

Institute of Environmental Sciences and Technology

IENT-RP-CC034.4

Contamination Control Division
Recommended Practice 034.4

HEPA and ULPA Filter Leak Tests



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HEPA and ULPA Filter Leak Tests

IEST-RP-CC034.4

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HEPA and ULPA Filter Leak Tests

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1 SCOPE AND LIMITATIONS

1.1 Scope

This Recommended Practice (RP) covers definitions, equipment, and procedures for leak testing high-efficiency particulate air (HEPA) filters and ultralow-penetration air (ULPA) filters in the factory as they are produced, at the job site before they are installed, and after they are installed in cleanrooms and in unidirectional-flow, clean-air devices. When used in conjunction with other RPs, including IEST-RP-CC001, IEST-RP-CC002, IEST-RP-CC006, IEST-RP-CC007, IEST-RP-CC021, IEST-RP-CC028, and IEST-RP-CC036, this RP may be used to define the basis of an agreement between the customer and supplier in the specification and procurement of HEPA and ULPA filters, and in the testing of these filters in unidirectional-flow, clean-air devices and cleanrooms. This RP also includes procedures for measuring the uniformity of the aerosol challenge approaching the filter under test.

Although the scanning methods in the factory and *in situ* (in the field) appear similar, they are not identical, mainly due to increased variability for *in-situ* testing. In this revision of the RP, the recommended procedures for factory and *in-situ* testing are separated for ease of use. In factory and *in-situ* testing, if a leak is detected while scanning a filter, it is recommended that the magnitude of the leak be quantified with the scanning probe stationary over the detected leak.

1.2 Limitations

This document does not cover in-place testing of banks of filters in nuclear power or nuclear research applications, nor does it cover biological safety or containment cabinets except for scanning of the filters for leaks. This document does not cover leak testing of filters in high-temperature environments. This document provides values of acceptance limits for guidance; however, it is the responsibility of the customer and supplier to specify which leak-test method is used and the acceptance criteria for each application. A brief guideline on *in-situ* leak testing based on the procedures recommended in this RP is provided in section 8.

CAUTION: Testing in accordance with this RP may involve hazardous materials, operations, and equipment. This RP does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use of this RP.

2 REFERENCES

The following documents are incorporated into this RP to the extent specified herein. If no specific edition is cited, the most recent edition should be used. Where specific editions are cited, subsequent revisions of these publications do not automatically supersede the cited editions and users should investigate the applicability of revised editions.

2.1 Reference documents

IENT-RP-CC001: HEPA and ULPA Filters

IENT-RP-CC002: Unidirectional-Flow, Clean-Air Devices

IENT-RP-CC006: Testing Cleanrooms

IEST-RP-CC007: Testing ULPA Filters

IEST-RP-CC013: Calibration Procedures and Guidelines for Select Equipment Used in Testing Cleanrooms and Other Controlled Environments

IEST-RP-CC014: Calibration and Characterization of Optical Airborne Particle Counters

IEST-RP-CC021: Testing HEPA and ULPA Filter Media

IEST-RP-CC028: Minienvironments

IEST-RP-CC036: Testing Fan Filter Units

ISO 14644-1 Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness by particle concentration

ISO 14644-3 Cleanrooms and associated controlled environments—Part 3: Test methods

MIL-STD-282: Filter Units, Protective Clothing, Gas-Mask Components, and Related Products: Performance Test Methods

2.2 Sources and addresses

Referenced documents may be obtained from the following sources:

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ISO (National Standards)

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MIL-STD

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3 TERMS AND DEFINITIONS

The following terms have special meaning in the context of this RP.

aerosol

A gaseous suspension of fine solid or liquid particles.

aerosol generator

A device that can supply an aerosol from an oil or microsphere source, in a concentration range and with a mean size suitable for the measurements described in this RP.

aerosol photometer (or photometer)

An instrument that measures mass concentrations of aerosol using the forward light scattering principle for multiple particle scattering. For the applications described in this RP, the instrument should be capable of measuring aerosol concentrations of up to 100 µg/L and have a threshold sensitivity capable of measuring 0.0001 µg/L. The device should have a detection limit of at least $0.1 \times$ the designated leak. The device should have a volumetric flow rate of 28.3 L/min (1.0 ft³/m).

calibrated equipment

Test equipment that has been calibrated in accordance with the manufacturer's recommendations or accepted industry practices.

challenge aerosol

An aerosol derived from the selected aerosol source material and used as the leak-test challenge for a filter leak test. Challenge aerosols may be produced by a variety of methods, with the choice determined by the aerosol type and the particle size characteristics.

clean-air device, unidirectional flow

A clean work station or other device (other than a cleanroom or clean zone) that incorporates one or more HEPA or ULPA filters and one or more motor-blowers for the purpose of supplying unidirectional-flow, clean air to a controlled work space. **NOTE:** These devices are often referred to as clean benches.

clean zone

A defined space in which the concentration of airborne particles is controlled to specified limits.

cleanroom

A room in which the air supply, air distribution, filtration of air supply, materials of construction, pressure gradients, and operating procedures are regulated to control airborne particle concentrations to meet established air cleanliness levels, as defined by ISO 14644-1.

coincidence loss

A particle concentration level, determined by the DPC electronics and optics, that represents the point where the presence of two or more particles simultaneously in the sensing volume of the instrument causes the instrument to interpret the combined signal erroneously as resulting from one larger particle.

count or number mean diameter of aerosol

The average particle size of the number distribution of the aerosol.

count or number median diameter of aerosol (CMD)

The 50th percentile of the number distribution of the aerosol; i.e., 50% of the particles are smaller than the count median diameter and 50% are larger than the count median diameter.

designated leak

Any penetration that has exceeded the maximum allowable penetration.

diluter

A device that reduces the particle concentration of the challenge aerosol by the dilution ratio of the device. These devices typically mix a known volume of sample air with a known volume of particle-free or filtered air to achieve the dilution. The ratio of the two volumes is the dilution ratio.

discrete-particle counter (DPC)

An instrument, such as an optical particle counter or condensation nucleus counter, capable of resolving and counting responses from individual particles. The device should be capable of measuring and sizing the challenge aerosols

over the particle size range of interest. The threshold size of the DPC should be equal to or smaller than the particle size(s) being measured.

DOP or DEHP

Diethyl phthalate (DOP) or di(2-ethylhexyl) phthalate (DEHP); CAS# 117-81-7.

DOS or DEHS

Diethyl sebacate (DOS) or di(2-ethylhexyl) sebacate (DEHS); CAS# 122-62-3.

Equal velocity sampling

Aerosol sampled at the same velocity as the average velocity exiting the filter (face velocity) within the agreed-upon tolerance, typically -10% to +20%. Not to be confused with the theoretical idea of isokinetic sampling, which is not practical in filter leak testing.

field bench test

A leak tests performed on HEPA or ULPA filters after unpacking at the location of use and prior to installation in the clean-air device or cleanroom. A portable test system is used.

HEPA (high-efficiency particulate air) filter

An extended-medium, dry-type filter in a rigid frame, having a minimum particle collection efficiency of 99.97% for 0.3- μm mass median diameter particles of DOP when tested at the rated airflow in accordance with MIL-STD-282.

NOTE: The foregoing is the traditional definition for the HEPA filter. Changes in the filter manufacture, end-user requirements, and testing have introduced products that vary parametrically from filters that have been considered standard according to this definition. Additional information on this topic is given in IEST-RP-CC001.

integral penetration

The particle penetration associated with the filter efficiency rating assigned by the filter manufacturer. A 99.995% factory rated HEPA filter will have an integral penetration of 0.005%.

Laskin nozzle

A nozzle used as part of a system to generate a heterogeneous aerosol from a liquid, such as PAO, DOP, or other oil, that uses a source of compressed gas as shown in IEST-RP-CC013.

Laskin-nozzle-generated aerosol

An aerosol generated by a Laskin nozzle from PAO, DOP, or other oil.

local leak penetration

The ratio of particle concentration upstream and downstream of the filter as obtained with the stationary scanning probe positioned directly over a leak.

mass mean diameter of aerosol

The particle diameter size that is the average particle size of the mass distribution of the aerosol. Typically, because the mass of a particle varies as the cube of its diameter, most of the mass of an aerosol tends to be in the larger sizes, resulting in the mass mean being larger than its count or number mean.

mass median diameter of aerosol (MMD)

The 50th percentile of the mass distribution of the aerosol; i.e., 50% of the mass of the aerosol is made up of particles smaller than the mass median diameter and 50% of the mass of the aerosol is made up of particles larger than the mass median diameter.

microspheres (or PSL)

Monodisperse or polydisperse sized particles usually made of polystyrene latex (PSL). Monodisperse particle size is traceable to the National Institute of Standards and Technology (NIST) or other national standards bodies with respect to the diameter. **NOTE:** PSL refers to a common type of highly uniform spheres, or a suspension thereof, used to generate a solid aerosol. PSL is useful for leak testing filters where other aerosols may contaminate the filters in an unacceptable manner. The term latex refers to an emulsion in water of finely divided particles of synthetic rubber, plastic, or other elastomer, and is not to be confused with natural rubber latex.

most-penetrating particle size (MPPS)

The particle size at which a given filter has its highest penetration (or lowest efficiency); i.e., the worst-case particle size with respect to filtration efficiency. From filtration theory, the efficiency is higher for particle sizes smaller or

larger than the MPPS. In practice, the MPPS of a filter is considered to be within a measured size range typical in commercial instruments rather than at one unique particle size.

PAO (4 cSt poly-alpha-olefin)

A grade of PAO with a viscosity of 4 centistokes at 100 °C. With reference to filter testing, PAO also refers to a poly disperse aerosol of the described material.

photometer (see aerosol photometer)

PSL (see microspheres)

representative upstream sample

A sample of the aerosol upstream of the filter that is being leak tested, used to set the 100% point of an aerosol photometer or to calculate values for discrete-particle-counter scanning. In factory test systems, in field bench test systems, and in unidirectional-flow, clean-air devices, a method of obtaining a representative upstream sample should be built into the device by the device manufacturer.

sample acquisition time

The time that the DPC accumulates counts before automatically resetting to zero and restarting counting. Some counters can be set to count continuously.

scanning

A method for disclosing leaks in HEPA and ULPA filters where the inlet of the scanning probe of an aerosol photometer or discrete-particle counter is moved in a series of parallel, slightly overlapping strokes across the test area at a distance of approximately 2.5 cm (1 in.) from the filter face and at a rate based on the leak penetration to be detected and the upstream concentration of the challenge aerosol.

scanning probe

A particle-sampling probe having a rectangular opening with a minimum width of 10 mm (0.4 in.) parallel to the direction of the scan.

standard local penetration

The penetration that would be measured by an aerosol photometer or DPC with a 28.3-L/min (1.0-ft³/min) sample flow rate when the sample probe is stationary.

super ULPA (ultra-low-penetration air) filter

An extended-medium, dry-type filter in a rigid frame, made with a filter medium having a minimum particle collection efficiency of > 99.9999% (i.e., a maximum particle penetration of < 0.00010%) for particles of the most-penetrating particle size (MPPS) when tested at the average medium velocity in the filter in accordance with the methods of IEST-RP-CC021.

thermal generator

A device that produces a liquid aerosol by means of an evaporation-condensation process in the absence of controlled nucleation. The particle size distribution and mass median diameter (MMD) of an aerosol produced by a thermal generator are measurably different from those of an aerosol from a Laskin nozzle.

thermally generated aerosol

An aerosol generated by quenching (condensing) vapor that has been evaporated from oils such as PAO or DOP by heat.

ULPA (ultra-low-penetration air) filter

A throwaway, extended-medium, dry-type filter in a rigid frame, having a minimum particle-collection efficiency of 99.999% (that is, a maximum particle penetration of 0.0010%) when tested in accordance with the methods of IEST-RP-CC007. ULPA filters are defined and described in IEST-RP-CC001.

unidirectional airflow

Air that flows in a single pass in a single direction through an air device or clean zone with generally parallel streamlines. **NOTE:** In previous cleanroom literature references, this phenomenon was commonly referred to as laminar airflow.

work zone

The volume within the clean-air device or cleanroom that is designated for clean work and for which testing is required. The work zone volume is defined by an entrance plane and an exit plane (normal to the airflow where there is unidirectional airflow).

4 BACKGROUND AND PURPOSE

HEPA and ULPA filters such as those used in cleanrooms, clean benches, and other clean-air devices are tested for particle removal efficiency and resistance to airflow when they are manufactured. Frequently, these filters are scanned for leaks as an additional precaution. This scanning is commonly performed by the filter manufacturer before the filters are packaged and shipped. The scan test may be repeated as a field bench test when the filters are unpacked at the customer location before the filters are installed. If product is exposed or located immediately downstream of the HEPA or ULPA filter(s), a scan test is often performed after the filters are installed, *in situ*, to verify the integrity of the filter and its installation. Typically, the *in-situ* scanning is repeated at regular time intervals to verify the continued integrity of the filtration system. If the filters are remote to the cleanroom (clean zone), a test to determine the total leakage of the filter installation is adequate.

Leak testing HEPA and ULPA filters is one important part of verifying their performance, as manufactured and in use. Other tests, such as those described in IEST-RP-CC001, IEST-RP-CC002, IEST-RP-CC006, IEST-RP-CC007, IEST-RP-CC021, IEST-RP-CC028, and IEST-RP-CC036, are also important for characterizing the performance of HEPA and ULPA filters, clean-air devices, and cleanrooms.

The choice of which test procedures are required depends on the performance level of the filters, clean-air device, or cleanroom, and on the intended application. Specific test requirements are the result of an agreement between the customer and supplier.

This RP provides a set of recommended procedures for testing HEPA and ULPA filters for leaks. Two methods are provided for scanning the downstream surface of HEPA and ULPA filters for leaks. One method is provided for determining if there are leaks in inaccessible HEPA and ULPA filters. Section 5 provides guidance for selecting the appropriate leak-test method.

The recommended procedures for factory and *in-situ* testing are separated as follows for ease of use:

- Factory filter scan test: aerosol photometer method (section 7.2.1) and discrete-particle counter (DPC) method (7.2.2).
- *In-situ* filter scan test: aerosol photometer method (section 8.3) and DPC method (Appendix H1).
- Total leakage test (*in situ*): aerosol photometer method (section 8.4) and DPC method (Appendix H2).

When purchasing HEPA or ULPA filters, or a clean-air device or cleanroom containing HEPA or ULPA filters, the appropriate sections of this RP should become part of the purchase order to define the expected performance of the filters as received.

5 CHOICE OF TESTS

This section provides guidance for selecting leak-test methods, materials, and criteria. Selection of a specific method, aerosol material, and criterion is the responsibility of the user. The test method, aerosol material, and criteria should be an explicit part of the agreement between the customer and supplier for the filters, clean-air device, cleanroom, or testing services.

Table 1 summarizes the selection process.

Table 1. Guide for selecting appropriate leak-testing strategies.

Condition	Aerosol photometer	Discrete-particle counter (DPC)
Filter type per IEST-RP-CC001		
HEPA (Type A)	Total leakage test method as installed only (section 8.4). No factory test.	Refer to ISO 14644-3
HEPA (Type B)	Two-flow leak test in factory ¹	Two Flow leak test in factory ¹
HEPA (Type C)	Yes	Caution ²
HEPA (Type D)	Yes ³	Caution ²
HEPA (Type E)	No test	No test
ULPA (Type F)	No	Yes
Super ULPA (Type G)	No	Yes
HEPA (Type H)	Total leakage test method as installed only (section 8.4). No factory test.	Refer to ISO 14644-3
HEPA (Type I)	Yes ¹	Two-flow leak test in factory ¹
HEPA (Type J)	Yes ⁵	Caution ^{2, 5}
HEPA (Type K)	Yes ⁵	Yes ⁵
Use/application		
ISO Class 6 ⁹ and less clean	Yes	Not recommended
ISO Class 5 ⁹	Yes	Yes
ISO Class 4 ⁹	Caution ^{3, 4, 5}	Yes
ISO Class 3 ⁹ and cleaner	No	Yes
Remote mount filters	Total leakage test method (section 8.4)	Refer to ISO 14644-3
V-bank filters	Total leakage test method (section 8.4)	Refer to ISO 14644-3
Semiconductor, disk drive, optics	Caution ^{3, 4, 5}	Yes ⁵
Pharmaceutical	Yes	Caution ⁶
Test method/location		
Factory	Yes ⁷	Yes ⁷
Bench test	Yes	Yes
Manual or automatic scanning	Yes	Yes
Particle counter		
≥ 5 count defines leak (Np)	Not applicable	Counter should have continuous or long duration count mode with beep output per each particle detected
Aerosol material		
Polystyrene latex (PSL)	No	Yes
PAO	Yes	Caution ⁹
DOP CAS# 117-81-7	Yes	Caution ⁹
Other	Customer/supplier agreement ¹⁰	Customer/supplier agreement ¹⁰

NOTES:

¹ Test using total leakage test method for installed filters (sections 8.4 and Appendix H2). Filter may not pass a filter media scan test.

² Leak criteria should be less stringent than 0.010% (0.005% for type D), especially if particle size near the most penetrating particle size (MPPS) is used.

³ Membrane-type ULPA filters (PTFE or ePTFE) may exhibit a rapid increase in filter resistance when using oil-based aerosols.

⁴ Aerosol photometer should be sensitive enough to detect below designated-leak levels.

⁵ If filter use application does not permit testing using oil-based aerosols, an aerosol photometer cannot be used. Use DPC with microspheres (PSL).

⁶ Suitability depends on US Food & Drug Administration (FDA) or other regulatory acceptance.

⁷ Factory test method should be based on customer use needs and methods of test for field certification.

⁸ Liquid aerosol should be introduced with caution into DPCs as optics contamination is an operational concern that may impact testing accuracy.

⁹ Cleanliness classes per ISO 14644-1.

¹⁰ By agreement between customer, supplier, and filter testing agency, other aerosol material may be used.

NOTE: The test procedures described in this RP involve introducing an aerosol upstream of a HEPA or ULPA filter, a clean-air device or cleanroom, or into the environment of a clean-air device or cleanroom. HEPA and ULPA filters, clean-air devices, and cleanrooms are used to provide clean environments. Introduction of the aerosols may contaminate the filter, the clean-air device or cleanroom, equipment in or around the clean-air device or cleanroom, product in or around the clean-air device or cleanroom, or the surrounding area.

Aerosols to be used when testing clean-air devices should be specified in agreements with contractors testing the clean-air device. Examples include but are not limited to:

- DOP or DEHP
- DOS or DEHS
- mineral oil
- oleic acid
- PAO (US patents concerning the use of PAO for efficiency testing filters are listed in Appendix I)
- PSL

The use of ambient aerosols is not acceptable. The size distribution, concentration, and material of ambient aerosols vary from location to location and from time to time. The variability of ambient aerosols means that the leak-test results are not repeatable. The concentrations are normally too low. The unknown characteristics of ambient aerosol make it difficult to establish leak criteria. Increase in resistance to airflow due to loading may be observed, depending on the test aerosol and concentration utilized in cases when filter media such as expanded polytetrafluoroethylene (ePTFE) membranes are used in the construction of the filter.

NOTE: Some particles will penetrate the filter medium even in the absence of any leak. The particles penetrating the unbroken medium will be detected by the aerosol photometer or DPC used to scan the filter. The reading or counts from the particles penetrating the unbroken filter medium gives an inherent background penetration (i.e., the nominal penetration of the filter usually noted on the filter label. In order for a scanning procedure to be practical, the designated-leak penetration criterion should be substantially greater than the background level. It is recommended that the designated-leak penetration be a minimum of five times the background level.

The efficiency of HEPA and ULPA filters is strongly dependent on particle size and airflow velocity. Therefore, the background level is a strong function of the aerosol and filter flow rate used for scanning. There are numerous combinations of particle size, flow rate, designated-leak criteria, filter efficiency, and scanning methods that work. Listing all of the possibilities and related recommended practices is outside the scope of this RP. Appendix A describes selected situations. In an unusual situation, the methods outlined in this RP may be used to develop an appropriate leak-testing practice.

6 GENERAL CONSIDERATIONS FOR LEAK TESTING

When leak testing filters, there are several considerations and requirements that apply whether the filter is tested for leaks on a test bench, in the factory, or as installed in the field. This section outlines the recommended minimum requirements and considerations to obtain consistent and valid leak test results.

6.1 Instrumentation

This section lists the main instruments and hardware required for leak testing filters in accordance with the procedures outlined in sections 7, 8, and Appendix H. The minimum specification requirements are also provided as a guideline. Whereas hardware with more stringent specifications may be used without concern, use of less stringent specifications for hardware and instruments will lead to poor quality leak-test results and therefore is discouraged. All hardware (DPCs, diluters, photometers, flow devices) should be in calibration per IEST-RP-CC013, IEST-RP-

CC014, manufacturer guidelines, or an equivalent standard. The accuracy of all measurements should be $\pm 10\%$ of the reading unless otherwise specified. It is also good practice not to make measurements at the extremities of the sensitivity range of an instrument. Regardless, in all cases, the operating instructions, flow rates, and limits provided by the test equipment manufacturer should be followed during filter testing.

6.1.1 Aerosol photometer

This instrument measures mass concentrations of aerosol using the forward light scattering principle for multiple particle scattering. For the applications described in this RP, the instrument should be capable of measuring aerosol concentrations of up to 100 $\mu\text{g/L}$ and have a threshold sensitivity capable of measuring 0.0001 $\mu\text{g/L}$, which in most cases will ensure that leak concentrations measured are well above the threshold sensitivity. The photometer should have a detection limit of at least $0.1 \times$ the designated leak and a volumetric flow rate of 28.3 L/min (1.0 ft^3/min). The photometer should be calibrated in accordance with IEST-RP-CC013.

6.1.2 Discrete-particle counter (DPC)

The discrete-particle counter (DPC) is a light-scattering instrument that uses display, recording means, or both to count and size discrete particles in air. The DPC should have a sample flow rate of 28.3 L/min (1.0 ft^3/min) and have the capability to detect the particle sizes designated in the challenge aerosol. The minimum particle size of interest is a matter of agreement between the device owner and the tester. It is recommended that the lower size sensitivity of the DPC used is at least the same as the particle size of interest, to as low as 0.1 μm . For leak testing, especially in the field, it is recommended that a particle size larger than the smallest size sensitivity of the DPC be considered.

For example, 0.3 or 0.5 μm is preferred to 0.1 μm . The known concentration limit of the DPC should be large enough to measure the upstream concentration with an aerosol diluter and to count individual particles at least one-log division below the filter's standard leak penetration of designated leak for tests, with or without the use of an aerosol diluter. For manual leak testing, the DPC should have an audible alarm capability that beeps for each particle that is counted and have a counting mode that is continuous or at least long compared with the time required to scan a filter. The DPC should have essentially zero reset time between known sampling time increments.

The DPC should be calibrated in accordance with IEST-RP-CC014.

6.1.3 Aerosol detection instrument response time

All measurement instruments require a finite response time to record and display the magnitude of the measured variable. When the response time approaches a significant fraction of the sampling time, the effect of the response time on the fidelity of the measured signal may become unacceptable. For particle measurements, the variable measured is either the concentration or counts. During scanning where the sample head is moving rapidly over the face of the filter, the response time will affect the measured values of the particle concentration or counts. This is especially true for older instruments with analog outputs or slower processors. Therefore, the use of devices with significant response times is not recommended for leak testing.

6.1.4 Aerosols and aerosol generators

An aerosol generator produces aerosol derived from a selected aerosol source material and used as the leak-test challenge for a filter medium leak test. Challenge aerosols may be produced by a variety of methods, with the choice determined by the aerosol type and the particle size characteristics.

a) Laskin-nozzle aerosol generator

This type of aerosol-generation system utilizes a precision-built nozzle immersed in a test liquid and compressed air to produce a polydisperse aerosol of known particle size distribution and challenge concentration. Detailed description and drawings of the Laskin nozzle are provided in IEST-RP-CC013. The aerosol generator operating gas pressure is dictated by the test liquid in order to achieve a known aerosol concentration within an airstream of measured air volume. When operating at the designed operating pressure the generator creates a polydisperse aerosol that ranges in size from 0.1 μm to 1.0 μm with a mass mean diameter of approximately 0.5 μm . Many suitable test liquids are available; consult the generator manufacturer for specific limitations or operating parameters related to the test liquids. Laskin-nozzle aerosol generators are available with a variety of nozzle physical positioning configura-

tions, control methods, output couplings or connections for aerosol injection into air systems, and internal or external compressed air source options.

b) Thermal aerosol generator

This device generates a polydisperse aerosol from a liquid such as PAO or DOP by means of an evaporation-condensation process in the absence of a controlled nucleation. The thermal aerosol generator requires a sampled upstream challenge concentration measurement. The output of the thermal aerosol generator is significantly greater than that produced by a Laskin-nozzle aerosol generator. The particle size distribution and mass mean diameter of an aerosol produced by a thermal generator may be measurably smaller than those of an aerosol from a Laskin nozzle. Refer to the manufacturer's published particle size distribution charts for specific models of thermal aerosol generators.

c) Polystyrene latex (PSL) generator

The PSL aerosol generator is a commercially available ultrasonic humidifier. This type utilizes a solution of water, polymer microspheres, and a non-ionic surfactant to reduce the surface tension of the solution. These units are intended for smaller systems or individual filters. Aerosol generators available from suppliers of cleanroom test equipment utilize spraying nozzle systems. These spraying nozzle units are intended for larger air handling systems. Laskin nozzles intended for use in oil-type aerosol generators are not recommended for use with polymer microspheres. IEST-RP-CC013 provides more information on aerosol generators.

d) Challenge aerosol

The most common materials used for leak testing are PAO and mineral oil. Both of these materials may be used for leak testing with either the photometer or DPCs within the constraints discussed in sections 7, 8, and Appendix H. These aerosols are usually generated using one of the generators discussed in this section. However, the most common aerosol reagent used in conjunction with DPCs is microspheres (PSL).

6.1.5 Aerosol diluter

This device uses a set dilution ratio to reduce the particle concentration. These devices typically mix a known volume of sample air with a known volume of particle-free or filtered air to achieve the dilution. The ratio of the two volumes is the dilution ratio.

Aerosol diluters are needed when using a DPC to accurately sample the high upstream concentrations required for filter testing. The function of the aerosol diluter is to help minimize coincidence counting errors and the risk of contaminating the optics of the DPC. Coincidence count errors occur when concentrations of individual particles exceed the capability of the DPC. The counting errors can be due to both optical and electronic coincidence. When used, diluters should be in calibration per IEST-RP-CC013.

6.1.6 Volumetric flow

In air filtration in ambient conditions, it is customary to test filters at their rated *volumetric* airflow, since filters as installed operate at actual volumetric flow rate and not standard airflow rate. Either volumetric or mass airflow measurement devices may be used for filter testing. The flow accuracy of these devices should not exceed $\pm 5\%$ at test flow rate. If mass flow devices are used, the results should be corrected for ambient conditions to obtain actual volumetric flow rate.

6.1.7 Scan head dimensions

A scanning probe with an inlet opening of square or rectangular configuration provides an inlet airflow velocity within -10% to $+20\%$ of the average exit airflow velocity of the filter(s) being scanned when operating at the sample flow rate of the aerosol photometer or DPC (see Figure 1). The schematic shows a scan head shown designed to meet this flow requirement when the sample flow is 28.3 L/min ($1.0 \text{ ft}^3/\text{min}$). It is customary to operate HEPA filters and perform filter testing with an average filter exit airflow velocity of 0.45 m/sec ($\sim 90 \text{ ft/min}$). All of the test procedures outlined in this RP, except where specifically noted, are based on this underlying assumption. Filter exit