INTERNATIONAL

Designation: F1471 – 09

Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air Filter System[1]

This standard is issued under the fixed designation F1471; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the procedure and equipment for measuring the penetration of test particles through high-efficiency particulate air (HEPA) filter systems using a laser aerosol spectrometer (LAS). This test method provides the capability of evaluating the overall effectiveness of HEPA filter systems consisting of one or two filter stages.

1.2 The aerosols used for testing have a heterodisperse size distribution in the submicrometer diameter range from 0.1 to 1.0 µm.

1.3 The purpose for conducting in-place filter testing by this test method is in the ability to determine penetration of multi-stage installations, without individual stage tests. Particle penetration as low as 10^{-8} can be measured by this test method. Also, the LAS provides a measure of penetration for discrete particle sizes.

1.4 Maximum penetration for an installed HEPA filter system is 5×10^{-4} for one filter stage, and 2.5×10^{-7} for two stages in series is recommended.

NOTE 1—Acceptance penetration criteria must be specified in the program, or owners specifications. The penetration criteria suggested in this test method is referenced in Ref (**1**).[2]

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in 9.6.

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

F328 Practice for Calibration of an Airborne Particle Counter Using Monodisperse Spherical Particles (Withdrawn 2007)[4]

2.2 *Military Standard:*

MIL-STD 282 Military Standard Filter Units, Protective Clothing, Gas Mask Components, and Related Products: Performance Test Method[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *diluter*—a device used to reduce the aerosol particle concentration to eliminate coincidence counting is in the LAS.

3.1.2 *dilution ratio*—the ratio of the undiluted aerosol particle concentration entering the diluter to the diluted portion of the particle concentration. Because diluters have inherent particle losses that may vary according to the particle size, the dilution ratio may not be constant with respect to size.

3.1.3 *laser aerosol spectrometer (LAS)*—a precision particle detector that allows single particle counting and sizing by the amount of scattered light from individual particles, where the signals can be grouped into categories corresponding to particle size.

3.1.4 *penetration*—the number of particles passing through the filter stage, to the number of particles challenging the upstream side of the filter stage. The penetration, or the challenge aerosol, may be associated for each particle size of interest.

---

[1] This test method is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.05 on Indoor Air.

Current edition approved March 1, 2009. Published March 2009. Originally approved in 1993. Last previous edition approved in 2001 as F1471 – 93 (2001). DOI: 10.1520/F1471-09.

[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

4. Summary of Test Method

4.1 A challenge aerosol produced by Di(2-Ethylhexyl) Sebacate (DOS), Di(2-Ethylhexyl) Phthalate (DOP), or Poly-Alpha Olefin (PAO) is injected upstream of the filter system and allowed to mix with the airstream. Using a LAS, samples of the aerosol are collected from the airstream through probes, both upstream and downstream of the filter system. With this test method, the penetration of the filter system can be calculated either as a function of particle size, or in a particular size of interest. Due to high particle concentrations that may be required to evaluate the performance of HEPA filter systems, it may become necessary to dilute the upstream sample to avoid errors due to coincidence counting by the LAS.

4.2 If a diluter is required, the diluter system is calibrated using lower particle counts of the same aerosol and using the LAS for the measurements (refer to Annex A1 for calibration).

4.3 Heterodisperse submicrometer aerosols spanning the diameter range from 0.1 to 1.0 µm are used in the testing.

5. Significance and Use

5.1 This test method describes a procedure for determining the penetration of aerosols through a one- or twostage HEPA filter installation. Testing multiple filter stages as a single unit eliminates the need for: installation of auxiliary aerosol bypass ducts, installation of aerosol injection manifolds between filter stages, and entry of test personnel into contaminated areas. It provides for filter testing without interruption of plant processes and operation of ventilation systems.

5.2 The procedure is applicable for measuring penetrations requiring sensitivities to 0.1 µm.

5.3 A challenge concentration of 2.5×10^5 particles/cm^3 (p/cm^3), is required for evaluation of one-filter stage, and 2×10^6 p/cm^3, or about 30 µg/L (assuming unit density), is required to properly evaluate a two-stage HEPA filter system as one unit.

5.4 This test method can determine the penetration of HEPA filters in the particle-size range from 0.1 to 0.2 µm where the greatest penetration of particles is likely to occur.

6. Apparatus

6.1 *LAS*—The LAS is a particle detector for the purpose of sizing and counting single particles in a gas stream. Up to 3000 particles per second (p/s) can be counted with less than 10 % coincidence, or electronic loss at its maximum flow rate. The quantitative particle size distribution shall be a distribution by number, not mass, volume, or surface area.

6.2 The test aerosol should be in the diameter range from 0.1 to 1.0 µm.

6.3 The primary particle-size calibration of the LAS by the manufacturer shall be based on at least three sizes of monodisperse polystyrene latex spheres (PSLs), covering the dynamic range of the LAS. Calibration standards must be traceable to the National Institute of Standards and Technology (NIST) or other national standards laboratory.

6.4 Sample flow accuracy through the LAS of ±5 % is required, based on the manufacturer's specifications. (Refer to manufacturer's guide for altitude adjustments of the sample volume.)

6.5 The LAS must have the capability for producing a listing of the particle size distribution over the LAS range.

6.6 For calibration aerosol having a median size two times the minimum detectable size of the LAS, the relative standard deviation of the particle size distribution indicated by the LAS, shall not be increased more than 10 % over the actual relative standard deviation of the calibration aerosol.

6.7 An aerosol diluter is required to reduce the number of particles of the upstream sample to avoid significant coincidence counting losses in the LAS. The diluter must have minimum particle losses over the size range of interest and that the losses are constant with particle size. Calibration of the diluter is done with the LAS. The diluter calibration procedure is indicated in Annex A2. A schematic diagram of the diluter in calibration mode is shown in Fig. A2.1. The diluter calibration plot is presented in Fig. A2.2. A typical diluter with dimensions is illustrated in Fig. A2.3.

6.8 *Aerosol Generation*—It is required that the generator produce a particle-size distribution covering the diameter range from 0.1 to 1.0 µm. It must have the capability of achieving up to 3000 p/s in gas streams when testing multiple-stage HEPA filter systems.

6.9 For streams where large volumes of aerosol are not required, an air-operated or small gas-thermal generator may be used.

6.10 Injection ports, or manifolds, must be provided for distributing the aerosol uniformly with the gas stream. Upstream and downstream probes are required to extract aerosol samples from inside the filter housing. The location of injection ports and sample collection probes or manifolds must be located in accordance with the requirements in Annex A3.

6.11 It is recommended that sample lines between the LAS, diluter, and the upstream and downstream probes be the same size and material, and the same length as practicable.

7. Reagent and Materials

7.1 *DOP, DOS, or PAO* is used as the liquid material to form test aerosols. Concerns about the human health impacts of DOP have been raised by some U.S. government agencies. DOP is also known Di(2-ethylhexyl) phthalate (DEHP), and has the CAS registry number 117-81-7. PAO, whose CAS registry number is 68649-12-7, is considered a suitable substitute for DOP.

7.2 *Polystyrene Latex Spheres.*

8. Calibration and Standardization

8.1 Perform the primary calibration of the LAS by the instrument manufacturer or by qualified personnel using acceptable standard methods in accordance with Ref (**2**). Perform calibrations at regular twelve-month intervals and following any repair or modification of the instrument. Place a label showing the due date of the next calibration on the instrument.

8.2 A check calibration by the operator is recommended periodically if the instrument is used continuously or is moved to a new test location requiring vehicle transportation or rough handling. The calibration check consists of testing the LAS with at least two sizes of PSLs. The LAS must correctly size the calibration aerosols and reproduce the spectral peak to within 0.05 µm. If the instrument cannot be adjusted to within those calibration limits, then it must be returned to the manufacturer for service and calibration. Annex A1 describes a procedure for calibration of the LAS.

8.3 *Aerosol Diluter*—It is recommended that the same aerosol used in the in-place testing be used for diluter calibration. If more than one dilution stage is required, each stage must be calibrated independently. A procedure for calibration of the diluter using the LAS is outlined in Annex A2.

9. Procedure

9.1 An example of an in-place filter test system and sampling arrangement is illustrated in Fig. 1. Components include the gas-flow duct, filter housing with filters, the LAS, diluter, and aerosol generator.

9.2 *Aerosol Mixing Uniformity Tests*—Conduct these tests upon completion of initial installation and after any modifications or repair to the filter system. It is not required to conduct these tests each time the in-place test is performed. However, if aerosol mixing and sampling parameters are changed, then new air aerosol mixing uniformity tests are required. Refer to Annex A3 for procedure.

9.3 Measure the airflow of the test gas stream and the resistance across the filter stage following the procedure outlined in Annex A3.

9.4 Establish the arrangement of sample lines between the probes, the diluter, and LAS. Make the upstream and downstream sample lines as equal in length as practicable.

9.5 Because of expected low particle counts that can penetrate HEPA filter systems, it is necessary to measure the non-test particles in the gas stream to serve as background samples. With no aerosol generation and no sample dilution, use the LAS to sample the gas stream from the downstream sample probe only. Collect samples at this location for the same duration as will be required for the test aerosol. The background particle counts may vary depending on external leaks to the filter housing, but should not exceed 30 % of the expected test aerosol. If higher background particles are found than those suggested and if leaks in the filter housing are suspected, they must be plugged before testing can continue.

9.6 Generate the challenge aerosol at the suggested particle concentration, see 5.3 (**Warning—**Avoid unnecessary loading of the filters by the test aerosols by injecting the aerosols only when ready to perform penetration measurements).

9.7 Collect samples from the upstream probe and establish the challenge particle count. This is accomplished by switching the sample line from the LAS to the diluter. Sampling periods are usually 20 s, refer to Annex A2.

9.8 Purge the sample collection system and zero the LAS before proceeding to the next step in the procedure. The purging procedure is described in A2.1.2 of Annex A2.

9.9 Accumulate two successive samples from the downstream location. Sampling time periods should be selected to yield net particle counts over background of at least 100. A10-min sampling period is usually sufficient. The difference between each set of samples shall not exceed 5 % of the larger count. If penetration of only one filter stage is being measured, shorter sampling times may be used because of higher particle counts. If significant penetration is experienced downstream of one-filter stage and coincidence counting is suspected in the LAS, then the diluter must be used in the sample line. See 6.1 and 6.7.)

10. Calculation

10.1 Calculate the penetration of the filter system for each discrete particle-size. The equation holds for each specific size particle diameter as:

$$P = \frac{C_d - C_b}{C_u D} \quad (1)$$

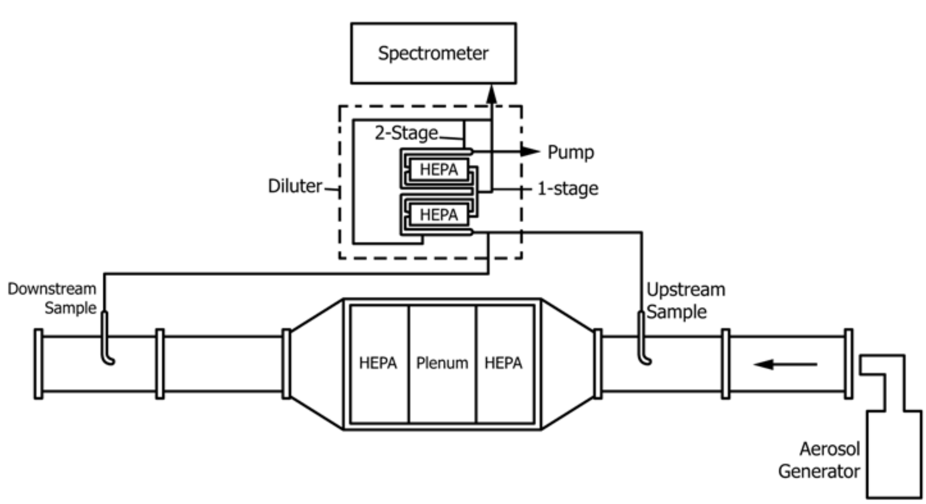

FIG. 1 Schematic Diagram of the In-Place Test Arrangement

where:

P = penetration,
C_d = particle counts downstream,
C_b = particle counts of background,
C_u = particle counts upstream, and
D = dilution ratio.

10.2 To calculate the uncertainty of the upstream and downstream penetration measurements, a theoretical value was used in the following equation. The value is based on standard propagation-of-error techniques neglecting covariance terms and using Poisson statistics to estimate uncertainties. The equation is as follows:

$$CV_p = \left[(PNT_d)^{-1} + (D/(NT_u)) + CV_D{}^2\right]^{1/2} \quad (2)$$

where:

CV_p = coefficient of variation for penetration,
P = aerosol number penetration,
N = undiluted upstream count rate, counts/s,
T_d = downstream counting time, s,
D = dilution ratio,
T_u = upstream counting time, s, and
CV_D = coefficient of variation for dilution ratio.

11. Report

11.1 The results of the testing shall contain, at a minimum, the following items:

11.2 Date of testing,

11.3 Identification of the filter system,

11.4 Penetration values, as a function of particle size,

11.5 The size for reporting the interval data may be either the minimum and maximum diameter for each interval or the geometric mean for the interval, and

11.6 Printed names and signatures of test personnel.

12. Precision and Bias

12.1 *Precision*—The precision of this test method for evaluating the air cleaning performance of a high efficiency particle air-filter system is being determined.

12.2 *Bias*—Since there is no reference material suitable for determining the bias for this test method, no statement on bias is being made.

13. Keywords

13.1 aerosol dilution; aerosol generator; average penetration; background particles; challenge aerosols; coincidence; compressed-air nebulizer; dilution ratio; fractional penetration; HEPA; laser aerosol spectrometer; test aerosols

ANNEXES

(Mandatory Information)

A1. LAS CALIBRATION

A1.1 The calibration procedure uses an aerosol having all particles of one size. Polystyrene latex spheres, (PSLs) are generated using a compressed-air nebulizer. The nebulizer is contained in a metal box with two chambers for diluting and drying the aerosol which contain an air-pressure regulator, dilution air control valve, and rotameter.

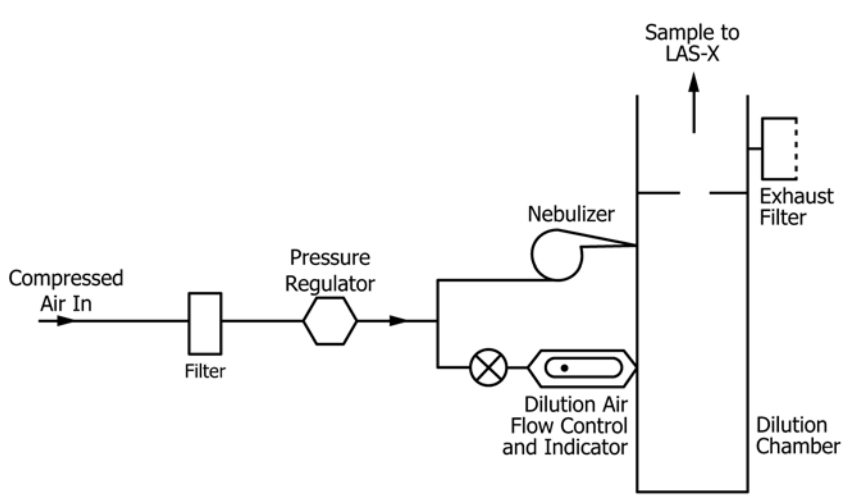

FIG. A1.1 Diagram of PSL Calibration Aerosol Generator

A1.2 A schematic view of the calibration generator is shown in Fig. A1.1. The aerosol generator must be connected to a compressed-air source that will allow the generator's pressure regulator to deliver 250 cm^3/s at standard temperature and pressure of air at 69-kPa pressure. The compressed-air source must not deliver any water droplets to the generator. If water is a concern, install a water trap before the generator. Connect the generator's output directly to sample inlet of the LAS. The nebulizer connects into a rubber stopper in the dilution chamber. The nebulizer has small internal passages for the air jet and the feed tube. These passages can become plugged if the PSL suspension is allowed to dry in the nebulizer. Upon completion of the calibration check, flush out the nebulizer with clean distilled water.

A2. DILUTER CALIBRATION

A2.1 The calibration of a diluter is very similar to that of the filter system penetration measurement. Refer to Fig. A2.1. However, generation of lower particle counts are required for the diluter calibration than for the actual penetration test. It is preferable, but not mandatory, to generate this aerosol in a flow system separate from the system housing of the in-place test to prevent unnecessary loading of the filters. If more than one diluter stage is required, each must be calibrated independently. An example of the diluter calibration plot is indicated in Fig. A2.2, Fig. A2.3. The diluter calibration procedure is as follows:

A2.1.1 Connect the diluter inlet to the flow system with a (HEPA-1) filter cartridge upstream of inlet duct and the diluter, and open Valves C and D. With this arrangement and no aerosol generation, accumulate a background sample with the LAS. Background particle counts are most likely due to leaks in the diluter system and must be eliminated before proceeding.

A2.1.2 Inject test aerosol upstream of the (HEPA-2) filter cartridge and allow a certain portion of the aerosol to bypass the filter by opening Valves A and B. Adjust Valve C to the desired dilution airflow in the diluter with the vacuum pump on. A typical dilution airflow of 250 cm^3/s and a ΔP across the capillary tube of 0.175 kPa are suggested for dilution ratios of 1200 to 1. Open Valve D and allow the LAS to sample the aerosol at the upstream side of the diluter to a level below which causes coincidence counting in the LAS (see 6.1). This sample arrangement establishes the challenge to the diluter. Position Valve D to purge and zero the LAS with filtered air (HEPA-3) before proceeding to the next section.

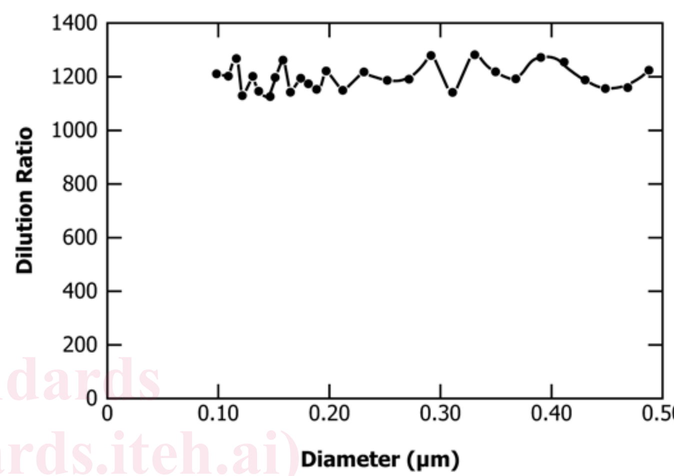

FIG. A2.2 Typical Aerosol Diluter Calibration Plot

A2.1.3 Position Valve D to sample the diluted aerosol at the downstream probe of the diluter and calculate the dilution ratio. The equation holds for each specific size particle diameter as:

$$D = \frac{C_u}{C_d} \quad \text{(A2.1)}$$

where:

D = dilution ratio,
C_u = upstream particle counts, and
C_d = downstream, or diluted particle counts.

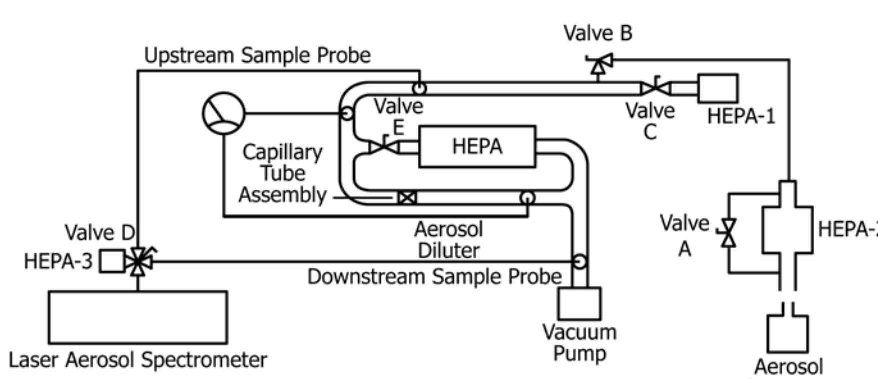

FIG. A2.1 Schematic Diagram of Aerosol Diluter in Calibration Mode

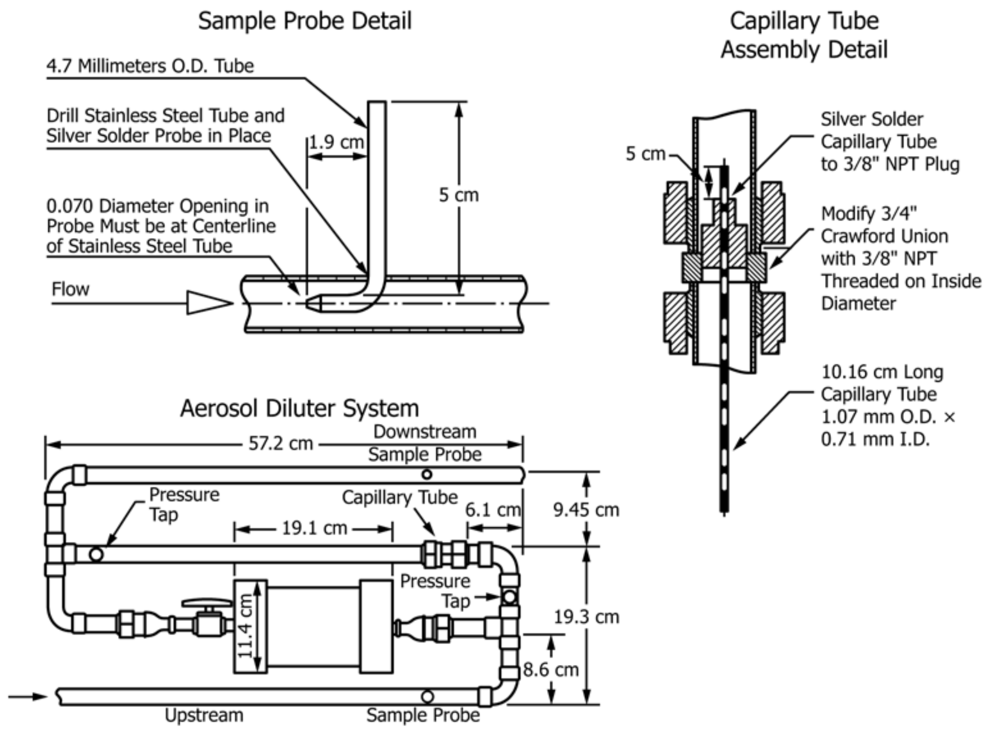

FIG. A2.3 Typical Aerosol Diluter with Dimensions

A2.1.4 Only use the data for the particle size ranges where the dilution ratio remains constant and does not increase by more than 10 % for the overall distribution. Data for particles in sizes above and below that size are not to be used.

A3. AIRFLOW DISTRIBUTION AND AIR-TEST AGENT MIXING TESTS

A3.1 *Purpose*—Perform these tests to verify that the system design airflow is consistent with the fan furnished under actual field conditions at minimum and maximum filter pressure drop, and to verify that the airflow distribution across each HEPA filter stage is uniform at the design flow rates.

NOTE A3.1—These tests are to be performed only during acceptance or after extensive modification to the system, except for the airflow capacity and filter pressure drop test, that are required each time the in-place tests are performed.

A3.2 *Acceptance Criteria:*

A3.2.1 *Airflow Capacity Tests*—The system airflow shall be within ±10 % of the value specified in the test program or project specifications. Maximum housing component pressure drop airflows shall be ±10 % of the value specified in the test program or project specifications with the pressure drop greater than or equal to the maximum housing component pressure drop.

A3.2.2 *Airflow Distribution Tests*—No velocity readings shall exceed ±20 % of the calculated average. The minimum number of velocity measurements shall be one in the center of each filter. Make all measurements at equal distance away from the filters. It is recommended to conduct these measurements downstream of the filters to take advantage of the airflow distribution dampening effects of HEPA filters.

A3.2.3 *Air-Aerosol Mixing Uniformity Tests*—The purpose of this test is to verify that the challenge aerosol is introduced so as to provide uniform mixing in the airstream approaching the HEPA stage to be tested. When acceptable uniformity is achieved, an upstream sample taken in the same position that the uniformity data were obtained is defined as an acceptable single-point upstream sample. No reading shall exceed ±20 % of the calculated average reading.