, under section 7.4.4 of this appendix.

(c) These parameters shall be accessible to the sampler operator as specified in Table L–1 of section 7.4.19 of this appendix. In addition, it is strongly encouraged that the flow rate for each 5 minute internal during the sample period be available to the operator following the end of the sample period.

7.4.6 *Leak test capability.*

7.4.6.1 *External leakage.* The sampler shall include an external air leak-test capability consisting of components, accessory hardware, operator interface controls, a written procedure in the associated Operation/Instruction Manual, under section 7.4.18 of this appendix, and all other necessary functioned capability to permit and facilitate the sampler operator to conveniently carry out a leak test of the sampler at a field monitoring site without addition equipment. The sampler components to be subjected to this leak test include all components and their interconnections in which external air leakage would or could cause an error in the sampler's measurement of the told volume of sample air that passes through the sample filter.

(a) The suggested technique for the operator to use for this leak test is as follows:

(1) Remove the sampler inlet and installs the flow rate measurement adapter supplied with the sampler, under section 7.3.6 of this appendix.

(2) Close the valve on the flow rate measurement adapter and use the sampler air pump to draw a partied vacuum in the sampler, including (at least) the impactor, filter holder assembly (filter in place), flow measurement device, and interconnections between these devices, of at least 55 mm Hg (75 cm water column), measured at a location downstream of the filter holder assembly.

(3) Plug the flow system downstream of these components to isolate the components under vacuum from the pump, such as with a built-in valve.

(4) Stop the pump.

(5) Measure the trapped vacuum in the sampler with a built-in pressure measuring device.

(6) (i) Measure the vacuum in the sampler with the built-in pressure measuring device again at a later time at least 10 minutes after the first pressure measurement.

(ii) **Caution**: Following completion of the test, the adaptor valve should be opened slowly to limit the flow rate of air into the sampler. Excessive air flow rate may blow oil out of the impactor.

(7) Upon completion of the test, open the adaptor valve, remove the adaptor and plugs, and restore the sampler to the normal operating configuration.

(b) The associated leak test procedure shall require that for successful passage of this test, the difference between the two pressure measurements shall not be greater than the number of mm of Hg specified for the sampler by the manufacturer, based on the actual interned volume of the sampler that indicates a leak of leas than 80 mL/min.

(c) Variations of the suggested technique or an alternative external leak test technique may be required for samplers whose design or configuration would make the suggested technique impossible or impractical. The specific proposed external leak test procedure, or particularly an alternative leak test technique proposed for a particular candidate sampler may be described and submitted to the EPA for specific individual acceptability either as part of a reference or equivalent method application under part 53 of this chapter or in writing in advance of such an intended application under part 53 of this chapter.

7.4.6.2 *Internal, filter bypass leakage.* The sampler shall include an internal, filter bypass leak-check capability consisting of components, accessory hardware, operator interface controls, a written procedure in the Operation/Instruction Manual, and all other necessary functioned capability to permit and facilitate the sampler operator to conveniently carry out a test for interned filter bypass leakage in the sampler at a field monitoring site without additional equipment. The purpose of the test is to determine that any portion of the sample flow rate that leaks past the sample filter without passing through the filter is insignificant relative to the design flow rate for the sampler.

(a) The suggested technique for the operator to use for this leak test is as follows:

(1) Carry out an external leak test as provided under section 7.4.6.1 of this appendix which indicates successful passage of the prescribed external leak test.

(2) Install a flow-impervious membrane material in the filter cassette, either with or without a filter, as appropriate, which effectively prevents air flow through the filter.

(3) Use the sampler air pump to draw a partial vacuum in the sampler, downstream of the filter holder assembly, of at least 55 mm Hg (75 cm water column).

(4) Plug the flow system downstream of the filter holder to isolate the components under vacuum from the pump, such as with a built-in valve.

(5) Stop the pump.

(6) Measure the trapped vacuum in the sampler with a built-in pressure measuring device.

(7) Measure the vacuum in the sampler with the built-in pressure measuring device again at a later time at least 10 minutes after the first pressure measurement.

(8) Remove the flow plug and membrane and restore the sampler to the normal operating configuration.

(b) The associated leaks test procedure shall require that for successful passage of this test the difference between the two pressure measurements shall not be greater than the number of mm of Hg specified for the sampler by the manufacture, based on the actual interned volume of the portion of the sampler under vacuum, that indicates a leak of less than 80 mL/min.

(c) Variations of the suggested technique or an alternative interned, filter bypass leak test technique may be required for samplers whose design or configuration would make the suggested technique impossible or impractical. The specific proposed interned leak test procedure, or particularly an alternative interned leak test technique proposed for a particular candidate sampler may be described and submitted to the EPA for specific individual acceptability either as part of a reference or equivalent method application under part 53 of this chapter or in

writing in advance of such intended application under part 53 of this chapter.

7.4.7 *Range of operational conditions.* The sampler is required to operate properly and meet all requirements specified in this appendix over the following operational range.

7.4.7.1 *Ambient temperature.* -30 to +45 °C (Note: Although for practical reasons, the temperature range over which samplers are required to be tested under part 53 of this chapter is -20 to +40 °C, the sampler shall be designed to operate properly over this wider temperature range.).

7.4.7.2 *Ambient relative humidity. 0 to* 100 percent.

7.4.7.3 *Barometric pressure range.* 600 to 800 mm Hg.

7.4.8 *Ambient temperature sensor.* The sample shall have capability to measure the temperature of the ambient air surrounding the sampler over the range of -30 to +45 °C, with a resolution of 0.1 °C and accuracy of ±2.0 °C, referenced as described in reference 3 in section 13.0 of this appendix, with and without maximum solar insolation.

7.4.8.1 The ambient temperature sensor mall be mounted external to the sampler enclosure and shall have a passive, naturally ventilated sun shield. The sensor shall be located such that the entire sun shield is at least 5 cm above the horizontal plane of the sampler case or enclosure (disregarding the inlet and downtube) and external to the vertical plane of the nearest side or protuberance of the sampler case or enclosure. The maximum temperature measurement error of the ambient temperature measurement system shall be less than 1.6 °C at 1 m/s wind speed and 1000 W/m^2 solar radiation intensity.

7.4.8.2 The ambient temperature sensor shall be of such a design and mounted in such a way as to facilitate its convenient dismounting and immersion in a liquid for calibration and comparison to the filter temperature sensor, under section 7.4.11 of this appendix.

7.4.8.3 This ambient temperature measurement shall be updated at least every 30 seconds during both sampling and standby (non-sampling) modal of operation. A visual indication of the current (most recent) value of the ambient temperature measurement, updated at least every 30 seconds shall be available to the sampler operator during both sampling and standby (non-sampling) modes of operation, as specified in Table L–1 of section 7.4.19 of this appendix.

7.4.8.4 This ambient temperature measurement shall be used for the purpose of monitoring filter temperature deviation from ambient temperature, as required by section 7.4.11 of this appendix, and may be used for purposes of effecting filter temperature control, under section 7.4.10 of this appendix, or computation of volumetric flow rate, under sections 7.4.1 to 7.4.5 of this appendix, if appropriate.

7.4.8.5 Following the end of each sample period, the sampler shall report the maximum, minimum, and average temperature for the sample period, as specified in Table L–1 of section 7.4.19 of this appendix.

7.4.9 *Ambient barometric sensor.* The sampler shall have capability to measure the barometric pressure of the air surrounding the sampler over a range of 600 to 800 mm Hg referenced as described in reference 3 in section 13.0 of this appendix; also see part 53, subpart E of this chapter. This barometric pressure measurement shall have a resolution of 5 mm Hg and an accuracy of ±10 mm Hg and shall be updated at least every 30 seconds. A visual indication of the value of the current (most recent) barometric pressure measurement, updated at least every 30 seconds, shall be available to the sampler operator during both sampling and standby (non-sampling) modal of operation as specified in Table L–1 of section 7.4.19 of this appendix. This barometric pressure measurement may be used for purposes of computation of volumetric flow rate, under sections 7.4.1 to 7.4.5 of this appendix, if appropriate. Following the end of a sample period, the sampler shall report the maximum, minimum, and mean barometric pressures for the sample period, as specified in Table W1 of section 7.4.19 of this appendix.

7.4.10 *Filter temperature control (sampling and post-sampling).* The sampler shall provide a means to limit the temperature rise of the sample filter (all sample filters for sequential samples), from insolation and other sources, to no more 5 °C above the temperature of the ambient air surrounding the sampler, during both sampling and post-sampling periods of operation. The post-sampling period is the non-sampling period between the end of the active sampling period and the time of retrieved of the sample filter by the sampler operator.

7.4.11 *Filter temperature sensor(s).*

7.4.11.1 The sampler shall have the capability to monitor the temperature of the sample filter (all sample fitted for sequential samplers) over the range of -30 to +45 °C during both sampling and non-sampling periods. While the exact location of this temperature sensor is not explicitly specified, the filter temperature measurement system must demonstrate agreement, within 1°C, with a test temperature sensor located within 1 cm of the center of the filter downstream of the filter during both sampling and non-sampling modes, as specified in the filter temperature measurement test described in part 53, subpart E of this chapter. This filter temperature measurement shall have a resolution of 0.1 °C and accuracy of ±1.0 °C referenced as described in reference 3 in section 13.0 of this appendix. This temperature sensor shall be of such a design and mounted in such a way as to facilitate its reasonably convenient dismounting and immersion in a liquid for calibration and comparison to due ambient temperature sensor under section 7.4.8 of this appendix.

7.4.11.2 The filter temperature measurement shall be updated at least even 30 seconds during both sampling and standby (non-sampling) modes of operation. A visual indication of the current (most recent) value of the filter temperature measurement, updated at least even 30 seconds, shall be available to the sampler operator during both sampling and standby (non-sampling) modes of operation, as specified in Table L–1 of section 7.4.19 of this appendix.

7.4.11.3 For sequential samplers, the temperature of each filter shall be measured individually unless it can be shown, as specified in the filter temperature measurement test described § 53.57 of this chapter, that the temperature of each filter can be represented by fewer temperature sensors.

7.4.11.4 The sampler shall also provide a warning flag indicator following any occurrence in which the filter temperature (any filter temperature for sequential samplers) exceeds the ambient temperature by more than 5 °C for more than 30 consecutive minutes during either the sampling or post-sampling periods of operation, as specified in Table L–1 of section 7.4.19 of this appendix, under section 10.12 of this appendix, regarding sample validity when a warning flag occurs. It is further recommended (not required) that the sampler be capable of recording the maximum differential between the measured filter temperature and the ambient temperature and its time and date of occurrence during both sampling and post-sampling (non-sampling) modes of operation and providing for those data to be accessible to the sampler operator following the end of the sample period, as suggested in Table L–1 of section 7.4.19 of this appendix.

7.4.12 *Clock/timer system.*

(a) The sample shall have a programmable real time clock timing/control system that:

(1) Is capable of maintaining local time and date, including year, month, day-of-month, hour, minute, and second to an accuracy of ±1.0 minute per month.

(2) Provides a visual indication of the current system time, including year, month, day-of-month, hour, and minute, updated at least each minute, for operator verification.

(3) Provides appropriate operator controls for setting the correct local time and date.

(4) Is capable of starting the sample collection period and sample air flow at a specific, operator-settable time and date, and stopping the sample air flow and terminating the sampler collection period 24 hours (1440 minutes) later, or at a specific, operator-settable time and date.

(b) These start and stop times shall be readily settable by the sampler operator to within ±1.0 minute. The system shall provide a visual indication of the current start and stop time settings, readable to ±1.0 minute, for verification by the operator, and the start and stop times shall also be available via the data output port, as specified in Table L–1 of section 7.4.19 of this appendix. Upon execution of a programmed sample period start, the sampler shall automatically reset all sample period information and warning flag indications pertaining to a previous sample period. Refer also to section 7.4.15.4 of this appendix regarding retention of current date and time and programmed start and stop times during a temporary electrical power interruption.

7.4.13 *Sample time determination.* The sampler shall be capable of determining the elapsed sample collection time far each $PM_{2.5}$ sample, accurate to within ±1.0 minute, measured as the time between the start of the sampling period, under section 7.4.12 of this appendix and the termination of the sample period, under section 7.4.12 of this appendix or section 7.4.4 of this appendix. This elapsed sample time shad not include periods when the sampler is inoperative due to a temporary interruption of electrical power, under section 7.4.15.4 of this appendix. In the event that the elapsed sample time determined for the sample period is not within the range specified for the required sample period in section 3.3 of this appendix, the sampler shall set a warning flag indicator. The date and time of the start of the sample period, the value of the elapsed sample time for the sample period, and the flag indicator status shall be available to the sampler operator following the end of the sample period, as specified in Table L–1 of section 7.4.19 of this appendix.

7.4.14 *Outdoor environmental enclosure.* The sampler shall have an outdoor enclosure (or enclosures) suitable to protect the filter and all "non-weatherproof" components of the sampler from precipitation, wind, dust, extremes of temperature and humidity; to help maintain temperature control of the filter (or filters, for sequential samplers); and to provide reasonable security for sampler components and settings.

7.4.15 *Electrical power supply.*

7.4.15.1 The sampler shall be operable and function as specified herein when operated on an electrical power supply voltage of 105 to 125 volts AC (RMS) at a frequency of 59 to 61 Hz. Optional operation as specified at addition power supply voltages and/or frequencies shall not be precluded by this requirement.

7.4.15.2 The design and construction of the sampler shall comply with all applicable National Electrical Code and Underwriters Laboratories electrical safety requirements.

7.4.15.3 The design of all electrical and electronic controls shall be such as to provide reasonable resistance to interference or malfunction from ordinal or typical leads of stray electromagnetic fields (EMF) as may be found at various monitoring sites and from typical levels of electrical transients or electronic noise as may often or occasionally be found on various electrical power lines.

7.4.15.4 In the event of temporary loss of electrical supply power to the sample, the sampler shall not be required to sample or provide other specified functions during such loss of power, except that the internal clock/timer system shall maintain its local time and date setting within ±1 minute per week, and the sampler shall retain all other time and programmable settings and all data required to be available to the sampler operator following each sample period for at least 7 days without electrical supply power. When electrical power is absent at the operator-set time for starting a sample period or is interrupted during a sample period, the sampler shall automatically start or resume sampling when electrical power is restored, if such restoration of power occurs before the operator-set stop time for the sample period.

7.4.15.5 The sampler shall have the capability to record and retain a record of the year, month, day-of-month, hour, and minute of the start of each power interruption of more than 1 minute duration, up to 10 such power interruptions per sample period. (More than 10 such power interruptions shall invalidate the sample, except where an exceedance is measured, under section 3.3 of this appendix.) The sampler shall provide for these power interruption data to be available to the sampler operator following the end of the sample period, as specified in Table L–1 of section 7..4.19 of this appendix.

7.4.16 *Control devises and operator interface.* The sampler shall have mechanical, electrical, or electronic controls, control devices, electrical or electronic circuits as necessary to provide the timing, flow rate measurement and control, temperature control, data storage and computation, operator interface, and other functions specified. Operator-accessible controls, data displays, and interface devices shall be deigned to be simple, straightforward, reliable, and easy to learn, read, and operate under field conditions. The sample shall have provision for operator input and storage of up to 64 characters of numeric (or alphanumeric) data for purposes of site, sampler, and sample identification. This information shall be available to the sampler operator for verification and change and for output via the data output port along with other data following the end of a sample period as specified in Table L–1 of section 7.4.19 of this appendix. All data required to be available to the operator following a sample collection period or obtained during standby mode in a post-sampling period shall be retained by the sample until reset, either manually by the operator or automatically by the sampler upon initiation of a new sample collection period.

7.4.17 *Data output port requirement.* The sampler shall have a standard RS-232C data output connection through which digital data may be exported to an external data storage or transmission device. All information which is required to be available at the end of each sample period shall be accessible through this data output connection. The information that shall be accessible though this output part is summarized in Table L–1 of section 7.4.19 of this appendix. Since no specific format for the output data is provided, the sample manufacturer or vendor shall make available to sampler purchasers appropriate computer software capable of receiving exported sampler data and correctly translating the data into a standard spreadsheet format and optionally any other formats as may be useful to sampler users. This requirement shall not preclude the sampler from offering other types of output connections in addition to the required RS-232C port.

7.4.18 *Operation/instruction manual* The sampler shall include an associated comprehensive operation or instruction manual, as required by part 53 of this chapter, which includes detailed operating instructions on the setup, operation, calibration, and maintenance of the sampler. This manual shall provide complete and detailed descriptions of the operation and calibration procedures prescribed for field use of the sampler and all instruments utilized as part of this reference method. The manual shall include adequate warning of potential safety hazards that may result from normal use or malfunction of the method and a Ascription of necessary safety precautions. The manual shall also include a clear description of all procedures pertaining to installation, operation, periodic and corrective maintenance, and troubleshooting, and shall include parts identification diagrams.

17.4.19 *Data reporting requirements.* The various information that the sampler is required to provide and how it is to be

provided is summarized in the following Table L–1.

8.0 Filter Weighting. See reference 2 in section 13.0 of this appendix, for additional, more detailed guidance.

8.1 Analytical balance. The analytical balance used to weigh filters must be suitable for weighing the type and size of filters specified, under section 6.0 of this appendix, and have a readability of ±1 µg. The balance shall be calibrated as specified by the manufacturer at installation and recalibrated immediately prior to each weighing session. See reference 2 in section 13.0 of this appendix for additional guidance.

8.2 *Filter conditioning.* All sample filters used shall be conditioned immediately before both the pre- and post-sampling weightings as specified below. See reference 2 in section 13.0 of this appendix for additional guidance.

8.2.1 Mean *temperature.* 20 - 23 °C.

8.2.2 *Temperature control* ±2 °C over 24 hours.

8.2.3 *Mean humidity.* Generally, 30-40 percent relative humidity; however, while it can be shown that the mean ambient relative humidity during sampling is less than 30 percent, conditioning is permissible at a mean relative humidity within ±5 relative humidity percent of the mean ambient relative humidity during sampling, but not less than 20 percent.

8.2.4 *Humidity control.* ±5 relative humidity percent over 24 hours.

8.2.5 *Conditioning time.* Not less than 24 hours.

8.3 *Weighing procedure.*

8.3.1 New filters should be placed in the conditioning environment immediately upon arrival and stored there until the pre-sampling weighing. See reference 2 in section 13.0 of this appendix for additional guidance.

8.3.2 The analytical balance shall be located in the same controlled environment in which the filters are conditioned. The filters shall be weighed immediately following the conditioning period without intermediate or transient exposure to other conditions or environments.

8.3.3 Filters must be conditioned at the same conditions (humidity within ±5 relative humidity percent) before both the pre- and past-sampling weighings.

8.3.4 Both the pre- and past-sampling weighings should be carried out on the same analytical balance using an effective technique to neutr e static charges on the filter, under refere 2 in section 13.0 of this appendix. If possi both weighings should be carried out by the same analyst.

8.3.5 The pre-sampling (tare) weighing shall be within 30 days of the sampling period.

8.3.6 The post-sampling conditioning and weighing shall be completed within 240 hours (10 days) after the end of the sample period, unless the filter sample is maintained at 4 °C or less during the entire time between retrieval from the sampler and the start of the conditioning, in which case the period shall not exceed 30 days. Reference 2 in section 13.0 of this appendix has additional guidance on transport of cooled filters.

8.3.7 Filter blanks.

8.3.7.1 New field blank filters shall be weighed along with the pre-sampling (tare) weighing of each lot of $PM_{2.5}$ filters. These blank filters shall be transported to the sampling site, installed in the sampler, retrieved from the sampler without sampling, and reweighed as a quality control check.

8.3.7.2 New laboratory blank filters shall be weighed along with the pre-sampling (tare) weighing of each set of $PM_{2.5}$ filters. These laboratory blank filters should remain in the laboratory in protective containers during the field sampling and should be reweighed as a quality control check.

8.3.8 Additional guidance for proper filter weighing and related quality assurance activities is provided in reference 2 in section 13.0 of this appendix.

9.0 Calibration. Reference 2 in section 13.0 of this appendix contains additional guidance.

9.1 General requirements.

9.1. 1 Multipoint calibration and single-point verification of the sampler's flow rate measurement device must be performed periodically to establish and maintain tractability of subsequent flow measurements to a flow rate standard.

9.1.2 An authoritative flow rate standard shall be used for calibrating or verifying the sampler's flow rate measurement device with an accuracy of ±2 percent. The flow rate standard shall be a separate, stand-alone device designed to connect to the flow rate measurement adapter, Figure L-30 of this appendix. This `flow` rate standard must have its own certification and be traceable to a National Institute of Standards and Technology (NIST) primary standard for volume or flow rate. If adjustments to the sampler's `flow` rate measurement system calibration are to be made in conjunction with an audit of the sampler's flow measurement system, such adjustments shall be made following the audit. Reference 2 in section 13.0 of this appendix contains additional guidance.

9.1.3 The sampler's flow rate measurement device shall be re-calibrated after electromechanical maintenance or transport of the sampler.

9.2 *Flow* rate calibration/verification procedure.

9.2.1 $PM_{2.5}$ samplers may employ various types of flow control and flow measurement devices. The specific procedure used for calibration or verification of the flow rate measurement device will vary depending on the type of flow rate controller and flow rate measurement employed. Calibration shall be in terms of actual ambient volumetric flow rates (Q_a), measured at the sampler's inlet downtube. The generic procedure given here serves to illustrate the general steps involved in the calibration of a $PM_{2.5}$ sampler. The sampler operation/instruction manual required under section 7.4.18 of this appendix and the Quality Assurance Handbook in reference 2 in section 13.0 of this appendix provide more specific and detailed guidance for calibration.

9.2.2 The flow rate standard used for flow rate calibration shall have its own certification and be traceable to a NIST primary standard for volume or flow rate. A calibration relationship for the flow rate standard, e.g., an equation, curve, or family of curves relating actual flow rate (Q_a)

TABLE L–1.—SUMMARY OF INFORMATION TO BE PROVIDED BY THE SAMPLER

Information to be pro-vided	Appendix L section reference	Availability				Format	
		Anytime[1]	End of period[2]	Visual display[3]	Data output[4]	Digital Reading[5]	Units
Flow rate, 30-second maximum interval.	7.4.5.1	✓	.....	✓	*	XX.X.....	L/min
Flow rate, average for the sample period.	7.4.5.2	*	✓	*	✓	XX.X.....	L/min
Flow rate, CV, for sample period.	7.4.5.2	*	✓	*	✓●	XX.X.....	%
Flow rate, 5-min. aver- age out of spec.	7.4.5.2	✓	✓	✓	✓●	On/Off	
Sample volume, total	7.4.5.2	*	✓	✓	✓●	XX.X.....	m^3
Temperature, ambient, 30-second interval.	7.4.8	✓	.....	✓	.....	XX.X.....	°C
Temperature, ambient, min., max., average for the sample period.	7.4.8	*	✓	✓	✓●	XX.X.....	°C
Baro pressure, ambient, 30-second interval.	7.4.9	✓	.....	✓	.....	XXX.....	mm Hg
Baro pressure, ambient, min., max., average for the sample period.	7.4.9	*	✓	✓	✓●	XXX.....	mm Hg
Filter temperature, 30-second interval.	7.4.11	✓	.....	✓	.....	XX.X.....	°C
Filter temperature, differential, 30-second interval, out of spec. (FLAG[6])	7.4.11	*	✓	✓	✓●	On/Off	
Filter temperature, maximum differential, form ambient, date, time of occurrence.	7.4.11	*	*	*	*	X.X YY/MM/DD HH:mm.	°C, Yr./Mon./Day Hrs. min
Date and time	7.4.12	✓	.....	✓	.....	YY/MM/DD HH:mm	Yr./Mon./Day Hrs. min
Sample start and stop time settings.	7.4.12	✓	✓	✓	✓	YY/MM/DD HH:mm	Yr./Mon./Day Hrs. min
Sample period start time.	7.4.12	.....	✓	✓	✓●	YYYY/MM/DD HH:mm	Yr./Mon./Day Hrs. min
Elapsed sample time.	7.4.13	*	✓	✓	✓●	HH:mm	Hrs. min
Elapsed sample time, out of spec. (FLAG[6]).	7.4.13	.....	✓	✓	✓●	On/Off	
Power interruptions > 1 min. start time of first 10.	7.4.15.5	*	✓	*	✓	1HH:mm, 2 HH:mm, etc ...	Hrs. min
User-entered information, such as sampler and site identification.	7.4.16	✓	✓	✓	✓●	As entered	

✓ Provision of this information is required.

Provision of this information is optional. If information related to the entire sample period is optionally provided prior to the end of the sample period, the value provided should be the value calculated for the portion of the sampler period completed up to the time the information is provided.

● Indicates that this information is also required to be provided to the AIRS data bank; see § § 58.26 and 58.35 of this chapter.

[1] Information is required to be available to the operator at any time the sampler is operating, whether sampling or not.

[2] Information relates to the entire sampler period and must be provided following the end of the sample period until reset manually by the operator or automatically by the sampler upon the start of a new sample period.

[3] Information shall be available to the operator visually.

[4] Information is to be available as digital data at the sampler's data output port specified in section 7.4.16 of this appendix following the end of the sample period until reset manually by the operator or automatically by the sampler upon the start of a new sample period.

[5] Digital readings, both visual and data output, shall have not less than the number of significant digits and resolution specified.

[6] Flag warnings may be displayed to the operator by a single-flag indicator or each flag may be displayed individually. Only a set (on) flag warning must be indicated, an off (unset) flag may be indicated by the absence of a flag warning. Sampler users should refer to section 10.12 of this appendix regarding the validity of samples for which the sampler provided an associated flag warning.

to the flow rate indicator reading, shall be established that is accurate to within 2percent over the expected range of ambient temperatures and pressures at which the flow rate standard may be used. The flow rate standard must be re-calibrated or re-verified at least annually.

9.2.3 The sampler flow rate measurement device shall be calibrated or verified by removing the sampler inlet and connecting the flow rate standard to the sampler's downtube in accordance with the operation/instruction manual, such that the flow rate standard accurately measures the sampler's flow rate. The sampler operator shall first carry out a sampler leak check and confirm that the sampler passes the leak test and then verify that no leaks exist between the flow rate standard and the sampler.

9.2.4 The calibration relationship between the flow rate (in actual L/min) indicated by the flow rate standard and by the sampler's flow rate measurement device shall be established or verified in accordance with the sampler operation/instruction manual. Temperature and pressure corrections to the flow rate indicated by the flow rate standard may be required for certain types of flow rate standards. Calibration of the sampler's flow rate measurement device shall consist of at least three separate flow rate measurements (multipoint calibration) evenly spaced within the range of -10 percent to +10 percent of the sampler's operational flow rate, section 7.4.1 of this appendix. Verification of the sampler's flow rate shall consist of one flow rate measurement at the sampler's operational flow rate. The sampler operation/instruction manual and reference 2 in section 13.0 of this appendix provide additional guidance.

9.2.5 If during a flow rate verification the reading of the sampler's flow rate indicator or measurement device differs by ±2 percent or more from the flow rate measured by the flow rate standard, a new multipoint calibration shall be performed and the flow rate verification must then be repeated.

9.2.6 Following the calibration or verification, the flow rate standard shall be removed from the sampler and the sampler inlet shall be reinstalled. Then the sampler's normal operating flow rate (in L/min) shall be determined with a clean filter in place. If the flow rate indicated by the sampler differs by ±2 percent or more from the required sampler flow rate, the sample flow rate must be adjusted to the required flow rate, under section 7.4.1 of this appendix.

9.3 Periodic calibration or verification of the calibration of the sampler's ambient temperature, filter temperature, and barometric pressure measurement systems is also required. Reference 3 of section 13.0 of this appendix contains additional guidance.

10.0 *$PM_{2.5}$ Measurement Procedure* The detailed procedure for obtaining valid $PM_{2.5}$ measurements with each specific sampler designated as part of a reference method for $PM_{2.5}$ under part 53 of this chapter shall be provided in the sampler-specific operation or instruction manual required by section 7.4.18 of this appendix. Supplemental guidance is provided in section 2.12 of the Quality Assurance Handbook listed in reference 2 in section 13.0 of this appendix. The generic procedure given here serves to illustrate the general steps involved in the $PM_{2.5}$ sample collection and measurement, using a $PM_{2.5}$ reference method sampler.

10.1 The sampler shall be set up, calibrated, and operated in accordance with the specific, detailed guidance provided in the specific sampler's operation or instruction manual and in accordance with a specific quality assurance program developed and established by the user, based on applicable supplementary guidance provided in reference 2 in section 13.0 of this appendix.

10.2 Each new sample filter shall be inspected for correct type and size and for pinholes, particles and other imperfections. Unacceptable filters should be discarded. A unique identification number shall be assigned to each filter, and an information record shall be established for each filter. If the filter identification number is not or cannot be marked directly on the filter, alternative means, such as a number-identified storage contains, must be established to maintain positive filter identification.

10.3 Each filter shall be conditioned in the conditioning environment in accordance with the requirements specified in section 8.2 of this appendix.

10.4 Following conditioning, each filter shall be weighed in accordance with the requirements specified in section 8.0 of this appendix and the presampling weight recorded with the filter identification number.

10.5 A numbered and preweighed filter shall be installed in the sampler following the instructions provided in the sampler operation or instruction manual.

10.6 The sampler shall be checked and prepared for sample collection in accordance with instructions provided in the sampler operation or instruction manual and with the specific quality assurance program established for the sampler by the user.

10.7 The sampler's timer shall be set to start the sample collection at the beginning of the desired sample period and stop the sample collection 24 hours later.

10.8 Information related to the sample collection (site location or identification number, sample date, filter identification number, and sampler model and serial number) shall be recorded and, if appropriate, entered into the sampler.

10.9 The sampler shall be allowed to collect the $PM_{2.5}$ sample during the set 24-hour time period.

10.10 Within 96 hours of the end of the sample collection period, the filter, while still contained in the filter cassette, shall be carefully removed from the sampler, following the procedure provided in the sampler operation or instruction manual and the quality assurance program, and placed in a protective container. This protective container shall be made of metal and contain no loose material that could be transferred to the filter. The protective container shall hold the filter cassette securely such that the cover shall not come in contact with the filter's surfaces. Reference 2 in section 13.0 of this appendix contains additional information.

10.11 The total sample volume in actual m^3 for the sampling period and the elapsed sample time shall be obtained from the sampler and recorded in accordance with the instructions provided in the sampler operation or instruction manual. All sampler warning flag indications and other information required by the local quality assurance program shall also be recorded.

10.12 All factors related to the validity or representativeness of the sample, such as sampler tampering or malfunctions, unusual meteorological conditions, construction activity, fires or dust storms, etc. shall be recorded as required by the local quality assurance program. The occurrence of a flag warning during a sample period shall not necessarily indicate an invalid sample but rather shall indicate the need for specific review of the QC data by a quality assurance officer to determine sample validity.

10.13 After retrieval from the sampler, the exposed filter containing the $PM_{2.5}$ sample should be transported to the filter conditioning environment as soon as possible ideally to arrive at the conditioning environment within 24 hours for conditioning and subsequent weighing. During the period between filter retrieved from the sampler and the start of the conditioning, the filter shall be maintained as cool as practical and continuously protected from exposure to temperatures over 25 °C. See section 8.3.6 of this appendix regarding time limits for completing the post-sampling weighing. See reference 2 in section 13.0 of this appendix for additional guidance on transporting filter samplers to the conditioning and weighing laboratory.

10.14. The exposed filter containing the $PM_{2.5}$ sample shad be re-conditioned in the conditioning environment in accordance with the requirements specified in section 8.2 of this appendix.

10.15. The filter shall be reweighed immediately after conditioning in accordance with the requirements specified in section 8.0 of this appendix, and the post–sampling weight shall be recorded with the filter identification number.

10.16 The $PM_{2.5}$ concentration shall be calculated as specified in section 12.0 of this appendix.

11.0 *Sampler Maintenance*

The sampler shall be maintained as described by the sampler's manufacturer in the sampler-specific operation or instruction manual required under section 7.4.18 of this appendix and in accordance with the specific quality assurance program developed and established by the user based on applicable supplementary guidance provided in reference 2 in section 13.0 of this appendix.

12.0 *Calculations*

12.1 (a) The $PM_{2.5}$ concentration is calculated as:

$PM_{2.5} = (W_f - W_i)/V_a$.

where:

$PM_{2.5}$ = mass concentration of $PM_{2.5}$, $\mu g/m^3$.

W_f, W_i = final and initial weights, respectively, of the filter used to collect the $PM_{2.5}$ particle sample, μg;

V_a = total air volume sampled in actual volume units, as provided by the sampler, m^3.

(b) Note: Total sample time must be between 1,380 and 1,500 minutes (23 and 25 hours) for a fully valid $PM_{2.5}$ sample; however, see also section 3.3 of this appendix. 13.0 *References*.

1. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume I. Principles. EPA/ 600/R-94/038a. April 1994. Available from CERI. ORD Publications, U.S. Environmental Protection Agency. 26 West Martin Luther King Drive, Cincinnati. Ohio 45268.

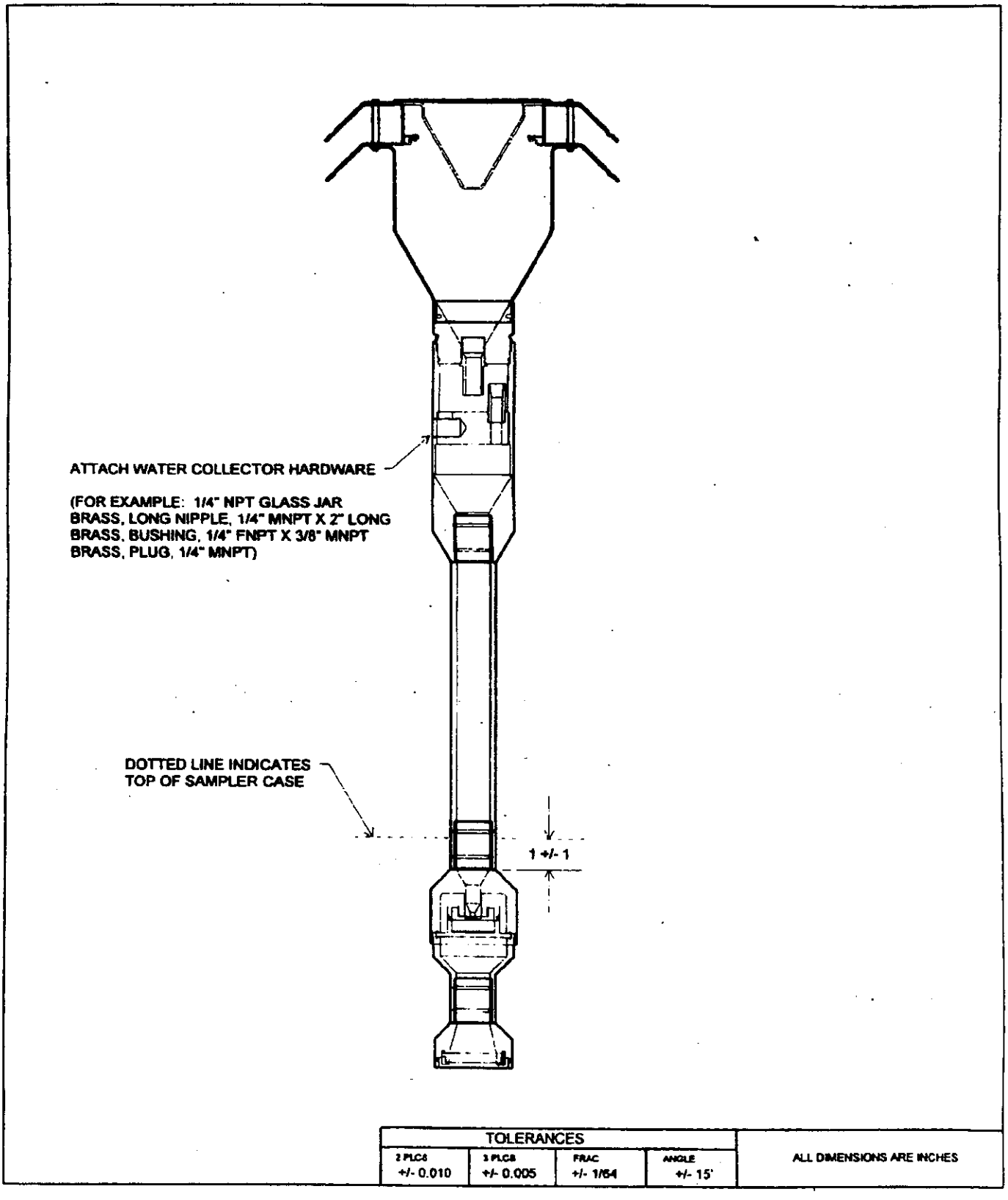
2. Copies of secton 2.12 of the Quality Assurance Handbook for Air Pollution Measurement Systems, Volume 11, Ambient Air Specific Methods, EPA/600/R-94/038b. are available from Department E (MD-77B), U.S. EPA Research Triangle Park, NC 27711.

3. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, (Revised Edition) EPA/600/R-94/ 038d, March, 1995. Available from CERI, ORD Publications. U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268.

4. Military standard specification (mil. spec.) 8625F, Type II, Class I as listed in Department of Defense Index of Specifications and Standards (DODISS), available from DODSSP-Customer Service, Standardization Documents Order Desk. 700 Robbins Avenue, Building 4D, Philadelphia, PA 1911-5094.

14.0 *Figures L–1 through L–30 to Appendix L*

FIGURE L-1. PM2.5 SAMPLER, ASSEMBLY



Excerpts of *Guidelines for Speciated Particulate Monitoring*

4.0 PARTICLE SAMPLERS

9.0 MONITORING STRATEGIES

TABLES

FIGURES

4.0 PARTICLE SAMPLERS

Particle filtration samplers consist of combinations of size-selective inlets, filter media, filter holders, and flow movers/controllers. Denuder systems and absorbing materials that capture gases associated with volatile species such as ammonium nitrate and some organic compounds can be installed behind the size-selective inlet and behind the particle collection filter. The dimensions, materials, and construction of these components affect the particles that are measured.

This section summarizes the current knowledge of sampler components, describes compliance monitoring samplers (e.g., Federal Reference Method [FRM], Federal Equivalent Method [FEM], and Interagency Monitoring of Protected Visual Environments [IMPROVE]), and introduces monitors that have been used or might be applied for $PM_{2.5}$ chemical speciation.

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4.2 Federal Reference and Equivalent Methods

Table 4-5 identifies the particle sampling systems that have achieved reference or equivalent status for PM_{10} compliance monitoring. $PM_{2.5}$ compliance monitoring networks (i.e., State and Local Air Monitoring Stations [SLAMS], National Ambient Monitoring Stations [NAMS]) are equipped with Federal Reference Method (FRM) and Federal Equivalent Method (FEM) samplers. IMPROVE samplers are located at regional transport and background sites to satisfy SLAMS requirements (U.S. Environmental Protection Agency, 1997a-b).

4.2.1 $PM_{2.5}$ Federal Reference Method

U.S. EPA (1997b) specifies sampler design, performance characteristics, and operational requirements applicable to the $PM_{2.5}$ FRM in 40 CFR part 50, Appendix L; 40 CFR part 53, Subpart E; and 40 CFR part 58, Appendix A (U.S. EPA, 1997a-d). $PM_{2.5}$ FRMs are intended to acquire deposits over 24-hour periods on Teflon-membrane filters from air drawn at a controlled flow rate through the WINS $PM_{2.5}$ inlet. The inlet and size separation components, filter types, filter cassettes, and internal configurations of the filter holder assemblies are specified by design, with drawings and manufacturing tolerances published in 40 CFR part 53 (U.S. EPA, 1997b). Other sampler components and procedures (such as flow rate control, operator interface controls, exterior housing, data acquisition) are specified by performance characteristics, with specific test methods to assess that performance.

Design specifications of the FRM samplers include the a modified SA-246 PM_{10} inlet (Figure 4-3) that has previously been wind tunnel tested and approved for PM_{10} compliance monitoring. The inlet cover has been extended by 2.5 inches and bent 45° downward to minimize water presentation during rainstorms. Sample air enters the inlet and is drawn through the WINS (Figure 4-4) that is designed to removes particles with aerodynamic diameter greater than 2.5 μm by impacting them on the bottom of an open-topped aluminum cylindrical container. The impacting particles are trapped at the bottom of the well on an oil-impregnated filter (35 to 37 mm borosilicate glass-fiber) impregnated with a low vapor-pressure oil (tetramethyltetraphenyltrisiloxane, maximum vapor pressure 2×10^{-8} mm Hg, density 1.06 to 1.07 g/cm^3, 32 to 40 centistoke viscosity at 25 °C). More than 50% of the particles with aerodynamic diameters less than 2.5 μm follow the air flow through the WINS, which turns up and out of the well and is directed back down to a Teflon-membrane filter where the particles are removed by filtration. The fraction of each particle size passing through the WINS is shown in Figure 4-1. Internal surfaces exposed to sample air prior to the Teflon-membrane filter are treated electrolytically in a sulfuric acid bath to produce a clear, uniformly anodized coating (at least 1.08 mg/cm^2 in accordance with military standard specifications).

Several $PM_{2.5}$ samplers using the WINS and other $PM_{2.5}$ inlets have been operated simultaneously in Birmingham, AL; Denver, CO; Phoenix, AZ; Tucson, AZ; Bakersfield, CA; and Azusa, CA; from November 1996 through May 1997 (Pitchford et al., 1997). Figure 4-5 (Pitchford et al., 1997) compares $PM_{2.5}$ measurements from two WINS samplers with simultaneous measurements from dichotomous and IMPROVE samplers. This comparison and others from areas with different particle size distributions and compositions show a reasonable equivalence between WINS and other $PM_{2.5}$ inlets, as well as collocated precisions of ~0.5 to 1.0 μg/m^3 among WINS samplers.

FRM performance specifications require constant volumetric flow rates (16.67 ± 0.83 L/min) to be monitored and recorded continuously with temperature and pressure of the sample air entering the inlet and near the filter. FRMs are required to maintain the temperature of the filter during and after sampling within ±5 °C of concurrent ambient temperatures regardless of heating and cooling from direct sun or shade during and after sampling. This specification intends to minimize losses from volatile particles such as ammonium nitrate and some organic compounds. Potential FRM designs use active ventilation of the enclosure that surrounds the filter holder and WINS impactor to attain these temperature performance specifications.

FRMs from different manufacturers may vary in appearance, but their principles of operation and resulting $PM_{2.5}$ mass measurements should be the

same within reasonable measurement precisions. Though they may follow the published design specifications, $PM_{2.5}$ samplers are not FRMs until they have demonstrated attainment of the published specifications (U.S. EPA, 1997b) and assigned an FRM number published in the Federal Register.

4.2.2 Class I $PM_{2.5}$ Federal Equivalent Method

Federal Equivalent Methods (FEMs) are divided into several classes in order to encourage innovation and provide monitoring flexibility. This is especially important for chemical characterization, as more than one filter medium is required to account for the significant chemical components.

Class I FEMs meet nearly all FRM specifications, with minor design changes that permit sequential sampling without operator intervention and different filter media in parallel or in series. Flow rate, inlets, and temperature requirements are identical for FRMs and Class I FEMs. Particles losses in flow diversion tubes are to be quantified and must be in compliance with Class I FEM tolerances specified in 40 CFR part 53, Subpart E.

4.2.3 Class II $PM_{2.5}$ Federal Equivalent Method

Class II FEMs include samplers that acquire 24-hour integrated filter deposits for gravimetric analysis, but that differ substantially in design from the reference-method instruments. These might include dichotomous samplers, high-volume samplers with $PM_{2.5}$ size-selective inlets, and other samplers identified in Table 4-6. More extensive performance testing is required for Class II FEMs than for FRMs or Class I FEMs, as described in 40 CFR part 53, Subpart F. Key requirements for Class I and Class II FEM equivalence tests are summarized in Table 4-7.

4.2.4 Class III $PM_{2.5}$ Federal Equivalent Method

Class III FEMs include samplers that do not qualify as Class I or Class II FEMS. This category is intended to encourage the development of and to evaluate new monitoring technologies that increase the specificity of $PM_{2.5}$ measurements or decrease the costs of acquiring a large number of measurements. Class III FEMs may either be filter-based integrated samplers or filter- or non-filter-based *in situ* continuous or semi-continuous samplers. Table 4-8 identifies several types of continuous particle measurement inst ments may be candidates for Class III FEM status.

Watson et al. (1997b) describes these instruments in greater detail and describes current knowledge about how well they approximate $PM_{2.5}$ concentrations under a variety of environmental conditions. Test procedures and

performance requirements for Class III candidate method instruments will be determined on a case-by-case basis. Performance criteria for Class III FEMs will be the most restrictive, because equivalency to reference methods must be demonstrated over a wide range of particle size distributions and aerosol compositions.

4.3 IMPROVE Samplers

IMPROVE (Interagency Monitoring of PRotected Visual Environments) samplers can be used at regional background and transport sites to fulfill SLAMS requirements. IMPROVE samplers were developed for the IMPROVE network (~70 locations shown in Figure 4-6) to quantify PM chemical components that affect visibility at Federal Class I areas that include National Parks, National Monuments, and Wilderness Areas.

IMPROVE samplers consist of up to four parallel filter and inlet combinations (Modules A, B, and C for $PM_{2.5}$; Module D for PM_{10}) controlled by a common timer. All IMPROVE sites have module A to determine $PM_{2.5}$ mass and elemental composition, and additional modules are added when other size fractions and chemical components are desired. Each of the three $PM_{2.5}$ modules utilizes a modified Air Industrial Hygiene Laboratory (AIHL) cyclone as a $PM_{2.5}$ inlet at a flow rate of 23 L/min, a 25 or 47 mm Nuclepore filter holder assembly, a volumetric flow control device, and a pump (Eldred et al., 1987, 1990).

Module A uses a Teflon-membrane filter to measure $PM_{2.5}$ mass by gravimetry (Watson et al., 1995), light absorption (b_{abs}) by the integrated plate method (Campbell et al., 1989), hydrogen by proton elastic scattering analysis (PESA) (Cahill et al., 1971), and elements (Na to Pb) by proton induced x-ray emission analysis (PIXE) (Cahill, 1985). Module B is equipped with an acid-vapor diffusion denuder followed by a nylon filter to measure total (non-volatilized and volatilized) particulate nitrate by ion chromatography (Chow and Watson, 1997c). Module C contains two pre-fired quartz-fiber filters in series to measure organic and elemental carbon on the front filter and to assess the extent of organic artifacts on the backup filter by thermal/optical reflectance analysis (TOR) (Chow et al., 1993b).

To examine the magnitude of nitrate volatilization, Module B can be modified to adapt tandem nylon-membrane or sodium-chloride-impregnated cellulose-fiber filters to measure non-volatilized particulate nitrate on the front filter and volatilized particulate nitrate on the backup filter.

9.0 MONITORING STRATEGIES

The preceding sections identified different methods for PM sampling and chemical analysis. These sections showed that chemical analysis of $PM_{2.5}$ or PM_{10} samples must be closely coupled with the appropriate sampling methods and filter handling procedures. This section organizes that general knowledge into specific steps that can be applied when planning a $PM_{2.5}$ measurement study (Chow and Watson, 1994a). It also emphasizes the importance of field/laboratory integration. The analytical laboratory should be involved at the sampler design stage to assure compatibility among sampling methods, analysis methods, filter media, and lower quantifiable limits.

9.1 General Approach

The first step is to determine the specific monitoring objectives. Compliance determination, health effects evaluation, source apportionment, and control strategy assessment are the most common objectives for $PM_{2.5}$ monitoring. Data from $PM_{2.5}$ speciation monitoring networks may need to be augmented by additional sampling for transition metals, organics, and single particle characterizations. Compliance $PM_{2.5}$ monitoring networks do not provide samples amenable to all chemical analyses because of the limitations of single-filter media. Source apportionment and control strategy evaluation require chemical speciation, so additional measures must be taken when these objectives are to be addressed.

The second step is to determine which chemicals need to be measured and at what levels they are expected. When source apportionment is an objective, it is desirable to obtain chemicals which are present in the sources which are suspected of contributing to $PM_{2.5}$.

The potential contributors can often be determined from emissions inventory summaries in the study area. These inventories should include emissions estimates for suspended particles, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and ammonia (NH_3), if possible. The gaseous precursors are needed to assess whether or not secondary aerosol might contribute to elevated $PM_{2.5}$ concentrations.

When gridded inventories are available, or the locations of point sources are known, these should be examined to determine the locations of emitters relative to sampling locations. The closer the source, the greater the probability that some of the chemicals it emits will be detected at the receptor. Emissions events should be identified, such as prescribed fires, wildfires, construction and demolition activities, and plant upsets.

These may have a different chemical character from the sources which are listed in the inventory. Agricultural extension offices should be contacted to obtain land-use maps and soil conservation surveys. Periods of tilling, fertilizing, and grazing might be indicative of elevated emissions from these activities. Local fire departments, the National Forest Service, the Bureau of Land Management, and other fire management agencies can often supply information on local burning events.

Microinventories are also helpful for identifying potential contributors and the chemical species which correspond to these contributions (Pace, 1979). Microinventories include detailed surveys and locations of vacant lots, storage piles, major highways, construction sites, and industrial operations. These are plotted on a map with notes regarding the visual appearance of each potential emitter. For example, if chimneys are present in a residential neighborhood, this observation is recorded and photographs are taken. Roads in the vicinity of sampling sites are classified with respect to the type of traffic on them and whether or not they have sidewalks and paved shoulders.

Expected emissions cycles should be examined to determine sampling periods and durations. For example, residential woodburning will usually show up on samples taken during the night whereas agricultural burning will usually show up during the daytime. While these two source types may be indistinguishable based on their chemical profiles shown in Figure 3-2, their diurnal cycles will provide convincing evidence that one or the other is a major contributor when both activities occur simultaneously.

Particle size is of value in separating one source from another. Particle size fractions, chemical analyses, sampling frequencies, and sample durations need to be considered because more frequent samples, or samples taken at remote locations, may require a sequential sampling feature to minimize operator costs. Shorter sample durations may require a larger flow rate to obtain an adequate sample deposit for analysis. The types of analyses and size fractions desired affect the number of sampling ports and different filter media needed.

The third step is to calculate the expected amount of deposit on each filter for each chemical species and compare it to typical detection limits listed in Tables 5-1 and 5-2 for the analyses being considered. Urban samples acquire adequate deposits for analysis with flow rates as low as ~20 L/min for as short as 4-hour sample durations. Samples at non-urban sites may require >100 L/min flow rates for 24-hour durations to obtain an adequate deposit for chemical speciation.

The fourth step is to apply, create, adapt, or purchase the sampling system which provides the most cost-effective and reliable means of meeting the monitoring needs. Table 4-6 identifies several sampler designs which have been

applied to PM studies. FRM is used to determine compliance with the $PM_{2.5}$ standards. In complicated situations, however, especially those with many contributing sources, unknown sources, or secondary contributions, more complex sampling systems are needed which do not have reference status. Both reference and research sampling systems have been operated side-by-side in many PM_{10} studies when this is the case, and the same practice can be applied to $PM_{2.5}$ monitoring.

The final step is to create a written program plan which specifies the study objectives, sampling locations, analysis methods, filter media, sampling systems, sampling frequencies and durations, nominal flow rates, methods and schedules for inlet cleaning, calibration and performance tests, filter transport and handling procedures, database management system, data analysis methods, and record keeping protocols. A representative flow diagram of sampling and analysis strategies is shown in Figure 9-1, while Table 9-1 contains a typical outline for a study plan. Such a program plan is essential for assuring that all participants know what roles they are required to carry out as part of a $PM_{2.5}$ study.

The procedure outlined above describes an ideal program which may require several hundred thousand dollars to complete. Such expenditures are often worthwhile when costly pollution control decisions must be made, since these decisions may result in tens of millions of dollars of expenditures. These expenditures cannot always be justified without some pilot studies using existing equipment and samples to provide screening analysis. Sometimes these initial analyses can provide information which is sufficient to design the desired control strategy, and further measurements are not needed. The following sub-sections provide guidance on what can be done with different sampling and analysis configurations in a step-wise fashion.

9.2 Analysis of Archived $PM_{2.5}$ FRM Filters

Current regulations (section 2.8.15 of 40 CFR part 58) require air pollution control agencies to archive $PM_{2.5}$ filters from all SLAMS sites for a minimum of one year after collection (U.S. EPA, 1997a). These filters can be made available for supplemental chemical analysis to provide additional information on $PM_{2.5}$ chemical composition. Elemental, single particle, and/or ion analyses can be applied to these filters subject to the limitations discussed in Section 5 of Guidelines for Speciated Particulate Monitoring.

The archived filters of greatest interest are those which exhibit $PM_{2.5}$ concentrations in excess of 65 $\mu g/m^3$. Filters from all sites within the air quality management area on an exceedance day should be examined, even though the $PM_{2.5}$ standard may not be exceeded at every site. Differences in chemical content among sites, coupled with knowledge of emission source locations, will

assist in determining whether or not chemical contributions have a local or regional effect on $PM_{2.5}$ concentrations. Field and laboratory blanks corresponding to the same lots as archived samples should also be submitted to the same chemical analyses as the exposed filters. The levels of chemical concentrations in these blanks provide information on how the chemical concentrations on the exposed filters should be interpreted.

Depending on the source mixture in the sampled area, the Teflon-membrane filters can be submitted for elemental speciation, single particle, and/or ion analysis with the following options:

- **Option I:** If trace elements, single particle characteristics, and ions are of interest, these samples can be first submitted to non-destructive analyses by XRF or PIXE to determine concentrations of ~40 trace elements between sodium (11) and uranium (92). After the elemental data are evaluated, the Teflon-membrane filters can either be (1) resuspended and re-deposited onto polycarbonate-membrane filters for single-particle analysis of particle size, morphology, and composition; or (2) extracted in DDW for ionic speciation of Cl^-, NO_3^-, $SO_4^=$, NH_4^+, Na^+, and K^+. Because of the hydrophobic nature of Teflon-membrane filters, small amounts of ethanol or other wetting agents should be added to the exposed filter surface to ensure 100% extraction efficiency. Since XRF and PIXE analyses are performed under vacuum to achieve maximum efficiency and sensitivity, some volatile compounds (such as nitrate and chlorine) evaporate during analysis, so the nitrate and chloride measurements are often underestimated.

- **Option II:** If vegetative burning or diesel exhaust is a major emission source in the sampled environment, light transmission measurements can be applied using blank filter b_{abs} as a pre-b_{abs} concentration to provide a first-order estimate of elemental carbon concentration. After light absorption analysis, the same Teflon-membrane filter can also be submitted for analysis of elements, single particles, or ions listed in Option I.

- **Option III:** If secondary inorganic aerosols such as nitrate, ammonium, and sulfate are suspected to be the major components of $PM_{2.5}$, the Teflon-membrane filter can be submitted directly to ionic speciation. This option does not allow additional speciation to be performed since the filter will be destroyed during extraction.

9.3 Variations to FRM or FEM Sampling

If it is known that chemical speciation is anticipated within the State and local monitoring network, some precautions can be taken prior to field sampling. Most importantly, acceptance testing (see Section 5.2) needs to be performed on each chemical to be quantified. If the filter cassette can be modified to accommodate multiple filters, the following options can be taken with the existing FRMs:

- **Option I:** To address nitrate volatilization, modify the existing FRM filter cassette to add a nylon-membrane or sodium-chloride-impregnated cellulose-fiber filter behind the Teflon-membrane filter to measure total particulate nitrate (i.e., non-volatilized plus volatilized particulate nitrate). Note that a physical separation between the Teflon-membrane and impregnated filter is required to avoid cross-contamination due to the wetness of the impregnated filter. Configuring a nylon-membrane filter behind the Teflon-membrane filter will create a much larger pressure drop and may clog the flow due to high flow resistance. This configuration assumes that the anodized aluminum sampling surface in the FRM serves as an adequate nitric acid denuder to remove gaseous nitric acid. To ensure the removal of gaseous nitric acid, anodized denuders can also be installed in the FRM between the PM_{10} and WINS inlets.

- **Option II:** To address organic artifacts, modify the existing FRM filter cassette to add a quartz-fiber filter behind the Teflon-membrane filter to measure gaseous organic adsorption. A drain disc (resistance-free paper disc) can be used to physically separate the Teflon-membrane and quartz-fiber filters. Various versions of organic denuders can also be installed in the FRM between the PM_{10} and WINS inlets to estimate gaseous organic desorption.

- **Option III:** To obtain complete chemical speciation, collocate two FRMs per site. In the first unit, use a Teflon-membrane/drain disc/quartz-fiber filter pack (described in Option II) to measure mass, light absorption, elements, single particle (optional), and artifact organic carbon. If XRF or PIXE non-destructive analysis were performed, these filters can then be submitted for single particle analysis of particle size, shape, color, and additional composition. In the second unit, use a front quartz-fiber filter with backup sodium-chloride-impregnated or nylon filter pack to measure ions ($SO_4^=$, Cl^-, NH_4^+, K^+), non-volatilized and volatilized nitrate, organic and elemental carbon, organics (optional), and transition metals (optional).

In addition to module A of the IMPROVE sampler described in Section 4.3, additional modules B and C can be added to fulfill first-order chemical speciation. In the case of 24-hour sampling, continuous instruments such as Class III candidate FEMs can be collocated at the site to provide a better understanding of diurnal variations of $PM_{2.5}$ concentrations. Sequential samplers can be used to determine multi-day buildup of a variety of sources; it is desirable to have daily samples available that can be submitted to chemical speciation.

9.4 Saturation Sampling

There may be cases where one or more source categories are identified as major contributors to elevated $PM_{2.5}$, but the chemical profiles of specific emitters are too similar to differentiate them from each other. In this situation, Battery-powered Minivol $PM_{2.5}$ portable survey samplers using Teflon-membrane filters can be located within and around the suspected emitters (Watson et al., 1991b; Chow and Watson., 1997b).

If the objective of the study is to characterize fugitive dust sources, mass and elemental analyses are sufficient to separate this source category from others by receptor modeling. If ammonia is suspected to be a major source in the area, a citric-acid-impregnated filter can be placed behind the Teflon-membrane filter to address the spatial variations of $PM_{2.5}$ mass and ammonia (Chow and Egami, 1997). Several studies have applied the portable survey sampling approach to characterize the impact of residential wood combustion. In this case, collocated samplers with Teflon-membrane and quartz-fiber filters are required for full chemical speciation. The major chemical components of $PM_{2.5}$ can be used in spatial receptor models to identify the locations of specific emissions sources.

9.5 Precursor Gaseous Sampling

In cases where secondary ammonium sulfate and ammonium nitrate are major contributors, one or more sites should be operated to obtain precursor concentrations of nitric acid and ammonia gas (e.g., Chow et al., 1993c). In the eastern United States, sulfuric acid and ammonium bisulfate are also important components. In this situation, denuder methods can be applied to obtain accurate measures of the secondary aerosol and the precursor gases. These precursor gas measurements should be accompanied by collocated temperature and relative humidity measures so that equilibrium receptor models (e.g., Watson et al., 1994a) can be applied to determine whether the secondary particles are limited by ammonia or oxides of nitrogen emissions.

TABLES

Table 4-5. U.S. EPA Designated Reference and Equivalent Methods for PM_{10}

Reference/ Equivalent Method[a] (Designation No.)	Sampler Description	Federal Register Citation (Notice Date)
1. Reference method (RFPS-1087-062)	Wedding & Associates PM_{10} Critical Flow High-Volume Sampler (using a cyclone-type inlet, critical flow device, and 203 cm x 254 cm filters).	Vol. 52, 37366 (10/06/87)
2. Reference method (RFPS-1287-063)	Sierra-Andersen (SA) or General Metal Works (GMW) Model 1200 PM_{10} High-Volume Air Sampler System (using a SA- or GMW-1200 PM_{10} impaction-type size-selective inlet and 203 cm x 254 cm filters).	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
3. Reference method (RFPS-1287-064)	Sierra-Andersen or General Metal Works Model 321-B PM_{10} High-Volume Air Sampler System (using a SA- or GMW-321-B PM_{10} impaction-type size-selective inlet and 203 cm x 254 cm filters).	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
4. Reference method (RFPS-1287-065)	Sierra-Andersen or General Metal Works Model 321-C PM_{10} High-Volume Air Sampler System (using a SA- or GMW-321-C PM_{10} impaction-type size-selective inlet and 203 cm x 254 cm filters).	Vol. 52, 45684 (12/01/87) Vol. 53, 1062 (01/15/88)
5. Reference method (RFPS-0389-071)	Oregon DEQ Medium-Volume Sequential Filter Sampler for PM_{10} (using a SA-254 impaction-type PM_{10} inlet and 47 mm Teflon-membrane and quartz-fiber filters. Samples are collected simultaneously onto two filter substrates and can be programmed for up to six days of unattended operation and allow automatic filter-sequencing as filter overloading occurs).	Vol. 54, 12273 (03/24/89)
6. Reference method (RFPS-0389-073)	Sierra-Andersen Models SA-241 and SA-241M or General Metal Works Models G241 and GA-241M PM_{10} Low Volume Dichotomous Samplers (using a SA-246B or G246 impaction-type PM_{10} inlet, 2.5 mm virtual impactor assembly, and 37 mm $PM_{2.5}$ and coarse [PM_{10} minus $PM_{2.5}$] filter holders).	Vol. 54, 31247 (07/27/89)
7. Equivalent method (EQPM-0990-076)	Andersen Instruments Model FH621-N PM_{10} Beta Attenuation Monitor (using a SA-246B impaction-type PM_{10} inlet and 40 mm filter tape).	Vol. 55, 38387 (09/18/90)
8. Equivalent method (EQPM-1090-079)	Rupprecht & Patashnik TEOM Series 1400 and Series 1400a PM_{10} Monitor (using an impaction-type PM_{10} inlet, internal tapered element oscillating microbalance, and 12.7 mm diameter filter).	Vol. 55, 43406 (10/29/90)
9. Equivalent method (EQPM-0391-081)	Wedding & Associates PM_{10} Beta Gauge Automated Particle Sampler (using a cyclone-type PM_{10} inlet and 32 mm filter tape).	Vol. 56, 9216 (03/05/91)
10. Reference method (RFPS-0694-098)	Rupprecht & Patashnik Partisol Model 2000 Air Sampler (using an impaction-type PM_{10} inlet and 47 mm diameter filter).	Vol. 59, 35338 (07/11/94)

[a] Code of Federal Regulations (1988)

Sampling System (Reference)	Particle Size (m)	Inlet	Flow Rate (L/min.)	Sampling Surface	Filter Holders	Filter Media	Features
				Teflon	Savillex PFA Teflon in-line	47mm nylon-membrane 47mm etched poly-carbonate	
Sequential Filter Sampler (SFS) (Chow et al., 1996a)497	PM10	Aluminum medium-volume impactor	20 out of 113	Aluminum	Nuclepore polycarbonate open-face	47mm Teflon-membrane 47mm quartz-fiber	Option to add nitric acid denuders in the sampling stream. Sequential sampling.
	PM2.5	Aluminum medium-volume cyclone	20 out of 113	Teflon-coated aluminum	Nuclepore polycarbonate open-face	47mm Teflon-membrane 47mm quartz-fiber 47mm nylon-membrane 47mm impregnated cellulose-fiber	
California Acid Deposition Monitoring Program (CADMP) Dry Deposition Sampler (Chow et al., 1993c)489	PM10	Aluminum medium-volume impactor	20 out of 113	Aluminum	Savillex open-face	47mm Teflon-membrane 47mm impregnated cellulose-fiber	Includes nitric acid denuders. Sequential sampling.
	PM2.5	Teflon-coated steel medium-volume cyclone	20 out of 113	PFA Teflon-coated aluminum	Savillex PFA Teflon open-face	47mm Teflon-membrane 47mm nylon-membrane	
Versatile Ambient Pollutant Sampler (VAPS) (Pinto et al., 1992, 1993; Mukerjee et al., 1993, 1994; Stevens et al., 1993a-b; Ma et al., 1994) 499-506	PM10, PM2.5	Teflon-coated aluminum low-volume elutriator and Teflon-coated aluminum low-volume virtual impactor	33	Teflon-coated aluminum	University Research Glassware glass filter pack (Model 2000-30F)	47mm Teflon-membrane 47mm etched polycarbonate membrane 47mm quartz-fiber	Includes annular denuders to capture nitric acid, nitrous acid, and sulfur dioxide; and polyurethane foam (PUF) to collect organic compounds.

Table 4-6. Filter-Based Particle Sampling Systems

Sampling System (Reference)	Particle Size (m)	Inlet	Flow Rate (L/min.)	Sampling Surface	Filter Holders	Filter Media	Features
Western Region Air Quality Study (WRAQS) Sampler (Tombach et al., 1987)473	PM15	Aluminum high-volume impactor	113 out of 1,130	Aluminum and copper	Nuclepore polycarbonate in-line	47mm Teflon-membrane 47mm quartz-fiber	
	PM2.5	Steel medium-volume cyclone)	113	Aluminum and copper	Nuclepore polycarbonate in-line	47mm Teflon-membrane 47mm quartz-fiber	
Size Classifying Isokinetic Sequential Aerosol (SCISAS) Sampler (Rogers et al., 1989)381	PM15	Aluminum high-volume impactor	113 out of 1,130	Aluminum and polyvinyl chloride	Nuclepore polycarbonate open-face	47mm Teflon-membrane 47mm quartz-fiber	Sequential sampling.
	PM2.5	Steel medium-volume cyclone	113 out of 1,130	Stainless steel and aluminum	Nuclepore polycarbonate open-face	47mm Teflon-membrane 47mm quartz-fiber	
Southern California Air Quality Study (SCAQS) Sampler (Fitz and Zwicker, 1988; Fitz et al., 1989; Wolff et al., 1991)494-496	PM10	Aluminum medium-volume impactor	35 out of 113	Stainless steel and aluminum	Gelman stainless steel in-line	47mm Teflon-membrane 47mm quartz-fiber	Option to add 20 cm flow homogenizer.
	$PM_{2.5}$	Bendix 240 cyclone	35 out of 113	Teflon-coated aluminum	Gelman Stainless steel	47mm Teflon-membrane 47mm quartz-fiber 47mm impregnated quartz-fiber	Option to add 20 cm flow homogenizer.

Sampling System (Reference)	Particle Size (m)	Inlet	Flow Rate (L/min.)	Sampling Surface	Filter Holders	Filter Media	Features
California Institute of Technology Sampler (Solomon et al., 1988, 1989)126,507	PM10	Aluminum low-volume impactor	16.7	Stainless steel and aluminum	Gelman stainless steel in-line	47mm Teflon-membrane 47mm quartz-fiber	
	PM2.5	Aluminum low-volume cyclone	22	Teflon-coated aluminum and glass	Gelman stainless steel in-line	47mm Teflon-membrane 47mm quartz-fiber 47mm nylon-membrane	
Stacked Filter Unit (SFU) (Cahill et al., 1990)320	PM2.0 to PM3.0	Large-pore etched polycarbonate filters	10	Polycarbonate	Nuclepore polycarbonate open-face	47mm etched poly-carbonate membrane 47mm Teflon-membrane	Uses large-pore etched polycarbonate filters as PM2.5 inlet.
BYU Organic Sampling System (BOSS) (Eatough, 1993; Eatough et al., 1993a-b)404,405,509	PM2.5	Teflon-coated aluminum medium-volume cyclone	140 L/min through inlet and 35 L/min per channel	Teflon-coated stainless steel	University Research Glassware glass filter pack (Model 2000-30F)	47mm quartz-fiber 47mm activated-charcoal impregnated filter (CIF)	A multichannel diffusion denuder sampler to determine semi-volatile organic compounds.
BYU Big Organic Sampling System (BOSS) (Tang et al., 1995)510	PM2.5, PM0.8, PM0.4	Aluminum high-volume virtual impactor	1,130 L/min through inlet, with 11, 60, 93, and 200 L/min per channel	Teflon-coated stainless steel	University Research Glass filter pack (Model 2000-30F)	47mm quartz-fiber 47mm activated-charcoal impregnated filter (CIF) compounds	A multichannel diffusion denuder sampler to determine semi-volatile organic compounds.
Harvard/EPA Annular Denuder System (HEADS) (Koutrakis et al., 1989, 1991, 1992)420,511,512	PM2.5	Teflon-coated low-volume glass impactor	10	Glass	Graseby-Andersen open-face ring	37mm Teflon-membrane 37mm impregnated quartz-fiber	Includes sodium carbonate coated denuders to collect acidic gases (e.g., nitric acid, nitrous acid, sulfur dioxide, organic acids) and citric acid coated denuders to collect ammonia.

Sampling System (Reference)	Particle Size (m)	Inlet	Flow Rate (L/min.)	Sampling Surface	Filter Holders	Filter Media	Features
New York University Medical Center/ Sequential Acid Aerosol Sampling System (NYUMC/ SAASS) (Thurston et al., 1992)440	PM2.5	Teflon-coated glass low-volume impactor	4	Teflon-coated glass	Graseby-Andersen open-face rings	37mm Teflon-membrane 37mm nylon-membrane	Sequential sampling.
Minivol Portable Survey Sampler (Kemp, 1990; Chow and Watson, 1997b)497,513	PM10, PM2.5	Nylon low-volume impactor	5	Polycarbonate	Nuclepore polycarbonate open-face	47mm Teflon-membrane 47mm quartz-fiber	Battery-powered sampler weighs 18 pounds.

Table 4-7. Test Specifications for PM2.5 Equivalence to FRM [a]

Criteria	Specifications
Concentration Range	10 to 200 $\mu g/m^3$
Number of Test Sites	One for "Class I" monitors, two for "Class II" monitors
Number of Samplers	Three FRMs, three candidate samplers
Number of Samples	Class I 24-hour samples: R_j [b] > 40 $\mu g/m^3$ and R_j < 40 $\mu g/m^3$
	Class I 48-hour samples: R_j > 30 $\mu g/m^3$ and R_j < 30 $\mu g/m^3$
	Class II 24-hour samples: a. for $PM_{2.5}/PM_{10}$ ratio > 0.75: R_j > 40 $\mu g/m^3$ and R_j < 40 $\mu g/m^3$, b. for $PM_{2.5}/PM_{10}$ ratio < 0.40: R_j > 30 $\mu g/m^3$ and R_j < 30 $\mu g/m^3$,
	Class II 48-hour samples: a. for $PM_{2.5}/PM_{10}$ ratio > 0.75: R_j > 30 $\mu g/m^3$ and R_j < 30 $\mu g/m^3$, b. for $PM_{2.5}/PM_{10}$ ratio < 0.40: R_j > 20 $\mu g/m^3$ and R_j < 20 $\mu g/m^3$
Collocated Precision	2 $\mu g/m^3$ or 5% (largest)
Regression Slope	1 ± 0.05
Intercept	0 ± 1 $\mu g/m^3$
Correlation	≥ 0.97

[a] U.S. EPA (1997b).

[b] R_j = the minimum number of acceptable sample sets per site for $PM_{2.5}$. R_j must be equal to or greater than 3.

Table 4-8. Continuous Aerosol Sampling and Analysis Systems

Continuous System	Quantity Measured	Methodology
I. Mass Monitors		
Beta Attenuation Monitor (BAM)	Particle mass. Detection limit ~ 5 $\mu g/m^3$ for a one hour average	Beta rays (electrons with energies in the 0.01 to 0.1 MeV range) are attenuated according to an approximate exponential (Beer's Law) function of particulate mass, when they pass through deposits on a filter tape. Automated samplers utilize a continuous filter tape, first measuring the attenuation through the unexposed segment of tape to correct for blank attenuation. The tape is then exposed to ambient sample flow, accumulating a deposit. The beta attenuation measurement is repeated. The blank-corrected attenuation readings are converted to mass concentrations, with averaging times as short as 30 minutes.
Tapered Element Oscillating Microbalance	Particle mass. Detection limit ~ 5 $\mu g/m^3$ for a five minute average.	Particles are continuously collected on a filter mounted on the tip of a glass element which oscillates in an applied electric field. The glass element is hollow, with the wider end fixed; air is drawn through the filter and through the element. The oscillation frequency of the glass element is maintained based on the feedback signal from an optical sensor. The resonant frequency of the element decreases as mass accumulates on the filter, directly measuring inertial mass. The typical signal averaging period is 5 minutes. Temperatures are maintained at a constant value, typically 30°C or 50°C, to minimize thermal expansion of the tapered element.

Continuous System	Quantity Measured	Methodology
Piezoelectric Microbalance	Particle mass. Detection limit ~ 10 $\mu g/m^3$ for a one minute average.	Particles are deposited by inertial impaction or electrostatic precipitation onto the surface of a piezoelectric quartz crystal disk. The natural resonant frequency of the crystal decreases as particle mass accumulates. The changing frequency of the sampling crystal is electronically compared to a clean reference crystal, generating a signal that is proportional to the collected mass. The reference crystal also allows for temperature compensation.
II. Chemical-Specific Monitors		
Sulfur Analyzer, Chemiluminescent	Sulfur dioxide and sulfate. Detection limit ~ 0.05 $\mu g/m^3$ for a 12 minute average	Sulfur species are converted to SO in a hydrogen flame; the SO is reacted with O3 to produce an excited State of SO2. Particulate- and gas-phase sulfur compounds are detected by chemiluminescence emission at 340 nm. Sulfur dioxide and sulfate can be selectively measured by applying a denuder difference approach. Temperature-controlled inlets can be used with chemiluminescent detectors in order to attribute the sulfur to particle-phase compounds based on their evaporation temperatures (e.g., H2SO4 at 120°C; NH4HSO4 and (NH4)2SO4 at 300°C).

Continuous System	Quantity Measured	Methodology
Sulfur Analyzer, Flame Photometric Detection (FPD)	Sulfur dioxide and sulfate. Detection limit ~ 1 $\mu g/m^3$ for a one hour average.	Sulfur species are combusted in a hydrogen flame, creating excited sulfur dimers (S2*). Fluorescence emission near 400 nm is detected by a photomultiplier. The photomultiplier current is proportional to the concentration of sulfur in all species. With the quantitative addition of SF6 to raise the response baseline, the signal/noise ratio can be increased by an order of magnitude. Temperature-controlled and denuder inlets are also used with FPD detectors in order to attribute the sulfur to particle-phase compounds based on their evaporation temperatures. Four out of five FPD systems agreed to within ± 5% in a one-week ambient sampling intercomparison.
Ammonia Analyzer, Fluorescence	Gaseous ammonia. Detection limit < 1$\mu g/m^3$ for a one hour average.	Sampled ammonia is removed from the airstream by a diffusion scrubber, dissolved in a buffered solution, and reacted with o-phtaldialdehyde and sulfite. The resulting i-sulfonatatoisoindole fluoresces when excited with 365 nm radiation, and the intensity of the 425 nm emission is monitored for quantification. The diffusion scrubber might be modified to pass particles while excluding ammonia gas to continuously quantify ammonium ions.

Continuous System	Quantity Measured	Methodology
In-Situ Thermal/Optical Carbon Analyzer	Concentrations of organic and elemental carbon. Detection limit ~ 0.2 $\mu g/m^3$ for a two hour average.	This sampler provides on-line thermal/optical analysis of exposed quartz-fiber filters; the analysis principles are explained in Table X. In the first step, organic carbon (OC) compounds are volatilized by heating the filter to 650°C in a helium atmosphere. The OC vapor-phase compounds are passed through a MnO2 bed heated to 1000°C, where oxidation converts them to CO2. The CO2 is reduced to CH4 in a nickel-firebrick methanator; the CH4 is then measured in a flame ionization detector (FID). To quantify elemental carbon (EC), the temperature is then reduced to 350°C, and oxygen is added to the helium in order to oxidize the EC. The evolved CO2 is reduced to CH4 and measured by the same FID as applied to the OC. Light transmission through the filter is used to correct for charring (pyrolysis) of OC which may occur during the first analysis step. An identical quartz-fiber filter is exposed behind an absolute particle filter, allowing a correction for adsorbed OC vapor artifact. The measurement is calibrated by introducing CH4 standards at the end of each cycle. The system is operated at 8.5 to 9.0 L/min and requires 80 to 240 minutes for a complete filter exposure and analysis cycle, depending on ambient concentrations.
Nitric Acid Analyzer	Gaseous nitric acid. Detection limit < 2 µg/m3 for a one hour average.	Chemiluminescent, luminol, and tunable diode lasers detect nitrogen oxide, nitrogen dioxide, and nitric acjd, respectively. Nitric acid can be reduced to NO or NO_2 prior to detection by the first two units. A sample stream denuded of nitric acid, nitrogen dioxide, and peroxyacetyl nitrate would leave only particulate nitrate. Heating these particles would create nitric acid for measurement by these detectors.

Continuous System	Quantity Measured	Methodology
III. Other Aerosol Properties		
Integrating Nephelometer	In-situ, integrated light scattering from particles and gases; a direct estimate of the aerosol light-scattering coefficient, bscat; lower detection limit ~ 1 mm-1 for a ten minute average.	Ambient gases and particles are continuously passed through an optical chamber; the chamber is generally in the form of a long cylinder illuminated from one side, perpendicular to the long axis of the chamber. The light source is located behind a lambertian diffuser and illuminates the aerosol at visible wavelengths. Light is scattered by particles in the chamber over angles ranging from 0 ° to 180°; mounted behind a series of baffles, a photomultiplier tube located at one end of the chamber detects and integrates the light scattered over about 9° to 171°. The light detected by the photomultiplier is usually limited by filters to wavelengths in the 500 to 600 nm range, corresponding to the response of the human eye. The instrument is calibrated by introducing gases of known index of refraction, which produce a known scattered energy flux. (For this purpose, halocarbon gases must now be replaced by non-ozone-reactive alternatives.) A typical signal averaging period is about 2 minutes.
Coefficient of Haze Sampler (COH)	Optical density of particle deposited on a filter.	Particles are continuously deposited on a filter tape; a detector and light source are used to measure the blank-corrected optical density of the deposit. Though COH is reported in units of 1/1000 ft, the values are not traceable to primary standards.

Continuous System	Quantity Measured	Methodology
Aethalometer	Light absorption, reported as concentration of elemental carbon. Detection limit ~ 10 ng/m^3 elemental carbon for a one minute average.	Ambient air is continuously passed through a quartz-fiber filter tape. A separate portion of the tape is not exposed to the sample stream, and provides an optical reference (blank). Light-absorbing particles such as black carbon cause attenuation of a light beam which is provided by a stabilized lamp behind a diffuser. The difference in attenuation between the exposed and blank segments of the filter tape is proportional to the amount of light-absorbing material collected on the tape. By assuming that all light-absorbing material is black carbon, and that the absorption coefficient of the black carbon is known and constant, the net attenuation signals can be converted into black carbon mass concentrations. The time resolution of the aethelometer is on the order of a fraction of a minute with a flow rate of 5 L/min.
Photoacoustic Spectroscopy	Light absorption, reported as elemental carbon. Detection limit ~ 1.0 μg/m^3 for a one minute average.	Ambient air is aspirated through a resonant chamber, where it is illuminated by modulated (chopped) laser light at a visible wavelength (e.g., 514.5 nm). Light-absorbing particles, principally elemental carbon, absorb energy from the laser beam and transfer it as heating of the surrounding air. The expansion of the heated gas produces pressure pulses at the same frequency as the laser modulation. These pulses are detected by a microphone; its signal is proportional to the amount of absorbed energy. The illumination must be carefully chosen to avoid atmospheric gaseous absorption bands.
Aerodynamic Particle Sizer	Number of particles in different size ranges.	Parallel laser beams measure the velocity lag of particles suspended in accelerating air flows.

Continuous System	Quantity Measured	Methodology
Condensation Nuclei (CN) Counter	Number of nucleating particles (particles larger than about 0.001 μm).	Particles are exposed to high supersaturations (150% or greater) of a working fluid such as water; droplets are subsequently nucleated, allowing detection of the particles by light scattering.
Differential Mobility Analyzer-Spectrometer	Number of nucleating particles in different size ranges (0.01 to 1.0 μm size range).	Particles are classified according to their mobility in an electric field, which is a function of their size; a condensation nuclei counter then counts the population in a size "bin".
Diffusion Battery	Number of nucleating particles in the sub-micrometer size range.	Particles are collected from laminar flows in tubes or channels according to their size-dependent Brownian diffusion mobilities. A condensation nuclei counter or other detector counts the transmitted particles. Data inversion gives input size distributions.
Electrical Aerosol Analyzer	Number of particles in the sub-micrometer size range (0.003 to 1.0 μm).	Particles are collected according to their size-dependent mobilities in an electric field. The collected particles are detected by their deposition of charge in an electrometer.
Optical Particle Counter/Size Spectrometer	Number of particles in the 0.1 to 50 μm size range.	Light scattered by individual particles traversing a light beam is detected at various angles; these signals are interpreted in terms of particle size via calibrations.
Time-of-Flight Mass Spectrometry	Particle sizes and single particle compositions.	Particles in air are introduced into successively lower-pressure regions and acquire high velocities due to gas expansion. Particle size is evaluated by laser light scattering. The particles then enter a time-of-flight mass spectrometer.

FIGURES

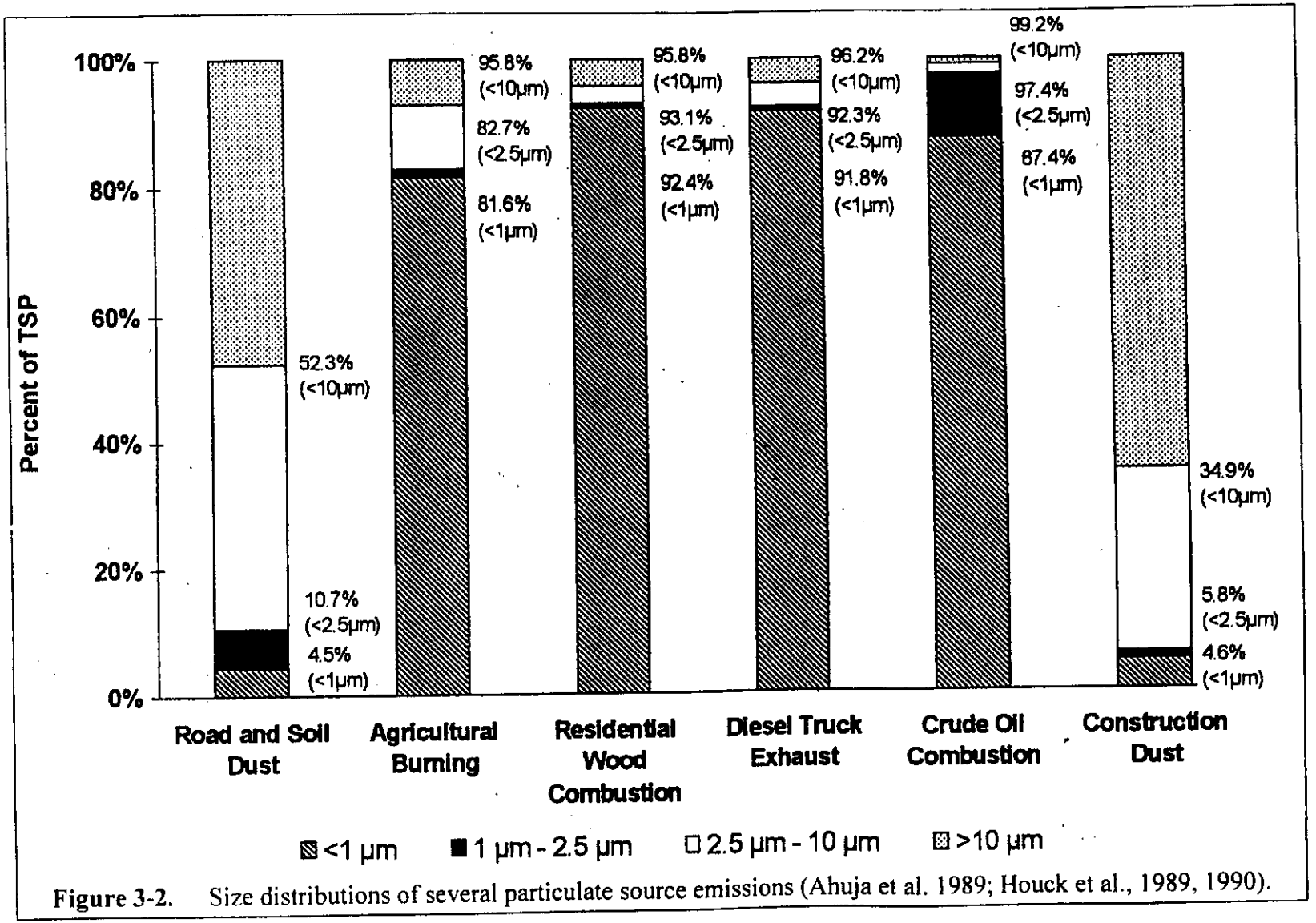


Figure 3-2. Size distributions of several particulate source emissions (Ahuja et al. 1989; Houck et al., 1989, 1990).

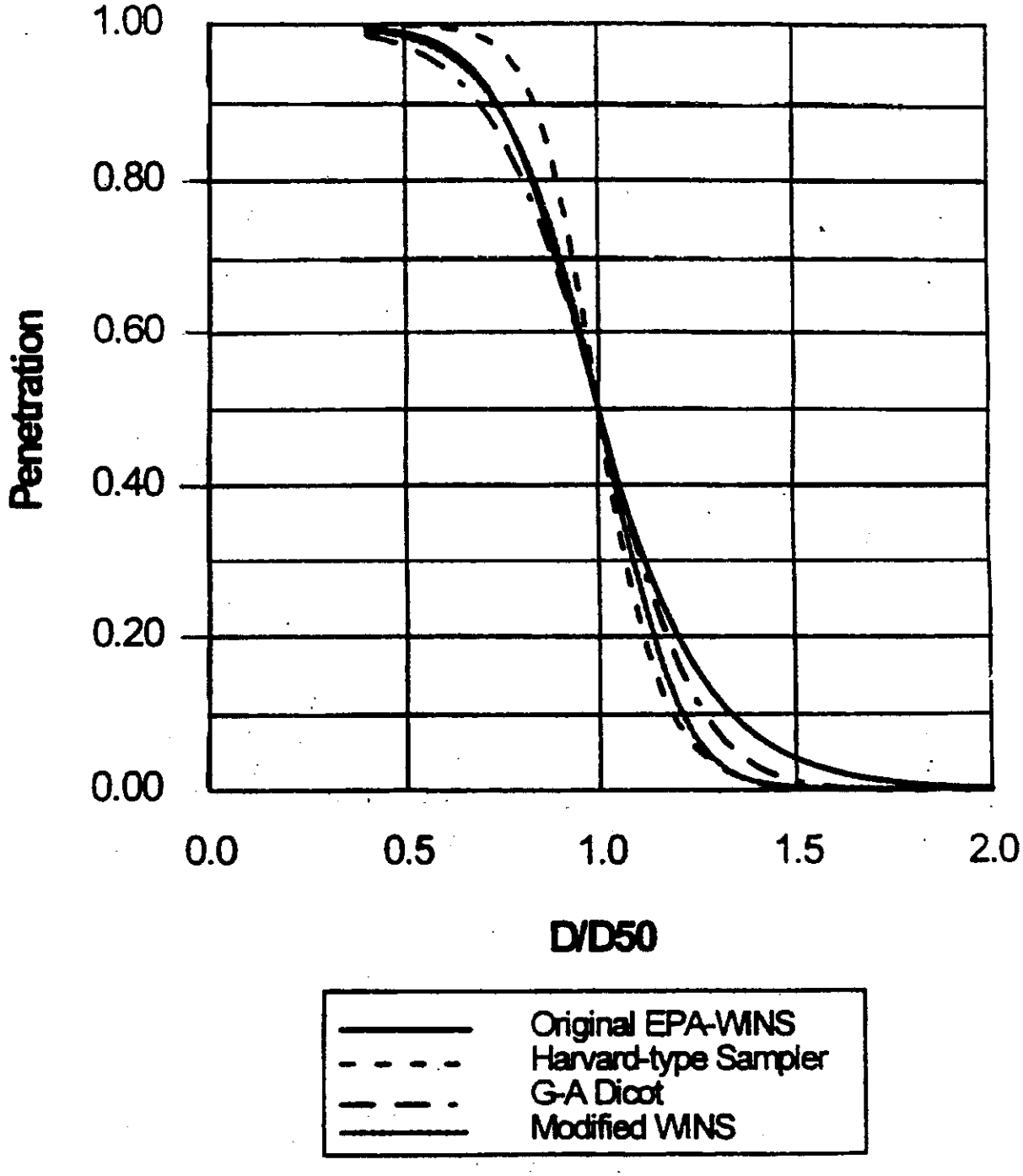


Figure 4-1. Characteristics of sampling effectiveness curves for WINS and other $PM_{2.5}$ inlets.

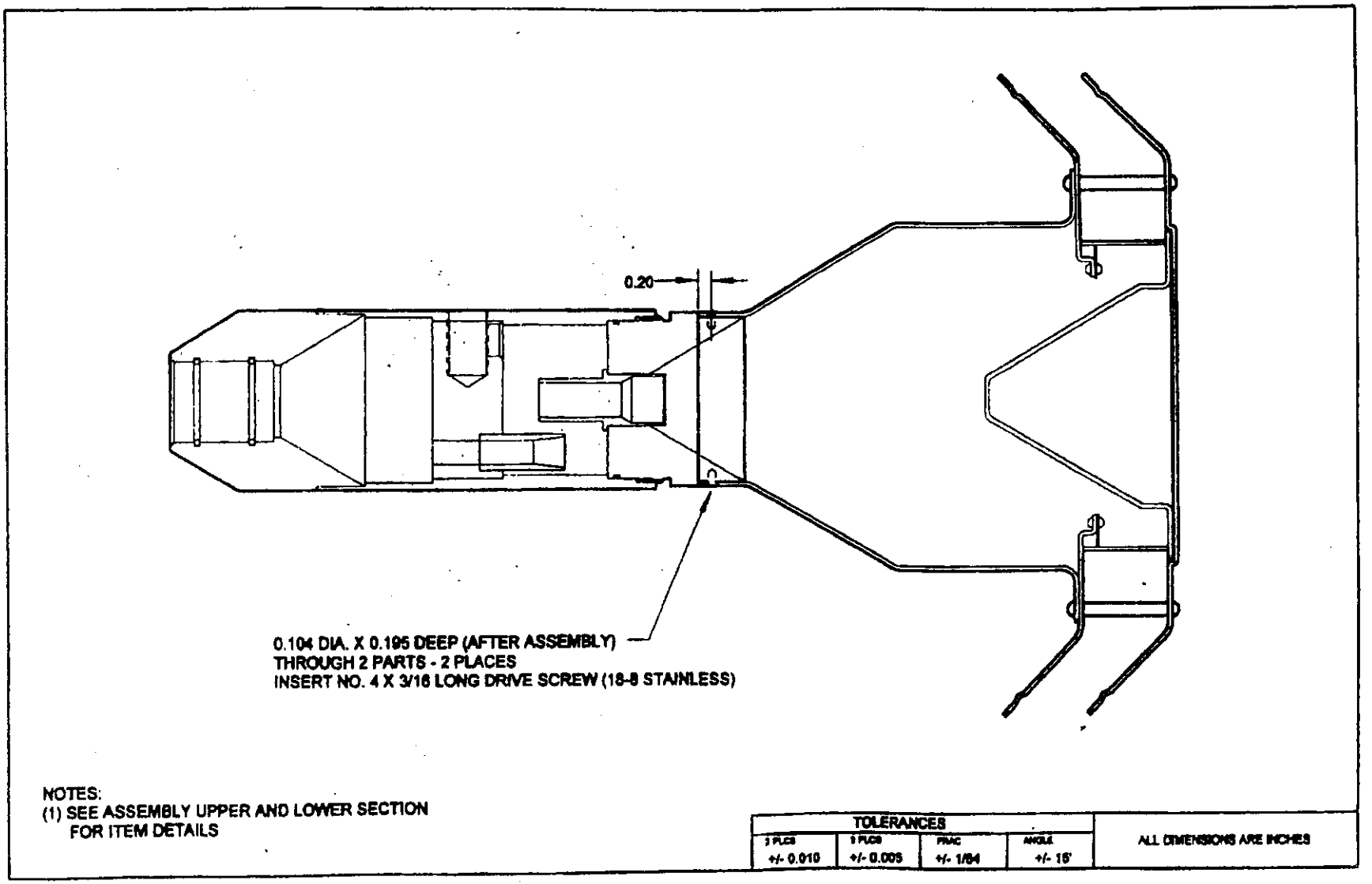
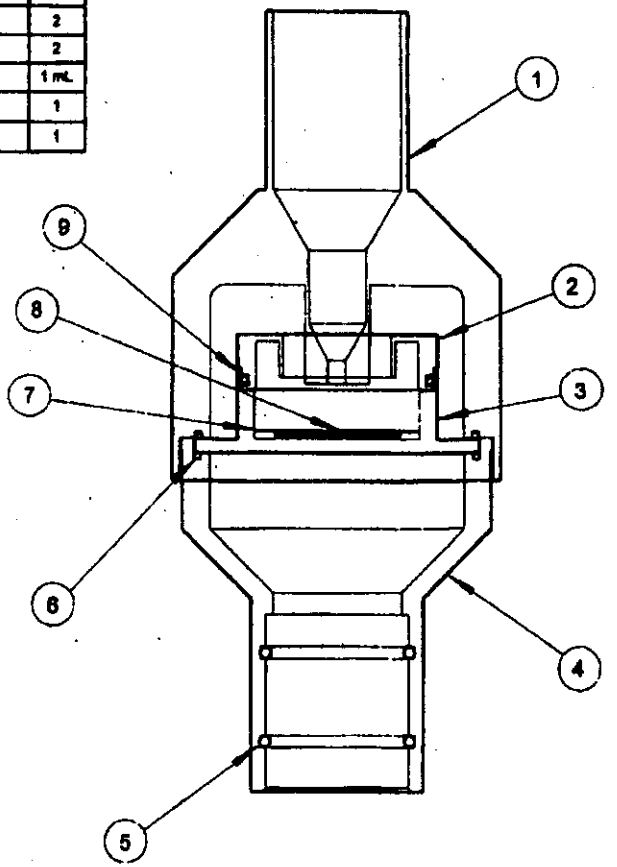


Figure 4-3. Schematic of a modified SA-246 PM_{10} inlet.

ITEM	DESCRIPTION	QTY.
1	2.5-MICRON IMPACTOR HOUSING, UPPER (FIGURE L-21)	1
2	2.5-MICRON IMPACTOR WELL, UPPER (FIGURE L-22)	1
3	2.5-MICRON IMPACTOR WELL, LOWER (FIGURE L-23)	1
4	[illegible] IMPACTOR HOUSING, LOWER (FIGURE L-24)	1
5	O-RING: AS568-028	2
6	O-RING: AS568-036 (VITON®)	2
7	IMPACTION OIL	1 mL
8	FILTER	1
9	O-RING: AS568-030 (VITON®)	1



VITON® IS A TRADEMARK OF DUPONT DOW ELASTOMERS L.L.C.

USE OF THIS NAME DOES NOT CONSTITUTE AN ENDORSEMENT OF EPA.

TOLERANCES				
2 PLCS	3 PLCS	FRAC.	ANGLE	ALL DIMENSIONS ARE INCHES
+/- 0.010	+/- 0.005	+/- 1/64	+/- 15'	

Figure 4-4. Schematic of a WINS $PM_{2.5}$ inlet.

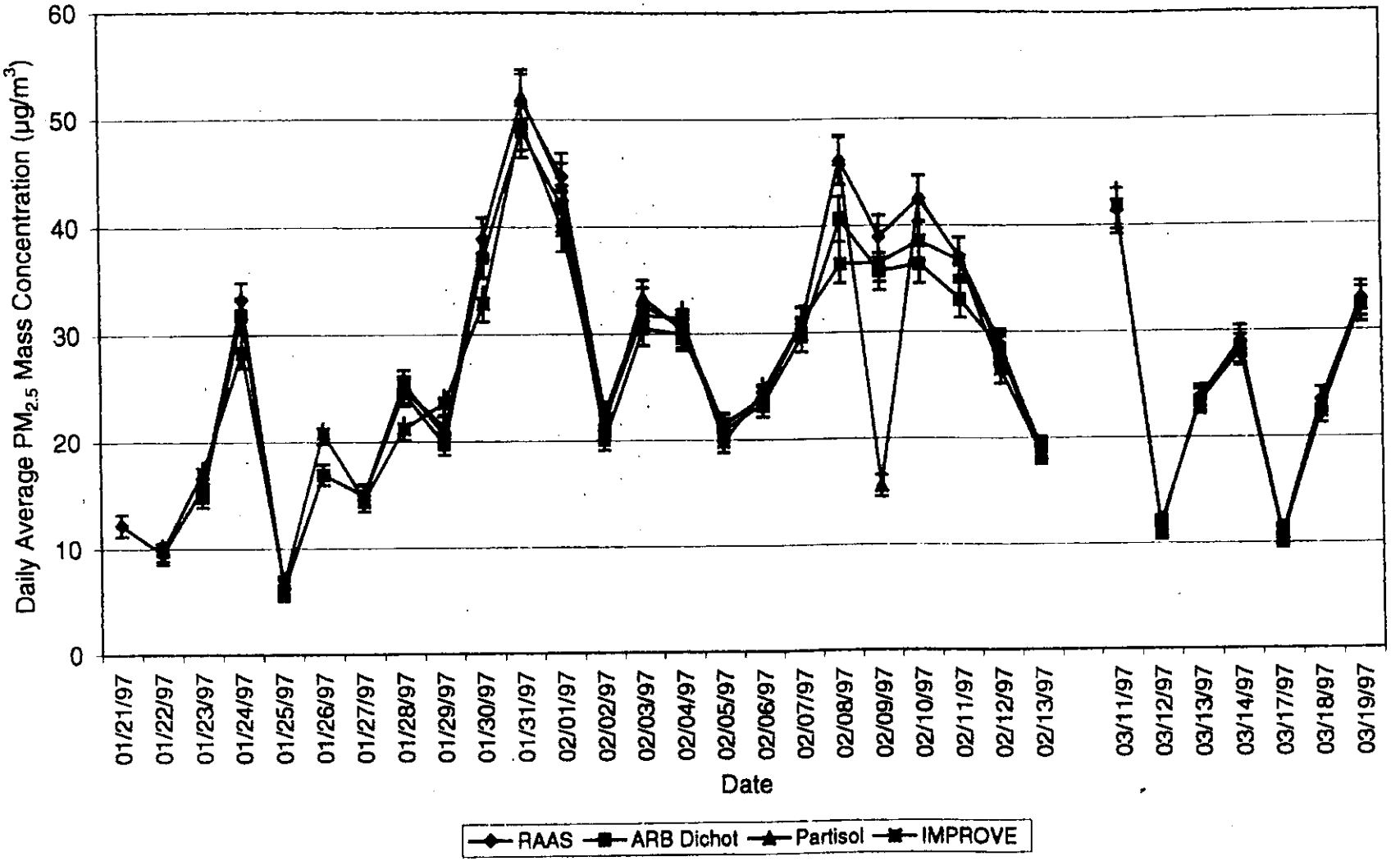


Figure 4-5. Comparison of $PM_{2.5}$ measurements from two WINS samplers with simultaneous measurements from dichotomous and IMPROVE samplers at the Bakersfield site between 01/21/97 and 03/19/97.

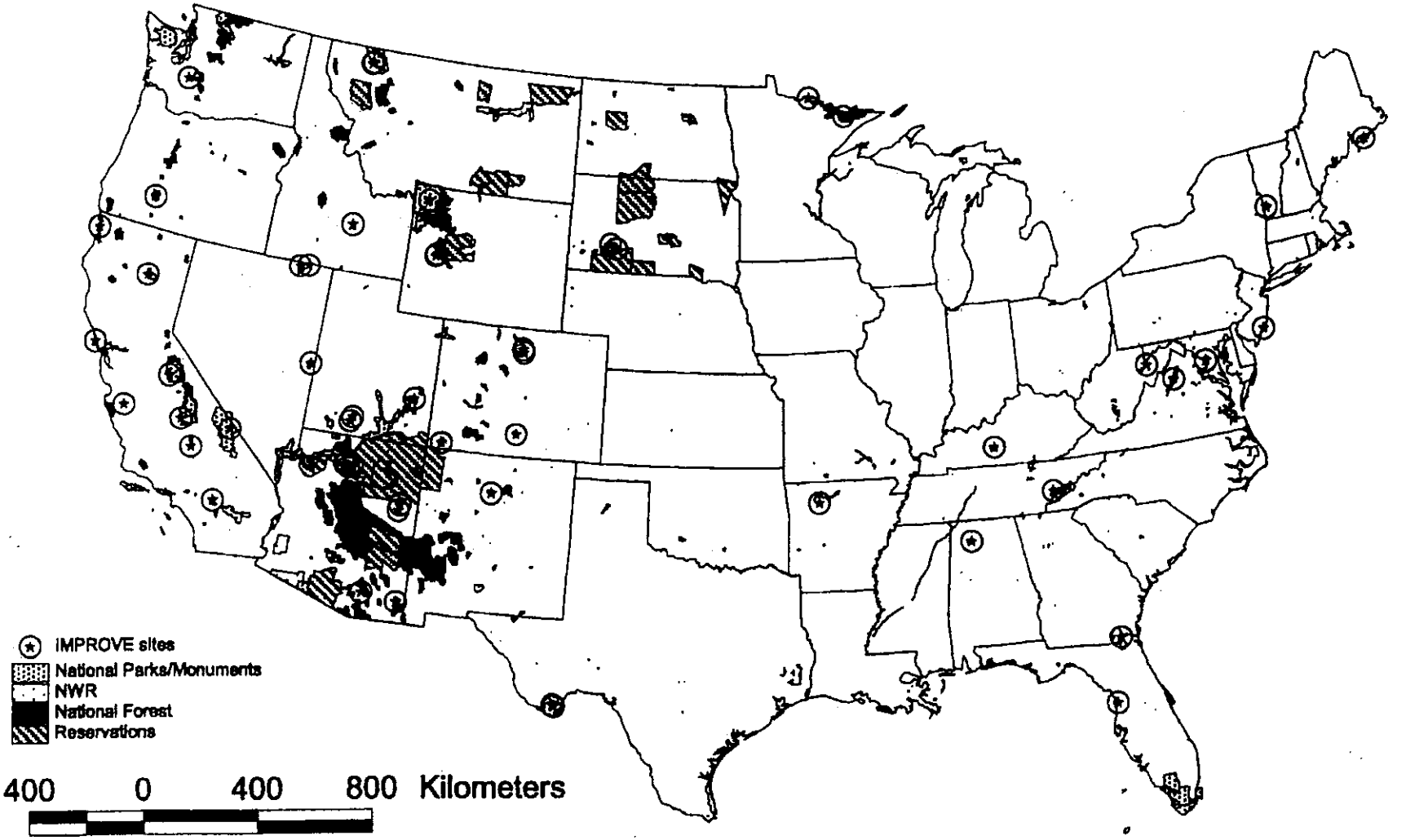


Figure 4-6. National parks and monuments, national wildlife refuges, national forests, Indian reservations, and IMPROVE background monitoring sites.

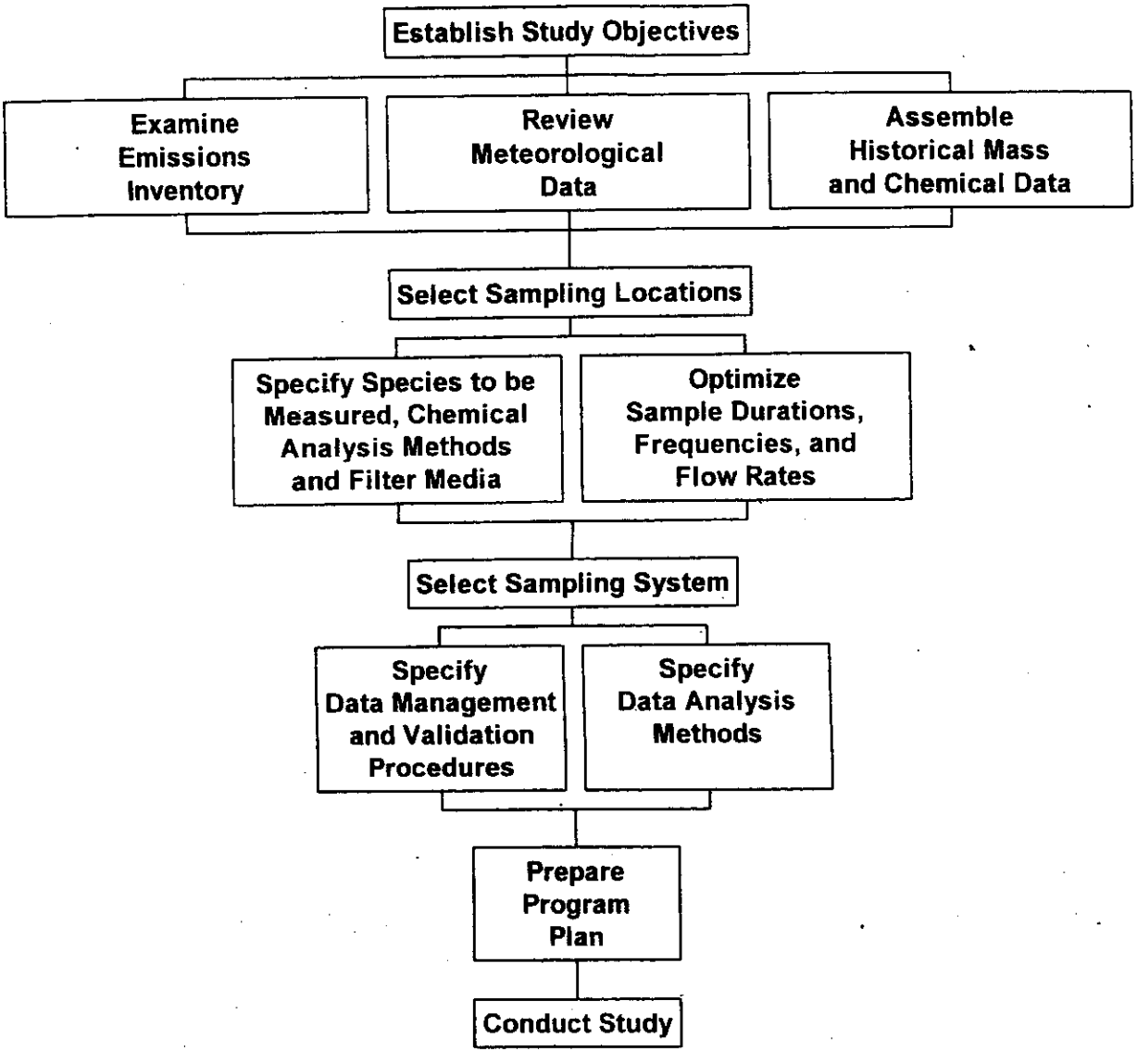


Figure 9-1. Steps in designing a speciated $PM_{2.5}$ study.

BIBLIOGRAPHY

T.A. Cahill, R. Sommerville, R. Flocchini, "Elemental Analysis of Smog by Charged Particle Beams: Elastic Scattering and X-Ray Fluorescence," Nuclear Methods in Environmental Research, pp. 26-29 (1971).

T.A. Cahill, "Proton-Induced X-Ray Emission (PIXE)," in *Metals Handbook: Materials Characterization*, American Society for Metals (1985).

D.S. Campbell, T.A. Cahill, R.A. Eldred, C. Cahill, J. Vesenka, T. VanCuren, "The Coefficient of Optical Absorption Particles Deposited on Filters: Integrating Plate, Integrating Sphere, and Coefficient of Haze Measurements," Document # 89-151.6, presented at the 82nd Annual Meeting (Anaheim, CA), Air & Waste Management Assoc., Pittsburgh, PA (1989).

J.C. Chow, J.G. Watson, J.L. Bowen, C.A. Frazier, A.W. Gertler, K.K. Fung, D. Landis, L.L. Ashbaugh, "A Sampling System for Reactive Species in the Western U.S.," in *Sampling and Analysis of Airborne Pollutants*, E.D. Winegar, L.H. Keith, Eds., Lewis Publishers, Ann Arbor, MI, pp. 209-228 (1993b).

J.C. Chow, J.G. Watson, L.C. Pritchett, W.R. Pierson, C.A. Frazier, R.G. Purcell, "The DRI Thermal/Optical Reflectance Carbon Analysis System: Description, Evaluation, and Applications in U.S. Air Quality Studies," *Atmos Environ.* **27A**:1185-1201 (1993c).

J.C. Chow, J.G. Watson, E.M. Fujita, Z. Lu, D.R. Lawson, L.L. Ashbaugh, "Temporal and Spatial Variations of $PM_{2.5}$ and PM_{10} Aerosol in the Southern California Air Quality Study," *Atmos. Environ.* **28**(12): 2061-2080 (1994a).

J.C. Chow, J.G. Watson, "Imperial Valley/Mexicali Cross Border PM_{10} Transport Study – Final Report," prepared for the U.S. Environmental Protection Agency, San Francisco, CA, by the Desert Research Institute, Reno, NV, 30 January (1997b).

J.C. Chow, J.G. Watson, "Ion Chromatography," in *Elemental Analysis of Airborne Particles*, S. Landsberger and M. Creatchman, Eds., accepted by Gordon and Breach Publishers, USA (1997c).

J.C. Chow, R.T. Egami, "San Joaquin Valley 1995 Integrated Monitoring Study: Documentation, Evaluation, and Descriptive Data Analysis of PM_{10}, $PM_{2.5}$, and Precursor Gas Measurements – Technical Support Studies No. 4 and No. 8 – Final Report," prepared for the California Regional Particulate Air Quality Study, California Air Resources Board, Sacramento, CA, by the Desert Research Institute, Reno, NV, 7 March (1997).

R.A. Eldred, T.A. Cahill, P.J. Feeney, "Particulate Monitoring at U.S. National Parks Using PIXE," *Nucl. Instr. Methods* **B22**:289-295 (1987).

R.A. Eldred, T.A. Cahill, L.K. Wilkinson, P.J. Feeney, J.C. Chow, W.C. Malm, "Measurement of Fine Particles and Their Components in the NPS/IMPROVE Network," in *Transactions: Visibility and Fine Particles*, C.V. Mathai, Ed., Air & Waste Management Assoc., Pittsburgh, PA, pp. 187-196 (1990).

T.G. Pace, "An Empirical Approach for Relating Annual TSP Concentrations to Particulate Microinventory Emissions Data and Monitor Siting Characteristics," Document EPA-45/4-79-012, U.S. Environmental Protection Agency, Research Triangle Park, NC (1979).

M. Pitchford, J. Chow, J. Watson, T. Moore, G. Allen, D. Campblel, R. Eldred, R. Vanderpool, P. Ouchida, S. Hering, N. Frank, "Prototype $PM_{2.5}$ Federal Reference Method Field Studies Report – An EPA Staff Report," prepared by U.S. Environmental Protection Agency, Las Vegas, NV (1997).

U.S. Environmental Protection Agency, "Revised Requirements for Designation of Reference and Equivalent Methods for $PM_{2.5}$ and Ambient Air Quality Surveillance for Particulate Matter – Final Rule," 40 CFR part 58, *Federal Register*, **62**(138):38830-38854, July 18 (1997a).

U.S. Environmental Protection Agency, "Revised Requirements for Designation of Reference and Equivalent Methods for $PM_{2.5}$ and Ambient Air Quality Surveillance for Particulate Matter – Final Rule," 40 CFR part 53, *Federal Register*, **62**(138):38763-38830, July 18 (1997b).

U.S. Environmental Protection Agency, "National Ambient Air Quality Standards for Particulate Matter – Final Rule," 40 CFR part 50, *Federal Register*, **62**(138):38651-38760, July 18 (1997c).

U.S. Environmental Protection Agency, "National Ambient Air Quality Standards for Particulate Matter; Availability of Supplemental Information and Request for Comments – Final Rule," 40 CFR part 50, *Federal Register*, **62**(138):38761-38762, July 18 (1997d).

J.G. Watson, J.C. Chow, C.A. Frazier, D.H. Lowenthal, "Program Plan for an Imperial Valley/Mexicali PM_{10} Source Apportionment Study, Draft Report," DRI Document No. 8623.1D2, prepared for EPA Region IX, San Francisco, CA, by the Desert Research Institute, Reno, NV, 20 December (1991b).

J.G. Watson, J.C. Chow, F. Lurmann, S. Musarra, "Ammonium Nitrate, Nitric Acid, and Ammonia Equilibrium in Wintertime Phoenix, AZ," *Air & Waste* **44**:261-268 (1994a).

J.G. Watson, P.J. Lioy, P.K. Mueller, "The Measurement Process: Precision, Accuracy, and Validity," in *Air Sampling Instruments for Evaluation of Atmospheric Contaminants*, 8th ed., B. Cohen and S.V. Hering, Eds., American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1995).

J.G. Watson, J.C. Chow, D. DuBois, M. Green, H. Moosmüller, N.F. Robinson, C.F. Rogers, N. Frank, M. Pitchford, "Guidance for Using Continuous Monitors in $PM_{2.5}$ Monitoring Networks," prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, by Desert Research Institute, Reno, NV (1997b).

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Review Exercise

Match each the following monitor types in Column A with its description in Column B. Answers May be used once, more than once, or not at all.

Column A	Column B
1. ___ Transport	a. Intended to represent regional-scale $PM_{2.5}$ concentrations that may be a combination of contributions from several MPAs and non-urban source areas.
2. ___ Special Purpose Monitor	b. Intended to assess the effects of emissions within one MPA on other MPAs.
3. ___ Background	c. Used to understand the nature and causes of excessive concentrations measured at community oriented compliance sites.

4. Which of the following is **NOT** a characteristic of a transport site?

   a. Typically located between MPAs
   b. Usually associated with meteorological measurements
   c. Principally used to assess compliance with NAAQS
   d. Assesses effects of emissions from one MPA on other MPAs

5. Non-attainment designations will not be based upon special purpose monitor data for the first _____ years of operation.

   a. three
   b. one
   c. two
   d. four

6. Which of the following is NOT a deployable PM sampling methodology?

   a. Random sampling
   b. Judgemental sampling
   c. Geographic sampling
   d. Systematic sampling

7. Which monitor category is LEAST similar to the Federal Reference Method (FRM)?

   a. Class III Equivalent
   b. Class II Equivalent
   c. Class I Equivalent

8. Test procedures and performance requirements for _____ will be determined on a case-by-case basis.

   a. Class III candidate method instruments
   b. Class II candidate method instruments
   c. Class I candidate method instruments
   d. All non-FRM candidate method instruments

9. The heterogeneous siting strategy developed by Nesbitt and Carter (1996) combined which sampling strategies?

   a. Systematic and random
   b. Random and judgmental
   c. Judgmental and systematic
   d. Random, systematic, and judgmental

10. The upper limit of the mass concentration range is determined by _____

    a. Filter size.
    b. Filter mass loading.
    c. Impactor velocity.
    d. Temperature and humidity conditions.

11. What is the sampler air flow rate required by the $PM_{2.5}$ Federal Reference Method?

    a. 16.67 L/min
    b. 17.66 L/min
    c. 6.67 L/min
    d. 7.67 L/min

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Required Readings

from many nearby monitors (Munn, 1975; Elsom, 1978; Handscombe and Elsom, 1982). Munn (1981) identifies four types of correlation analysis: 1) time correlation (autocorrelation) at one site; 2) cross-correlation of several pollutant concentrations at one site; 3) spatial correlations among simultaneous measurements at different sites; and 4) spatial correlations among different sites with time lags.

2.4.2 Random Sampling

Random sampling locates sites by chance, without taking into consideration the sources of pollutants (Nesbitt and Carter, 1996). Random placement is accomplished by specifying boundaries of a rectangular domain, generating x and y coordinates from a uniform-distribution random number generator truncated at the domain boundaries, and placing samplers as close to these coordinates as practical.

The advantages of random sampling designs are: 1) measurement bias is minimized; 2) implementation simplicity, with no knowledge assumed about the spatial and temporal distribution of concentrations; and 3) sampling locations are objectively chosen. The disadvantages are that: 1) many sampling locations must be allocated for an acceptable sampling error; 2) there is large potential for redundancy in a network with many locations; and 3) there is a large risk of poorly representing exposures in a network with few locations.

Borgman *et al.* (1996) cites an example of how many samplers are required for a certain confidence interval. If the 95% confidence interval is 1 $\mu g/m^3$ with a variance, σ^2, of 6.5 $(\mu g/m^3)^2$ the estimated number of samples is found to be

$$\frac{1.96\sigma}{\sqrt{n}} = 1$$

and solving for n yields 25 samples. This large number of PM sampling sites would only be applicable to a very large urban area, or for a short-term special-study.

From a practical standpoint, random network siting is not a useful model for air quality monitoring. Prior knowledge, though sometimes incomplete, is always available concerning the sources and meteorology that affect PM concentrations in an area. Sampler siting constraints of power, security, and minimum separations from nearby emitters and obstructions impose logistical constraints that prevent a purely "random" selection of measurement locations. The community exposure monitoring philosophy of the new standards is not served by a random-sampling network design.

2.4.3 Systematic Sampling

Systematic sampling locates samplers on a grid system, with one sampler assigned to each grid cell. Noll and Miller (1977) call this type of sampling the "area method". This method is most applicable in flat terrain with a few large point sources. Samplers are placed as close to the center of the cell as practical. This method minimizes sampling bias because of its regular spacing of sensor locations. However, systematic sampling requires a

substantial number of samplers depending on the size of the MPA, and most of these samplers supply redundant information where $PM_{2.5}$ concentrations are spatially uniform.

Systematic sampling costs may be prohibitively high, even for small areas, except for short periods during which spatial uniformity is being evaluated. The positive characteristic of systematic sampling is that the network completely covers the planning area.

2.4.4 Judgmental Sampling

Judgmental sampling (Nesbitt and Carter, 1996) uses knowledge of source emissions and sensitive receptor locations, coupled with mechanisms for pollutant transport, to locate measurement sites. Noll and Miller (1977) call this the "source orientation method" and deem it most appropriate for monitoring point sources in uneven terrain. Air pollution models can be used to assist in this judgment, but this requires exceptional accuracy of the model formulation and the model input data. Few areas in the U.S. have good estimates of particle and precursor gas emissions, especially from mobile and area sources. Complex terrain and meteorology, as well as simulating secondary aerosol formation, also present challenges to currently available models for suspended particles.

Judgmental sampler locations may be determined by data from an existing monitoring network or by identifying the locations of pollutant sources and inferring pollutant transport from data analysis of emissions and wind measurements. Short-term experiments involving spatially dense measurements and modeling may assist in making or verifying judgments.

Monitoring networks for criteria pollutants always use judgmental sampling strategies that consider where source emissions are in relation to populations and which way the wind blows.

2.4.5 Heterogeneous Siting Strategies

Nesbitt and Carter (1996) combine judgmental and systematic sampling by applying the following steps: 1) identify potential sources of contamination or "hot spots" using existing measurements or models; 2) place a grid system over these areas; 3) perform sampling at these grid points; 4) define a systematic grid at points which yield positive contamination; 5) use the systematic grid to assess the remainder of the study area.

Figure 2.4.1 shows how a judgmental strategy compares with a combined judgmental and systematic strategy. The concentration isopleths can be interpolated from spatially dense measurements or produced by an air quality model. The judgmental strategy, by itself, missed areas of significant concentrations, while the combined judgmental and systematic strategy covered the areas of significant concentration that had not previously been monitored.

Another hybrid method for locating potential particulate matter samplers is based on geostatistical sampling (Journel, 1980; Russo, 1984; Kassim and Kottegoda, 1991; Trujillo-Ventura, 1991; Rouhani *et al.*, 1992; Borgman *et al.*, 1996). Kriging is a common method for interpolation to predict unknown values from existing spatial data (Volpi and

Gambolati, 1978; Lefohn *et al.*, 1987; Venkatram, 1988). Kriging uses the correlation

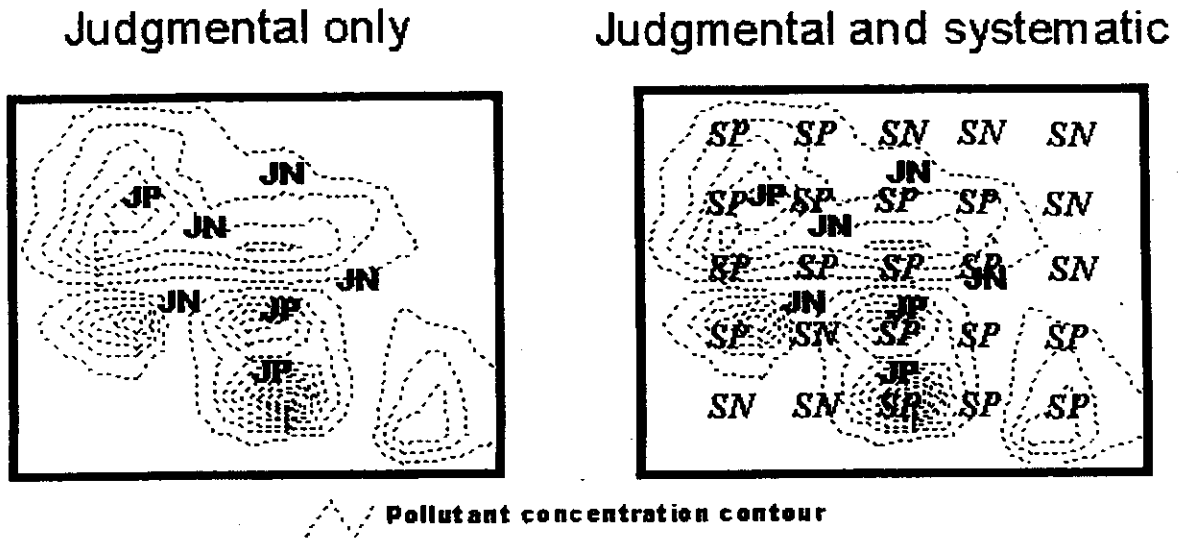

Figure 2.4.1. Examples of judgmental and hybrid sampling strategies.

structure to produce an estimator with the smallest possible mean square error and results in reduced sample size compared to other methods.

Most of this guidance is based on judgmental network design, though it is expected that networks will involve more of the hybrid approach as they are evaluated as future $PM_{2.5}$ measurements and improved aerosol modeling techniques are developed.

2.4.6 Other Siting Strategies

Other statistical tools to design air quality networks include: 1) the coefficient of geographic variation (Stalker and Dickerson, 1962; Stalker *et al.*, 1962); 2) structure functions (Goldstein *et al.*, 1974; Goldstein and Landovitz, 1977); 3) cluster analysis (Sabaton, 1976); 4) principal component analysis (Peterson, 1970; Sabaton, 1976); 5) the variational principle (Wilkins, 1971); and 6) linear programming (Darby et al., 1974; Hougland, 1977).

Modeling relies on a numerical or analytical model to estimate particulate concentrations in space and time. Because of its nature and sources, $PM_{2.5}$ is difficult to model over neighborhood- and urban-scales. As noted above, modeling requires a detailed

emissions inventory over the entire domain. Efforts are being made to archive emissions data in geographical information systems (GIS).

Numerical source-oriented models are designed to simulate atmospheric diffusion or dispersion and estimate concentrations at defined receptors. Numerical source models can be grouped as kinematic, first-order closure, or second-order closure models (Bowne and Lundergan, 1983). Kinematic models are the simplest both mathematically and conceptually. These models simplify the non-linear equations of turbulent motion, thereby permitting a closed analytical approximation to describe pollutant concentration (Green *et al.*, 1980). First-order closure models are based on the assumption of an isotropic pollutant concentration field. Consequently, turbulent eddy fluxes are estimated as being proportional to the local spatial gradient of the transport quantities. The Eulerian grid models, Lagrangian particle models, and trajectory puff/plume models are included in this category. Second-order closure models involve a series of algorithm transformations of the equations of state, mass continuity, momentum, and energy by using the Boussinesque approximation and Reynold's decomposition theory (Holton, 1992; Stull, 1988).

For estimating $PM_{2.5}$ levels, Eulerian models that include aerosol modules simulating the physical and chemical processes governing particulate concentrations in the atmosphere are more suitable than Lagrangian models such as plume trajectory models. Eulerian three-dimensional models may use either a simplified treatment of atmospheric chemistry (usually used to address long-term particulate concentrations at urban sites) or include a more detailed atmospheric chemistry treatment (usually used to simulate only a few days of episodes due to their compositional cost).

Commonly used long-term Eulerian models with simplified atmospheric processes include (Seigneur *et al.*, 1997):

- Urban Airshed Model Version V with Linear Chemistry (UAM-V).
- Regulatory Modeling System for Aerosol and Deposition (REMSAD).
- Visibility and Haze in the Western Atmosphere Model (VISHWA).

Commonly used short-term Eulerian models with complex atmospheric processes include:

- Urban Airshed Model Version V with Aerosols (UAM-AERO),
- Urban Airshed Model with Aerosol Inorganic Module (UAM-AIM).
- SARMAP Air Quality Model with Aerosols (SAQM-AERO).
- California Institute of Technology Model (CIT).
- Gas, Aerosol, Transport, Radiation Model (GATOR).

- Denver Air Quality Model (DAQM).

- Regional Particulate Model (RPM).

All of the above mentioned Eulerian models have been developed by various scientists from universities, federal and state agencies, and the private sector. These particulate air quality models provide a three-dimensional treatment to simulate the fate and transport of atmospheric contaminants. All of these Eulerian models include gas phase chemistry and aerosol dynamics and simulate atmospheric inorganics (such as sulfate, nitrate, and ammonium), but some of these models do not include the treatment of organics (i.e., REMSAD and UAM-LC).

In cases where secondary aerosols may not be a significant fraction of the $PM_{2.5}$ mass, the applicability of these Eulerian models needs to be investigated further. Less complex Gaussian plume dispersion models such as the Industrial Source Complex Model Version 3 (ISC3) and the Fugitive Dust Model (FDM) will continue to be useful in estimating impacts from particulate sources.

Required Readings

Answers to Quiz 2

1. d
2. b
3. d
4. c
5. a
6. a
7. a
8. b
9. a
10. e
11. d
12. c
13. b
14. b
15. a
16. a
17. c
18. a
19. c
20. b

APPENDIX A

Answers to Review Exercises

Lesson 4

1. b
2. c
3. a
4. c
5. c
6. c
7. a
8. a
9. c
10. b
11. a

Lesson 5

1.
   - Identify political boundaries of populated areas.
   - Identify natural air basins.
   - Locate existing air quality monitoring sites.
   - Reconcile boundaries with existing planning areas.
2. a
3. a
4.
   - Locate emissions sources and population
   - Identify meteorological patterns
   - Compare pm concentrations.
   - Adjust cmzs to jurisdictional boundaries
   - Locate sites
5. b
6. d
7. b
8. a
9. b