

**Introduction**

HEPA filters, once known as absolute filters, were originally developed as the particulate stage of a chemical, biological, radiological (CBR) filtration/adsorber unit for use by the U.S. Armed Services. In the late 1940s the U.S. Atomic Energy Commission adopted them for use for the containment of airborne radioactive particulates in the exhaust ventilation systems of experimental reactors as well as for use in other phases of nuclear research. The period from the mid 1950s to the present has seen the emergence of many new industrial and scientific technologies requiring particulate free air in order to produce more sensitive products such as microelectronic components, photoproducts, parenteral drugs and dairy products. These technologies fostered the development of a wide range of specialized devices to house HEPA filters to deliver clean air to production areas. Uses for HEPA filters in hazardous containment applications have increased also, and they are more routinely used on the exhaust side of bio-hazard hoods, animal disease research laboratories and whenever



*Vertical Laminar Flow HEPA Filter Ceiling*

airborne carcinogens must be controlled.

The many diverse applications for HEPA filters have resulted in a large number of industrial and governmental specifications which often conflict with one another, principally because of the different methods and devices used to test the performance of the filters, both at the factory and in service. In 1968, the American Association for Contamination Control (AACC) addressed this problem by issuing the specification AACC CS-1T, Tentative Standard for HEPA filters, which categorized the filters as Type A, B or C. Following that, Flanders originated the terms Industrial Grade, Nuclear Grade and Laminar Flow Grade for the Type A, B and C filters, respectively, to better relate them to the industry or application in which the filter is primarily used. The AACC organization ceased to exist and the standards written under its auspices were later adopted by the Institute of Environmental Sciences (IES) for a lengthy interim during which the standard became IES CS-1T. In November of 1983, following several years of committee work to update the material, the standard was reissued by the Institute of Environmental Sciences as IES RP-CC-001-83-T (Recommended Tentative Practice for Testing and Certification of HEPA Filters). Two more filters were added, Types D and E, the equivalent of the Flanders VLSI® Filter and the *(continued next page)*



*In-place test injection section, HEPA and PrecisionScan In-Place test section.*

## Recommended Test and Minimum Rating for Filter Types A-F

Flanders Grade	Filter Type	Penetration Test		Scan Test (See note)		Comments	Minimum Efficiency Rating
		Method	Aerosol	Method	Aerosol		
Industrial	A	MIL-STD 282	Thermal DOP or PAO	None	None		99.97% at 0.3 µm
Nuclear	B	MIL-STD 282	Thermal DOP or PAO	None	None	Two-Flow Leak Test	99.97% at 0.3 µm
Laminar Flow	C	MIL-STD 282	Thermal DOP or PAO	Photometer	Polydisperse DOP or PAO		99.99% at 0.3 µm
VLSI®	D	MIL-STD 282	Thermal DOP or PAO	Photometer	Polydisperse DOP or PAO		99.999% at 0.3 µm
Biological	E	MIL-STD 282	Thermal DOP or PAO	Photometer	Polydisperse DOP or PAO	Two-Flow Leak Test	99.97% at 0.3 µm
ULPA	F	IES-RP-CC007	Open	Particle Counter	Open		99.999% at 0.1 to 0.3 µm

Note: Either of the two test methods or an alternative method may be used for filter types C, D, E and F, if agreed upon between the buyer and the seller. Equivalency of the alternative method should be determined jointly by the buyer and the manufacturer.



### Flanders Precisionaire manufactures and tests its cleanroom filter products in its own cleanroom.

Type F filter has been added, which is the equivalent to the Flanders ULPA Grade filter. By definition, a HEPA filter has a minimum efficiency of 99.97% when challenged with a thermally generated dioctylphthalate (DOP) aerosol whose particle size is 0.3 micrometers (homogeneous-monodisperse). This efficiency is a manufacturing standard that the filter producer must attain, although most Flanders HEPA filters average above 99.98%. Since a filter's efficiency increases as it accumulates particulate matter, the initial efficiency is the lowest efficiency

during the life of a filter. It is important to note that a filter's initial (clean) efficiency represents the average initial efficiency of that filter. Minute areas of greater penetration, either in the edge sealant between the filter element and the filter's integral frame or in the element itself, are often present. When the filter is tested, these small penetrations are diluted by the greater amount of clean air passing through the filter. These penetrations can be tolerated as long as the overall penetration through the filter does not exceed .03% (Note: 100% - .03%=99.97%.)

The instrument used by manufacturers to test filters for efficiency is commonly referred to as the Hot DOP machine because it uses thermally generated particles to challenge the filter. The hot DOP test was a joint development of the U.S. Army and U.S. Navy and is performed on a forty foot long apparatus called a Q 107 Penetrometer.

As shown in Figure 1, when a filter is tested on the penetrometer, two values are taken: the penetration reading and the pressure drop at a specified flow rate (Test Flow). These values are recorded on a bar-coded serialized label that is applied to each filter and a duplicate label appears on each filter carton. Rarely is the information alike on any two filters. Filters larger than 24 x 12 x 5 7/8 are individu-



Figure 1: Flanders Industrial Grade Filter Label

Typical test results are entered on the label. Originally, HEPA filter specifications called for a maximum pressure drop of 1" w.g. at 1000CFM for a 24" x 24" x 11 1/2" size filter. Most nuclear specifications still require this. However, many filters perform better and manufacturers have rated separator-type filters as high as 1200 CFM at 1" w.g. This difference between Test Flow and Rated Flow has caused some confusion in the industry.

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As shown in Figure 1, when a filter is tested on the penetrometer, two values are taken: the penetration reading and the pressure drop at a specified flow rate (Test Flow). These values are recorded on a bar-coded serialized label that is applied to each filter and a duplicate label appears on each filter carton. Rarely is the information alike on any two filters. Filters larger than 24 x 12 x 5 7/8 are individually packaged. A certification of compliance report listing the penetration and pressure drop values relative to the serial number and bar code on each filter can be sent to the buyer upon request.

The specification, Mil-Std-282, DOP Smoke Penetration and Air Resistance of Filters, describes the operating procedure for testing filters with the Hot DOP penetrometer and is referenced throughout industry. In order to comply with the definition of a HEPA filter, each filter is required to be tested for resistance and efficiency. The Institute of Environmental Sciences and Technology, IEST-RP-CC001.3 states, HEPA Filter. . .having minimum particle collection efficiency of 99.97% for 0.3 micron thermally-generated dioctylphthalate (DOP) particles or specified alternative aerosol. Another challenge aerosol is polyalphaolefins (PAO) which provide appropriate testing characteristics. Further, a maximum clean pressure drop of 1.0-inch water gage [or 1.3, depending upon the type of HEPA filter. A manufacturer cannot certify that a filter is a HEPA filter unless he owns a penetrometer and has had it NIST (National Institute of Standards and

Technology) calibrated according to industry-accepted standards. The Type A filter, per IEST-RP-CC-001-3, is One that has been tested for overall penetration at rated flow with thermally generated DOP smoke. This is the equivalent of the Flanders Industrial Grade HEPA Filter.

The DOP Test (Figure 2) begins with the manufacture of particles that are homogeneous in size (0.3µm) to form a nearly monodispersed aerosol, because not 100% of all particles are exactly 0.3µm size. To test a filter at 1000 CFM on the Q 107 Penetrometer, outside air is drawn into a duct at 1200 CFM and then divided through three parallel ducts at 85, 265 and 850 CFM (200 CFM is eventually exhausted through an alternate exhaust path). As shown in Figure 2, the top duct contains three banks of heaters and a challenge aerosol oil reservoir with a fourth heating element beneath the reservoir. The center duct contains a cooling coil and a bank of heating elements. The air passing through the top duct is heated to approximately 365° F and is then impinged through an orifice onto the challenge aerosol oil in the reservoir. The

heating causes the challenge aerosol oil to evaporate and it is then carried forward to the confluence of the top and center ducts where it is quenched with the cooler air from the center duct. The 0.3 micrometer particle size is controlled here by maintaining the temperature at 72° F. By increasing or decreasing the temperature, the particle size can be increased or decreased.

Next, the combined airflow from the upper two ducts is mixed with the remaining 850 CFM from the bottom duct. A series of baffles mixes the aerosol (smoke) thoroughly into the airstream to distribute the aerosol uniformly prior to challenging the filter. A similar set of baffles is located on the exhaust

side of the filter being tested to thoroughly mix the effluent.

An upstream sample is taken and, when the aerosol concentration reading is between 80 and 100 milligrams per liter, that value is accepted as a 100% challenge. Next, a reading (% concentration) is taken downstream of the filter (downstream of the baffles so that any leakage is thoroughly mixed into the effluent) and is compared to the upstream value. This is read as a penetration, that is, if the downstream concentration is .04% that is the percentage of the upstream value that has penetrated the filter. When subtracted from the 100% value, the filter would have an efficiency of 99.96% and would be rejected.

Los Alamos National Laboratories developed an alternate test method in the 1980's under contract to the U.S. Department of Energy (DOE). It is often referred to as the HFATS test (High Flow Alternative Test System). It was developed specifically to test filters rated at airflows higher than 1100 CFM, but it can be used for lower flows. It is only limited by the size of the system fan and the aerosol generator output. This method was later standardized in the publication of a recommended practice, IEST-RP-CC007.1, Testing ULPA Filters, published by the Institute of Environmental Sciences and Technology. Currently, ASME AG-1 Section FC allows for testing by this method. The filter is challenged with an acceptable polydispersed oil aerosol and the penetration through the filter is measured with a Laser Particle Counter. The Particle Counter counts and sizes individual droplets in a size range from 0.1 to 3.0 micrometers in diameter. The ratio of the downstream counts to the upstream counts in each size range is the penetration. Although this value is not equal to the penetration measured by the Q-107, research performed by Los Alamos National Laboratory verified it to be very similar and the method to be an acceptable alternative to the penetration measured by Mil-Std-282 Test Method.

Since this system measures the penetration in each size range, and a HEPA filter penetration varies with particle size, the maximum allowable penetration is 0.03% for the most penetration particle size (MPPS). FFI can use this system to test filters that are rated at flows higher than 1100 CFM, if specified by the customer.

## Q 107 Penetrometer Instrumentation

### 1. Temperature Controllers

- a. Hot Air @ (approx.) 365° F
- b. Oil Reservoir @ 390° F
- c. Quench Air @ 72° F

### 2. Mechanical Analyzer

This enables the operator to determine when he has the correct particle size. Smoke is drawn through a chamber and in between two photomultiplier tubes. The operator reads the particle size on the Size Indicator.

### 3. Linear Photometer (.0001% to 100%)

This is used for reading the upstream and downstream samples and comparing them. The downstream value as a percentage of the upstream value is the Penetration.

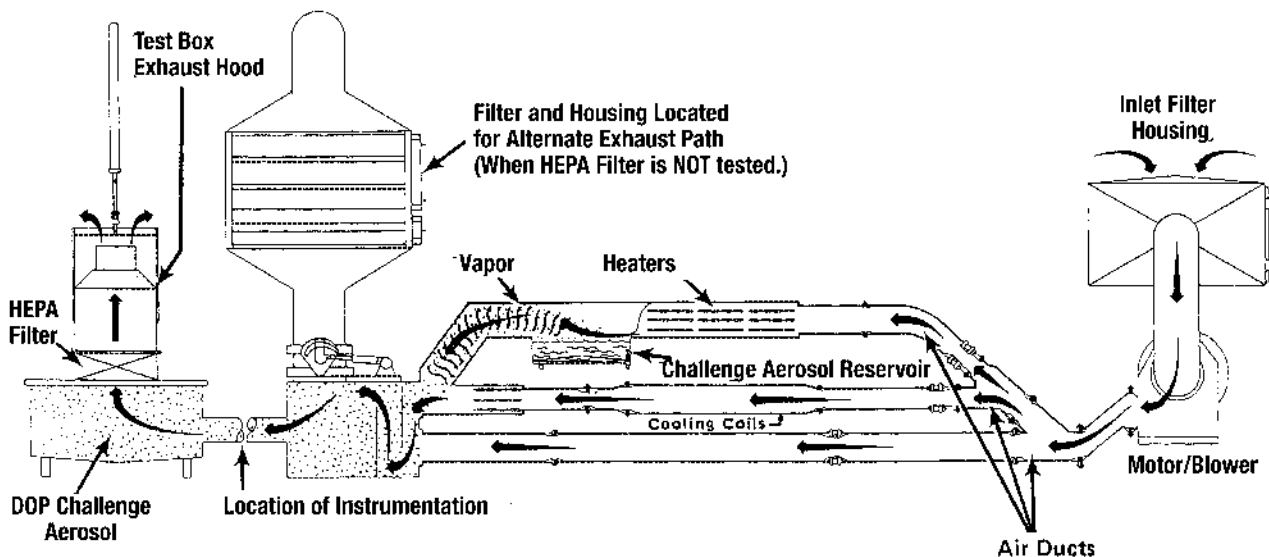
### 4. Manometer

Determines the pressure drop across the filter at the test flow.

### 5. Averaging Pitot Tube Systems

Enables the operator to determine the volume of airflow through the filter.

Figure 2: Challenge Aerosol Test



## Scan Testing or the Cold Challenge Aerosol Test

When individual filters cannot be tested, most containment requirements are satisfied by achieving average filter bank efficiencies of 99.95% or greater. A single pass through a correctly installed and field-tested filter or bank of filters is sufficient to accomplish this efficiency although most nuclear facilities, because of additional safety related considerations such as fire protection and redundancy, can have two or more banks of HEPA filters in series on the exhaust of their HVAC systems. As previously stated, the areas of greater penetration that can occur on HEPA filters, frequently called "pinhole leaks," are tolerated as long as the overall penetration does not exceed .05%.

This is not the case in laminar flow systems (clean work stations, clean rooms, downflow hoods) where the HEPA filters are located at the boundary of the air supply entering the clean room or work area. In order to dilute the pinhole leak with the greater volume of clean air passing through the filter, either a considerable distance or some method of agitating such as a baffle would be pointless in a laminar flow clean room. Therefore, it could happen that the product or process requiring particulate free air during its manufacture or assembly could be located directly downstream of a pinhole leak.

Realizing this early researchers into clean room techniques developed a procedure to scan or probe the downstream face of a bank of filters in a laminar flow system, not only to locate pinhole leaks in the filter element, but to determine whether the filters were sealed to their mounting frames. A challenge aerosol, with a particle size range of 0.1 to 3.0 micrometers (polydispersed), is generated and introduced upstream of the filter bank while the system is in operation. The downstream side is probed with a portable forward light scattering photometer. Pinhole leaks and filter-to-frame are identified and patched.

HEPA filter manufacturers, confronted with the prospect of failing a field test that could locate defects escaping detection in the overall efficiency test with the Q 107 Penetrometer, began to factory probe filters destined for laminar flow clean rooms. In time, this additional test requirement became an industry standard. The Type C filter, per IEST-RP-CC001.3 is "One that has been tested for overall penetration. . .and in addition has been leak tested using air-generated challenge aerosol smoke. . ."



This is the equivalent of the Flanders Laminar Flow Grade HEPA Filter.

As shown in Figure 3, there are three major components used to perform the cold challenge aerosol test; the challenge aerosol generator, the test box (plenum) with motor/blower and the light scattering photometer. (The vernacular description cold challenge aerosol test frequently is used to distinguish between the polydispersed DOP aerosol generated at ambient temperatures and the thermally generated monodispersed aerosol.)

In this case, the challenge aerosol is generated by forcing air at 20-25 psi into liquid challenge aerosol contained in a reservoir. A sufficient challenge of 10-20 micrograms per liter can be maintained by using one Laskin nozzle per 500 CFM of air or increment thereof.

A single Laskin nozzle is illustrated in Figure 4. There are two sets of holes in the nozzle, one set of four holes is located directly beneath the collar around the bottom of the tube. The second set of four is located in the collar with each hole being positioned directly above the corresponding hole at the tube. The air flowing out of the holes in the tube causes the challenge aerosol oil to be drawn through the holes in the collar, fragmenting the liquid into an aerosol. Unlike the homogeneous, monodispersed particles generated by the hot challenge aerosol test, the cold challenge aerosol is heterogeneous of polydispersed having a particle size distribution as follows:

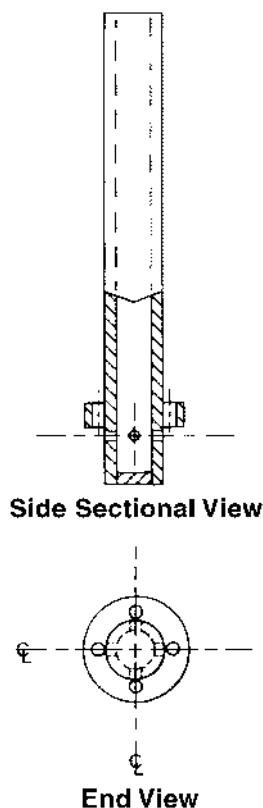
- 99% less than 3.0 micrometers
- 95% less than 1.5 micrometers
- 92% less than 1.0 micrometers
- 50% less than 0.72 micrometers
- 25% less than 0.45 micrometers
- 10% less than 0.35 micrometers

Although test plenums vary somewhat in size and design, the arrangement shown in Figure 3 is typical of the type used at Flanders. The essential purpose of the plenum is to mix and disperse the air/aerosol upstream of the filter to provide a uniform challenge to the filter. An important feature of the test equipment is the hood or baffle that is located on the air-leaving side of the filter. This device prevents the intrusion of particles from the room air onto the downstream face of the filter and is essential to obtain valid results. During the test, the filter is clamped in place between the hood and the test plenum. In older photometers, the operator set the needle of the meter to read at the zero point while holding the probe at the filter face and sampling the effluent from the filter. (Current photometers contain their own filter for setting the zero reading, but there is no specification requiring their use.) Next, an upstream reading is taken through an orifice in the plenum upstream of the filter. If the challenge is insufficient, an adjustment is made by increasing the air pressure into the generator and checking the upstream concentration reading until the correct limit is attained.

The photometer probe is connected by flexible tubing to the intake of the light-scattering chamber of the photometer. To test the filter, the operator scans the perimeter of the pack and then, using slightly overlapping strokes, probes the entire face of the filter. Most photometers sample at 1.0 CFM. Air is

drawn through the chamber and any entrained particles present in the sampled air deflect the light source onto the sensitive area of the photomultiplier tube. This causes the needle on the meter to move, indicating the size of the leak by the meter reading. If the photometer reading is greater than .01%, the leak is unacceptable and the spot must be repaired. Thus, a leak may not pass smoke in greater proportion than 1:10000 relative to the clean air that surrounds it.

Scan tested filters are frequently and erroneously described as “zero probe” or “99.99” filters with the inference that they have a higher efficiency rating than the minimum efficiency of 99.97% required for Industrial and Nuclear Grade filters.



**Figure 4: Laskin Nozzle**



**Figure 5: Challenge Aerosol Generator**

With a multiplicity of Laskin nozzles as shown. The generators used to test individual filters at Flanders Precisionaire have at least three nozzles. More are required to test larger filter systems.

Manufacturers who do not own a Q 107 Penetrometer to perform the overall efficiency test depend upon this misinformation to justify the minimal expense required to own the equipment required to perform cold DOP testing only. The probe test is described as a more stringent test with the implication that it is therefore better, when it is, in fact, unrelated to the overall efficiency test. At best, the probe test is a supplement, not a substitute, to the overall efficiency test. As described above, the procedure for probe testing includes setting the meter at zero while sampling the effluent from the filter being tested. This procedure could be followed just as easily using a 95% efficient filter! As stated above, some photometers are now equipped with HEPA filters which are used as the reference filter, but there is no industry-wide specification requiring their use.

A HEPA filter performance rated at 99.99% on cold DOP is one that has no pinhole, cracks or imperfections showing an indicated leak greater than .01% at specific location relative to the upstream concentration. It is pointless to compare this test to the overall efficiency rating obtained with the hot DOP test since there are so many differences, including the particle size(s) and concentration of the challenge. A filter which has passed the scan test can have an overall efficiency of 99.97%.

Resistance ("W.G.)		Test Flow	PENETRATION	
1.35		2000 CFM	0.004 %	
MODEL # 0-011-H-08-03-SU-11-00-GG-F				
ACTUAL SIZE 24.0 X 24.0				
FLO ORDER NO. 235835		CUSTOMER PO NUMBER ACT2266		MEDIA LOT NUMBER 53678003
SERIAL NO 809036		F0614063		APPLICABLE UNIT CLASSIFIED BY UNDERWRITERS LABORATORIE AS TO FLAMMABILITY CLASS 1 - SWP

## Two-Flow Efficiency Testing and Encapsulation

Pinhole leaks in filter media result in greater penetration at lower velocities because the constriction of air flow through a pinhole is a function of the square of the air velocity whenever the constriction of air flow through the filter media is close to a linear function of velocity. Therefore, at 20% or 1/5 of full test flow, a pinhole leak shows up as approximately 25 times greater in proportion to total flow than it does at full flow. Also, at higher velocities particles impact upon the fibers of the filter element whereas at lower velocities Brownian motion causes them to meander and they are more likely to "find" the leak.

The development of acceptance criteria for clean room components resulted in a greater awareness of the existence of pinhole leaks in HEPA filters. This, in turn, led to a reevaluation of the filter test procedures for filters used for radioactive containment. Prior to the advent of commercial nuclear power stations, most of these filters were used either by the U.S. weapons program or in the field of nuclear research. The U.S. Department of Energy (formerly the Atomic Energy Commission) operates, through prime contractors, a filter test facility equipped with Q 107 Penetrometers. HEPA filters purchased for weapons and nuclear research

facilities are retested en route to these plants.

Not wishing to commit additional time to scan test HEPA filters at the retest stations or to raise the purchase price for additional factory testing, a two-flow test was adopted wherein the HEPA filters are tested at the flow rate specified in ASME-AG-1, Section FC, HEPA Filters and again at 20% of that flow rate. The 20% flow test served to detect any gross pinhole leakage escaping notice in the full flow test. The test is not effective in detecting all pinhole leaks nor does it enable the operator to locate them, but it has been found as an effective device to aid in improving overall filter performance.

When the 20% flow test was added to the procedure, a second modification was also made: the addition of the encapsulation hood, shown in Figure 8. Previously, filters tested for efficiency had only the element and the frame tested. Experience has shown that HEPA filters can have frame leakage, caused primarily by improper sealing methods during manufacture, racking of the frame or leakage through the frame material (metal frame filters are particularly susceptible). By enshrining the entire filter, any leakage through the frame, joints or corners is included in the overall efficiency of the filter.

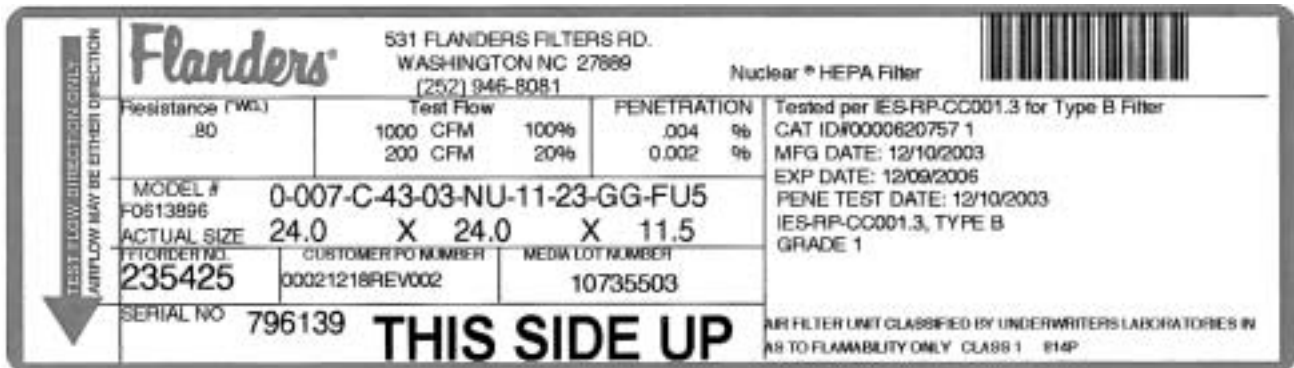
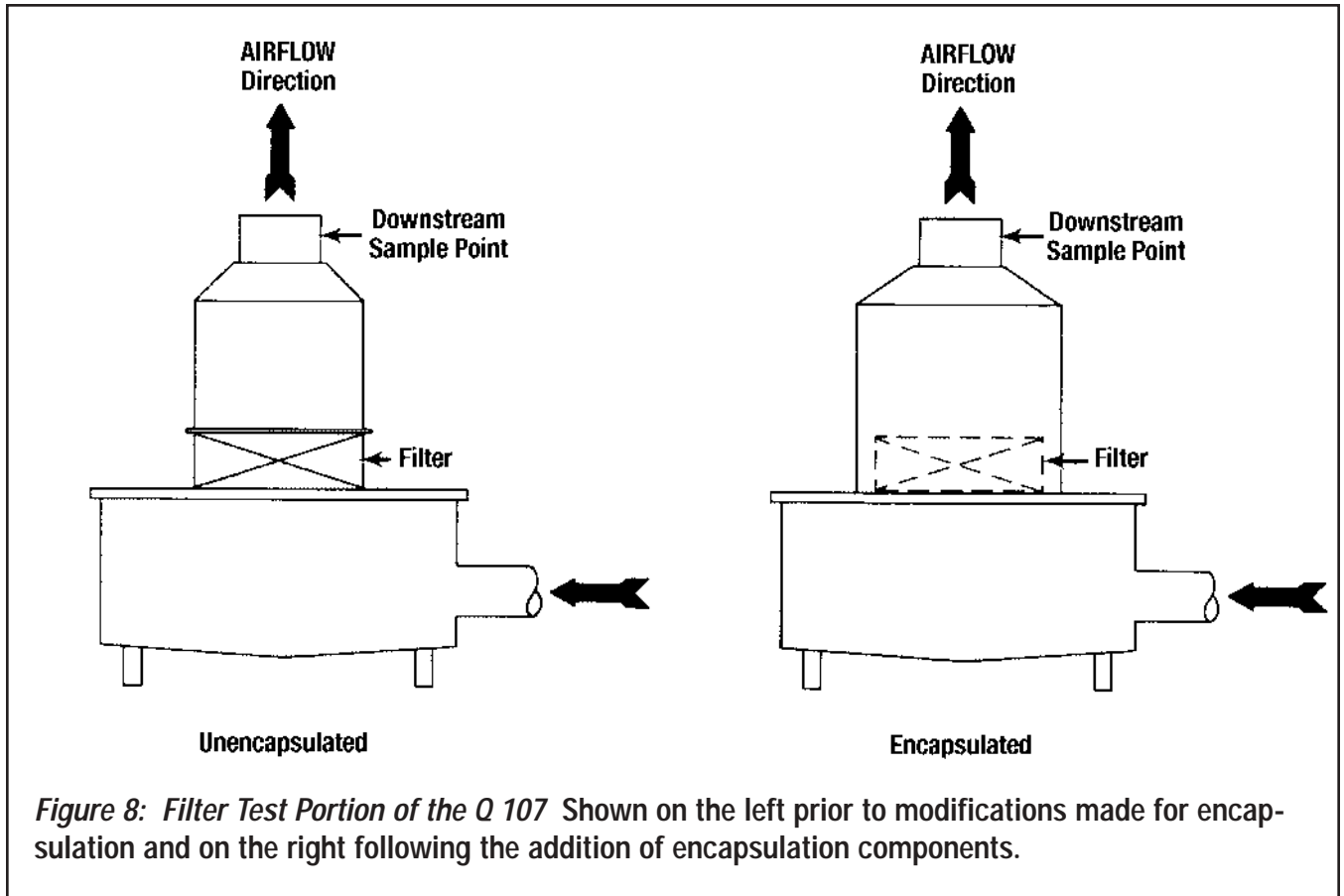


Figure 7: Flanders Nuclear Grade Filter Label - Type B Filter Indicating that the filter has been tested for efficiency at two flows while encapsulated.

# Two-Flow Efficiency Tested, Encapsulated and Scan Tested Filters

Specification requires filters used in air cleaning systems involving chemical, carcinogenic, radiogenic, or hazardous biological particles be given both a scan test (as is given to Type C, Laminar Flow Grade HEPA Filters) and Two-Flow Efficiency Testing and Encapsulation (as is performed upon Nuclear Grade HEPA Filters). This is described as

a Type E Filter in the IEST-RP-CC001.3 Recommended Practice. In the early 1980s, The National Institute of Health was preparing specifications for filters used in these applications. This specification was planned as MIL-F-51477(EA). It will be described in Flanders literature as a Bio/Hazard Grade HEPA Filter.



TEST FLOW DIRECTION ONLY AIR FLOW MAY BE EITHER DIRECTION	<b>Flanders</b>		531 FLANDERS FILTERS RD. WASHINGTON NC 27889 (252) 946-8081		Biological	
	Resistance (WGL) .57	Test Flow 1000 CFM    100% 200 CFM     20%		PENETRATION 0.004 % 0.002 %		MFG DATE: 11/14/2003
	MODEL # FO622590	T-007-W-04-05-BU-52-43-GG-FU5				
	ACTUAL SIZE 24.0 X 24.0 X 11.5					
FITTING NO. 235844	CUSTOMER PO NUMBER 25104CO1	MEDIA LOT NUMBER 11801110403				
SERIAL NO 805814	<b>THIS SIDE UP</b>				AIR FILTER UNIT CLASSIFIED BY UNDERWRITERS LABORATORIES IN AS TO FLAMABILITY ONLY CLASS 1 814P	

*Figure 9: Flanders Biological Grade Filter Label - Type E Filter Indicating that the filter has been tested for efficiency at two flows while being encapsulated and has been scan tested.*

# Two-Flow Efficiency Tested, Encapsulated and Scan Tested Filters



Figure 10: System using Two-Flow Efficiency Test



Figure 11: system using Calibrated Dual-Laser Spectrometer System A dilution device is used to test the Flanders VLSI Filter for both efficiency and resistance to airflow.

The invention of the Single Particle, Particle Size Spectrometer with a laser light source has made it possible to measure removal efficiencies on particles smaller than 0.3 micron size particles with convenience, accuracy and reproducibility. A system using a calibrated Dual Laser Spectrometer System and a dilution device is used to test the Flanders VLSI® Filter for both efficiency and resistance to airflow.

A cold challenge aerosol is introduced into the system while the Dual Laser Spectrometer samples simultaneously on both the upstream and downstream sides of the filter. The dilution device permits an upstream challenge which is sufficient for verification of filter efficiency. This sophisticated test system provides the operator with efficiency by particle size in thirty-one slightly overlapping bands

from .12 to 3.0 microns. A computerized printer produces a histogram presenting the efficiency data in both tabulated and graph form. VLSI® Filters have a minimum efficiency of 99.9995% on .12 micron-size particles. Because the Dual Laser System far exceeds the sensitivity of the Q 107 Penetrometer (used to test HEPA filters), it is the only method which can be used to verify the performance of these ultra high efficiency filters.

The breakthrough on VLSI® filtration is certain to have far-reaching effects in both containment and clean room applications in the years to come. At this time, industry and government are working together to develop industry standards for testing these filters. It is expected that the Institute of Environmental Sciences will issue a Recommended Practice within the next few years.

TEST FLOW DIRECTION ONLY AIRFLOW MAY BE EITHER DIRECTION 	<b>Flanders</b>		FLANDERS FILTERS, INC. 531 FLANDERS FILTERS RD. WASHINGTON NC 27889 (252) 946-8081		
	Resistance ("W.G)	Test Flow	PENETRATION		PO#111503
	1.60	1885 CFM	0.000294%		
	MODEL #	0-009-W-08-00-SU-12-00-YY-F			
	ACTUAL SIZE	23.375 X 23.375 <FM>			
FFI ORDER NO.	CUSTOMER PO NUMBER	MEDIA LOT NUMBER			
236346	544635	11102120503			
SERIAL NO	818472	F0618301			
					AIR FILTER UNIT CLASSIFIED BY UNOFFICIAL FILTERS LABORATORIES AS TO FLAMABILITY ONLY CLASS 1 BHP

Figure 12: Flanders Filter Label - Type D Filter Indicating that the filter has been tested for efficiency and has been scan tested.

Flanders Precisionaire - Foremost in Air Filtration

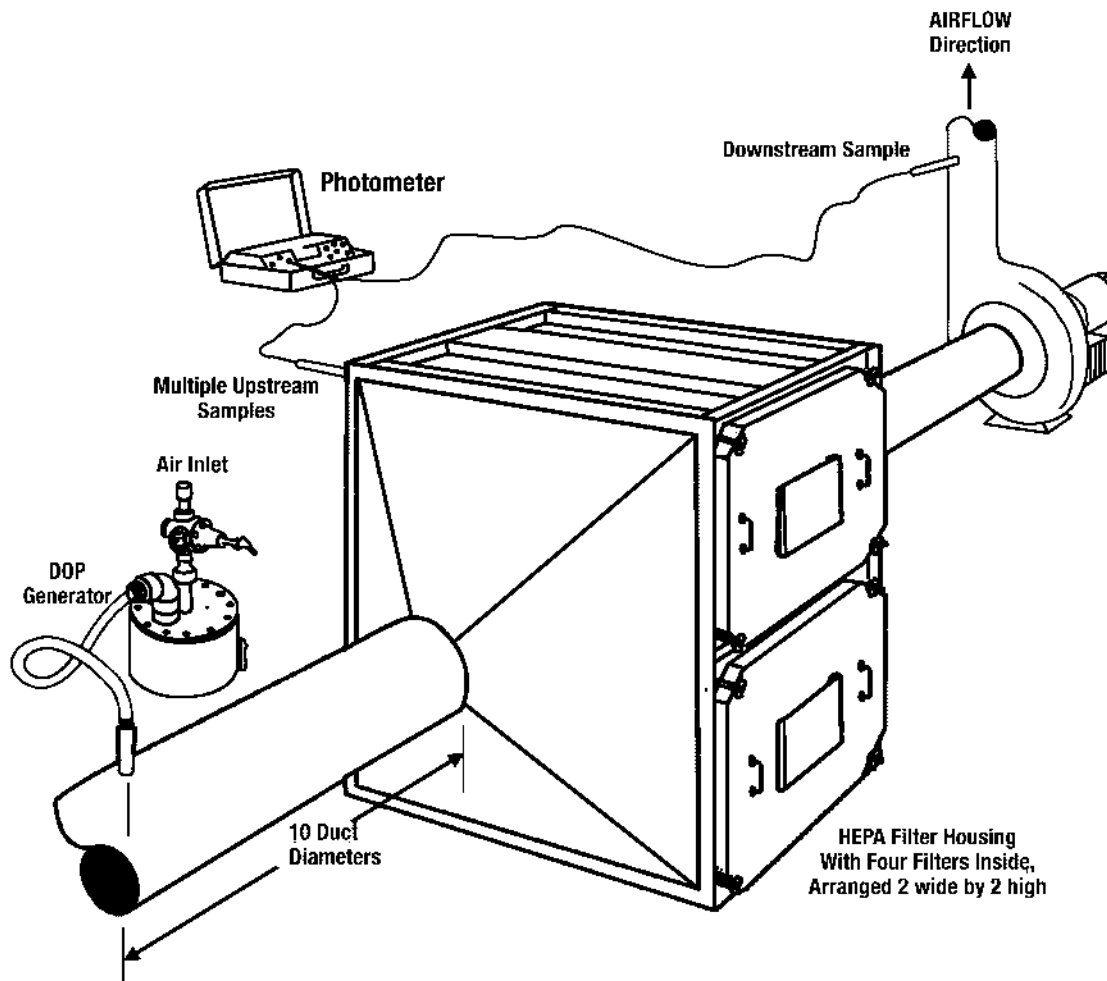
Engineered Products: 1-800-637-2803 Replacement Products: 1-800-347-2220

## In-Service Tests for HEPA Filters

The most stringent factory tests for HEPA filters have resulted from the requirements of both the nuclear industry and the operators of laminar-flow clean rooms. Experience has demonstrated that HEPA filters that have passed these tests do not always arrive at their destination without mishap. Damage can occur during shipping and handling by trained personnel. Once installed, the filter-to-mounting-frame seal or leaks in the mounting frame itself can contribute to a loss of the efficiency of the bank. Consequently, it is not surprising that the nuclear industry and those industries requiring laminar-flow clean rooms also require verification of in-service performance of both Nuclear Grade and Laminar-Flow Grade HEPA Filters and their supporting frameworks.

By comparison, Industrial Grade HEPA Filters are

generally used in industries less structured by either government regulations or industry standards and usually where the user is not concerned with conducting additional field testing to verify performance. This is not to say that Industrial Grade Filters cannot pass certain in-service tests, but they are less likely to do so for two reasons: First, by electing to not test the filters in service, the owner and/or the designer generally issue a less stringent procurement specification, with the result that the mounting frameworks of filter housings are of mediocre quality, not designed to pass an in-service test. If the owner should decide at a later time to upgrade the HEPA filter installation and add in-service testing, it may be necessary to modify or replace frames. A major reason for the failure of these filter banks, assuming that undamaged filters have been installed, is the filter-to-frame seal.



*Figure 13: Test of Ventilating System with a Single Bank of HEPA Filters*

Bypass leakage has long been a principal cause of improperly installed filters. This can be compounded by frame leaks in welds or caulking or by poor quality workmanship by the installer of the frames. Second, Industrial Grade Filters are not probe tested at the factory. Since all specifications for laminar-flow installations and devices call for probe testing in the field, a certain percentage will fail.

Exclusive of particle monitoring techniques, there are two kinds of field tests used to verify in-service performance: In-Place Testing, the testing of filter banks in nuclear air-cleaning systems; and, Probe or Scan Testing, discussed previously, required for clean rooms and laminar-flow devices.

**In-Place Testing — HEPA Filter Banks** HEPA filters installed in nuclear air-cleaning systems are required to be tested in-service following each filter change and periodically during the life of the filters. Since each ventilation system differs in design, a standard or uniform test throughout industry is a problem. Therefore, depending upon the arrangement of a particular system, the procedure can vary. The in-place leak test is frequently called an efficiency test of an individual filter.

The test by the factory of quality assurance station is an efficiency determination using a monodispersed challenge. The total filter is challenged at one time and a single reading of penetration is obtained. ASME, AG-1, Section FC, "HEPA Filters" provides requirements for the performance, design, construction, acceptance testing and quality assurance for Nuclear Grade HEPA filters.

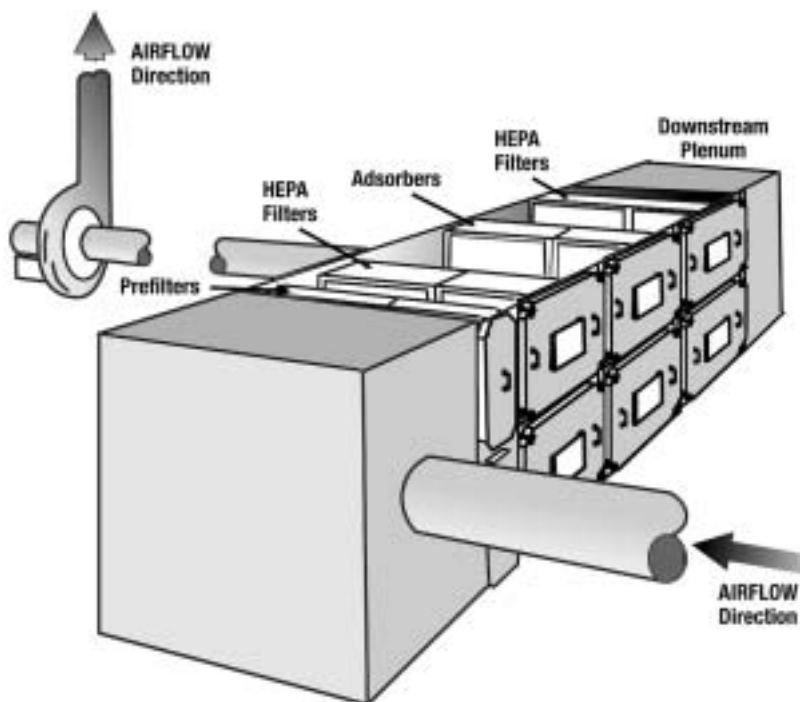
In-place field test of installed HEPA filters are made with a polydispersed aerosol, and do not show the efficiency of the filter but only reveal the presence of leaks in the filter bank. The in-place field leak test is not an efficiency test and should not be so considered. ASME, AG-1, Section TA, "Field Testing of Air Treatment Systems" provides procedural guidelines for HEPA filter bank in-place leak testing.

\*The authors have attempted to clarify the difference between factory testing an individual filter for efficiency using a monodisperse aerosol from the in-place field test conducted in service that uses a polydisperse challenge under a multitude of varying conditions.

Under ideal conditions, and with a well-designed filter system, an efficiency test on a bank of filters using a cold aerosol challenge can be performed, but such a system would prove to be the exception and not the rule. (Figure 13 illustrates such a system.) The operator must first generate the cold aerosol challenge by the same method and apparatus as described above for probe testing HEPA filters at the factory. To gain an accurate reading from the bank of filters being tested, the challenge must be uniform across the upstream face of the filter bank. In most cases, this can be achieved by introducing the challenge aerosol into the system at least ten duct diameters upstream of the bank to obtain thorough mixing of the air/aerosol. However, a uniform challenge is also dependent upon a balanced flow through the bank; therefore, careful attention should be given by system design-

*Figure 14: The Ductwork and Plenums in HVAC Systems*

Frequently designed for best use of building space. Filter systems having multiple stages of filters are grouped together for the same purpose, but also to facilitate maintenance operations. Unfortunately, this frequently results in HEPA filter banks that are difficult or impossible to test.



ers to this requirement.

Cold challenge aerosol is first generated and introduced into the system. A single sample is taken along a linear plane upstream of the bank to verify uniformity. The upstream concentration required is relative to the sensitivity of the instrument, but an acceptable minimum for most photometers is approximately 50 micrograms per liter. This value is accepted as 100% and a sample is taken downstream of the bank and compared to the upstream reading. The downstream reading should be taken far enough from the bank to allow thorough mixing between the bank and the sample. Usually a minimum of ten duct diameters is sufficient. The penetration cannot exceed .05%.

In performing an in-place test, the filter bank is treated as a single filter. Just as individual pinhole leaks are diluted by the greater volume of clean air and escape detection in the efficiency tests performed at the factory, bypass leaks, frame leaks and holes in the medium can escape detection in the in-place test provided the overall penetration does not exceed .05%. Certain holes that are undetected in large filter banks could not accurately be described as pinhole leaks. They can be quite large. For this reason, a visual examination of the filters is a good practice whenever possible.

In-place testing is almost always complicated by system design or location. Components such as prefilters, entrainment separators, gas adsorbers and secondary HEPA filter banks are frequently arranged in close proximity to one another and to the bank being tested. The ideal system described previously and illustrated in Figure 13 has several essential features: a frusto-converging transition piece both upstream and downstream of the bank and ten duct diameters on either side of the bank, unobstructed by other system components. The operator stands an excellent chance of obtaining a balanced flow through this system as well as good mixing both upstream and downstream of the bank. Figure 14 shows a typical air cleaning system with prefilters, HEPA filters, carbon adsorbers and a second bank of HEPA filters in series. The HEPA filters in the first bank could not be tested because thorough mixing of the air/aerosol would not take place if the challenge aerosol were injected between the prefilter and the HEPA banks. Further, it would be impossible to take a representative sample in the limited space between the HEPA filter and the adsorber. In this system, all the components are located too close to each other for a good test and the housing is too small for man entry. Figure 14 also illustrates another common problem in filter banks that must be tested in-place: the relationship of the duct and plenum design and its effect upon a

uniform flow through the filters. Certainly the arrangement, as shown, would have high and low velocity points across the face of the prefilter bank, and although the prefilters themselves would assist in balancing the flow ahead of the HEPA filters, the only way to test this particular bank of HEPA filters would be to pull both the prefilters and one bank of HEPA filters out of the system.

Factors that can contribute to the difficulties of performing an in-place test are as varied as the arrangements that the system planner can design. The standards anticipate these common problems and permit compromise solutions (e.g. Bypass ducting between system components may be used for filter test purposes.). In man entry housings where the banks of HEPAs are too large to generate enough challenge aerosol, a portion of the bank may be tested by shrouding adjacent sections. Scan testing techniques may also be used, averaging the results to compute a system efficiency. None of these methods fully solves such problems as access into housings that are too small or too remote for man-entry or the problem of uniform challenge where banks in series are located too close together. For this reason, in-place testing should be considered as a quantitative rather than a qualitative test. For many years, Flanders has designed, proof-tested and manufactured housings with complete in-place test equipment built into the housings, permitting testing of filters from outside the system at a remote location and the identification of the filter that might be leaking, because an individual efficiency leak test is performed on each filter in the system. The built-in test systems are compatible with other components in the housing and approximately two feet is required between consecutive filter banks, regardless of the size of the system.

# Clean Room Testing

Nuclear and biological facilities usually have their own safety or health physics personnel and maintenance crews who can perform in-place testing, thus enabling them to enforce industry specifications and design criteria.

The same is not always the case in plants having laminar-flow clean rooms or clean air devices. HEPA filters and ancillary equipment are not routine components in HVAC system construction, and the techniques of their installation and in-service validation are unfamiliar to many facility operators and their mechanical contractors. Even when a contractor can demonstrate previous experience in clean room construction, most of his employees are transitory, working for various contractors on a per job basis rather than for a single employer. As a result, many HEPA filter systems are incorrectly installed because of inexperience. To overcome this problem, factory service personnel are available from Flanders to supervise the contractor's installation of the Flanders products during the critical construction phase. Once the installation is satisfactorily completed, the service personnel test and certify the job to industry standards.

The control of airborne particulates within a clean room or laminar flow device is dependent upon the efficiency of the filters and their supporting framework, but it is also dependent upon achieving parallel and turbulent free air velocity patterns through the clean room or zone. The subject herein is the in-service testing and validation of the filter banks themselves, but it is important to stress that several other critical tests are conducted during the certification procedure by service personnel, including velocity profiles and particle monitoring at work surface levels.

Filters that have first been factory scan tested should also be tested in service in a manner similar to the factory test by challenging the installed filter and its supporting framework with a polydisperse challenge aerosol introduced upstream of the filter bank and by scanning the downstream face of the bank. As in the testing of nuclear systems in-place, a uniform challenge is required. Standard clean

room design criteria requires laminar-flow rooms and clean air devices to have a face velocity of 90 fpm,  $\pm 20$  fpm, far below the velocity of air required in conventional (e.g. non-laminar flow) ventilation systems. Consequently, it is not usually difficult in smaller laminar-flow systems to generate sufficient amounts of challenge aerosol and to attain uniform disbursement upstream of the filters. However, as the size of the system increases, it becomes increasingly more difficult to challenge the entire bank simultaneously. One alternate method of testing is to isolate adjacent sections and test the bank



**Figure 15: Probe Testing a Clean Room Ceiling**

section by section. Where this is not practical, the filters can be tested at the job site prior to installation, using the same test rig that is used at the factory for probe testing. This test verifies that there has been no damage incurred to the filters in transit or during unpacking and handling. Following this test, the filters are installed immediately under close supervision. When all filters have been installed, the seals between the filter and the supporting framework itself and the perimeter of the filter bank are scanned for bypass leakage. Considering the time that it takes to scan a large HEPA filter wall or ceiling bank, there is a valid argument for a less time consuming test.

# In-Place Test Housings for Efficiency Testing

The standard in-place test procedure calls for a suitable aerosol to be generated and introduced into the airstream at a sufficient distance upstream of the filter bank to thoroughly mix the challenge aerosol into the airstream before it reaches the filter bank. The recommended minimum distance is ten duct diameters upstream of the bank. If this distance is not available, a collapsible baffle may be used in conjunction with the injection port to assist in mixing the challenge aerosol. The baffle can be located six or seven duct diameters from the bank.

Samples are taken at points on a linear plane directly upstream of the filter bank to determine if there is a uniform challenge to the bank. The uniformity can be affected by incorrect mixing procedures or by uneven velocity of air through the bank. Once the tester is satisfied that the challenge is uniform, a sample is taken at a point downstream of the filter bank, usually ten duct diameters or more, to ensure that any leakage in the bank is thoroughly mixed with the clean air passing through the bank.

HEPA filters that are installed in ventilation systems to prevent the release of hazardous particulate matter into the atmosphere are required to be tested in-place following each filter change, as well as periodically during the service life of the filters, to determine the efficiency of the filter bank and its supporting framework. Leakage through the filters, bypass between the filters and the supporting framework, or leakage through the framework itself may reduce the efficiency of the filter bank below the required 99.95%.

The in-place procedure appears to be relatively simple; therefore, very often little consideration is given to in-place testing by the designers of ventilation systems that contain HEPA filters. Filter testing has historically been treated as a health physics function and not as a design

objective. Consequently, there are countless filter banks that have been installed in air cleaning systems that are impossible to test because system design interferes with attaining mixing and dispersion on both the upstream and downstream sides of the banks being tested.

To test HEPA filters in-place in the field under ideal conditions, an operator has a minimum ten duct diameters upstream and downstream of his filter bank. He has a well-designed transition piece on the inlet and outlet of his housing and has no obstructions such as other filters, adsorbers, etc., in his system. Figure 13 illustrates a bank of filters in

such a system. The two essential factors for a satisfactory test in this situation are distance and design. The former ensures mixing on both sides of the filter bank; whereas, it is the system design—e.g. the transition—that aids in balancing the flow through the bank and results in a uniform challenge to the bank.

Even with the ideal conditions shown in Figure 13, there are still certain impractical limitations:

- If the system, when tested, does not have a minimum efficiency of 99.95%, the operator is required to take corrective action.
- If the system is large enough for man-entry, a tester must suit up and enter the system on the downstream side to scan the bank.

Exposure time of maintenance and test personnel in containment systems is an increasing concern in facilities where toxic materials are present in the ventilation air.

The Flanders' in-place test housings use two identical mixing devices on the upstream and downstream side of the filter to achieve the same purpose. A hinged diffuser is located on both the air-entering and the air-leaving sides of the filter.

Prior to testing the filter, both diffusers are moved to the test position to mix the challenge aerosol into the airstream on the upstream side and to mix any leakage into the air on the downstream side. The challenge aerosol is then introduced into the system ahead of the first diffuser; upstream and downstream samples are taken and the results are compared to determine the penetration through the filter and its supporting framework.

Each test module is designed so that the readings are not affected by adjacent filter. Since each filter is tested individually, a penetration reading for every filter in the system is obtained.

## In-Place Test Housings for Scan Testing

The standard in-place scan (or pinhole) test procedure calls for a suitable aerosol to be generated and introduced into the airstream a sufficient distance upstream of the filter bank to thoroughly mix the challenge aerosol into the airstream before it reaches the filter bank. The recommended minimum distance is ten duct diameters upstream of the bank. If this distance is not available, a collapsible baffle may be used in conjunction with the injection port to assist in mixing the challenge aerosol.

The baffle may be located six or seven duct diame-

ters from the bank. Samples are taken at points on a linear plane directly upstream of the filter bank to determine if there is a uniform challenge to the bank. The uniformity can be affected by incorrect mixing procedures or when the velocity of air through the bank is uneven. Once the tester is satisfied that the challenge is uniform, scan testing can begin downstream of the filter bank, through a field fabricated and installed access area, typically found in the downstream ductwork. This arrangement requires test personnel to enter or reach into the airstream to find potential leaking HEPA filters.

This type in-place procedure also appears to be relatively simple; therefore, very often little consideration is given to in-place testing by the designers of ventilating systems that contain HEPA filters for scan testing. There are filter banks that have been installed in air cleaning systems that are impossible to test because system design often interferes with attaining mixing and dispersion on both the upstream and downstream sides of the banks being tested.

To scan test HEPA filters in-place under ideal conditions, an operator has a minimum ten duct diameters upstream and access to the downstream of his filter bank. A well-designed transition piece on the inlet and outlet of the housing, with no obstructions such as other filters, adsorbers, etc., in the system, are required. The outlet transition must have access to allow scan testing of each HEPA filter.

Exposure time of maintenance and test personnel in containment systems is an increasing concern in facilities where harmful toxic and biological materials are present in the ventilation air.

The Flanders PrecisionScan test housing uses two devices on the upstream and downstream side of the filter to achieve the same purpose. Access for scan testing is located on the air-leaving side of the filter.

Prior to testing the filter, the inlet diffuser is closed to mix the challenge aerosol into the airstream on the upstream side. The challenge aerosol is then introduced into the system ahead of the diffuser, an upstream sample is taken and the results are determined by scanning the filter face area and its supporting framework.

Each test housing is designed so the readings are not affected by the adjacent filter. Because each filter is tested individually, a penetration reading for every filter in the system is obtained.

## Conclusion

Figure 16 illustrates one of the many kinds of tests performed at the factory and in the field. Most filters purchased by the Department of Energy are shipped directly to the government retest facility where they are given a second efficiency test with a Q 107 Penetrometer and are then reshipped to the buyer. Unfortunately, there have been no shortcuts devised to verify the performance of HEPA filters, either at the factory or in the field,. Typically, these filters are susceptible to damage during shipping and handling unless stringent precautions are taken. Historically, HEPA filters have been difficult to seal into their supporting framework or housings, a fact which inspired Flanders to develop the Filter-to-Frame Fluid Seal in the 1960s. This seal is now known as the gel seal, and has been used in all applications of air filtration since its development. Finally, they are unfamiliar items to most mechanical contractors and construction workers. The matter-of-fact approach used in the installation of standard building components should not be applied when installing HEPA filters.

### **NOTICE . . . Compliance with installation and operation standards must be met to ensure quality performance.**

HEPA filters are factory tested to meet the requirements of IEST RP-CC001.3 for Type A, B, C, D, E or F filters:

- Industrial Grade
- Nuclear Grade
- Laminar Flow Grade
- Bio/Hazard Grade HEPA
- VLSI
- ULPA
- Pharmaceutical Grade

Test results appear on both the filter label and upon the filter carton label. An additional quality assurance test report is kept on file and is available upon request.

Flanders recommends that all HEPA filters be tested in place by qualified personnel to ensure that the filters have been correctly installed.

Flanders service personnel are available for installations, supervision of installation, testing and certification of compliance to industry and government

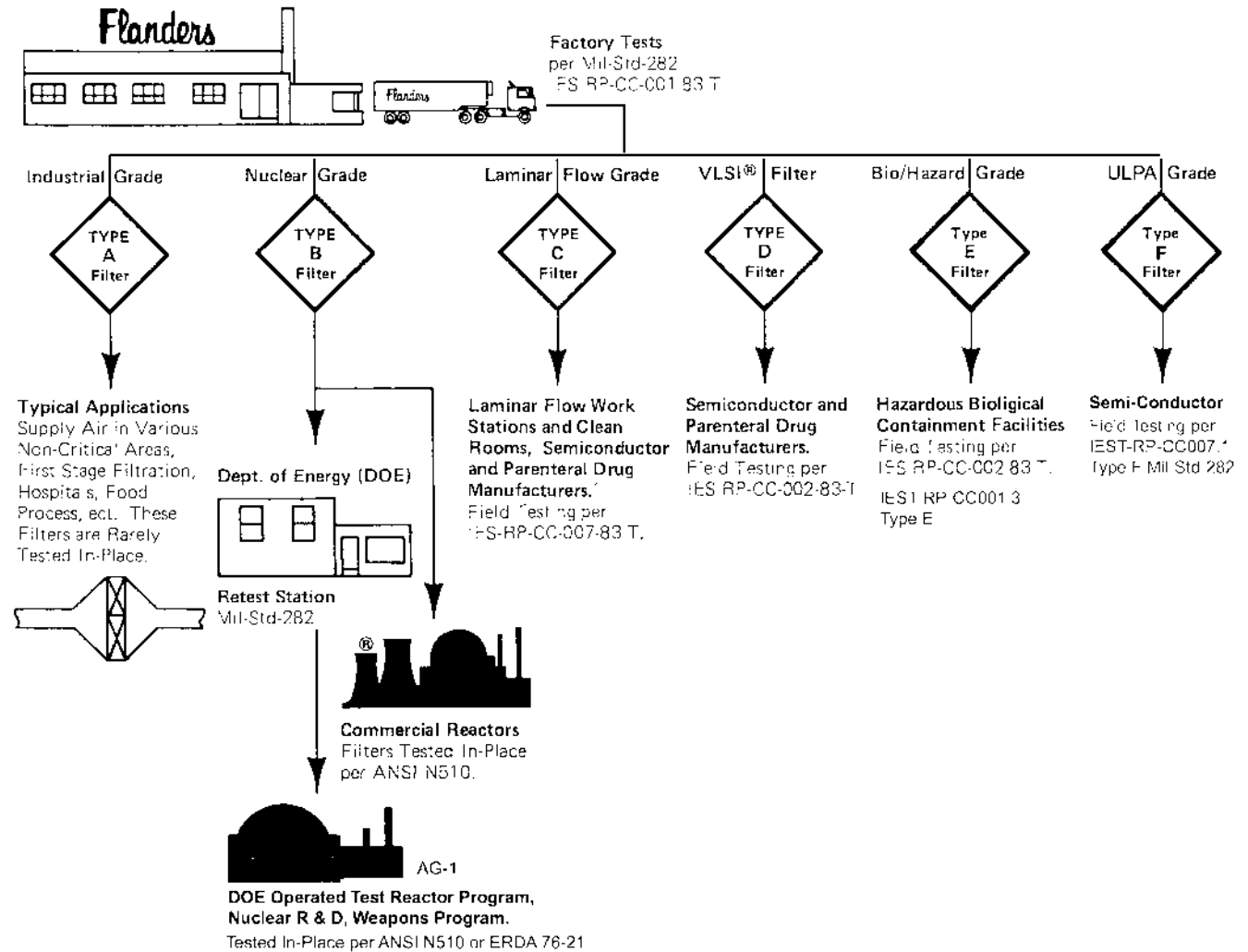


Figure 16: Factory Test Specifications, Field Test Specifications, Applications for HEPA and VLSI® Filters

standards and instruction of the owner's personnel in testing and maintenance procedures.

Flanders does not guarantee that its equipment will operate at the performance levels given on the identification labels or in the catalog specifications under all conditions of installation and use, nor does Flanders/CSC guarantee the suitability of its product for the particular end use which may be contemplated by the buyer.

For best results, it is recommended that the buyer supply complete information about the operating conditions of the ventilation system to

Flanders/CSC for evaluation.

When the system components are supplied to the buyer or his agent for final installation and assembly in the field, it should be under the supervision of factory trained personnel.

Failure to adhere to this recommendation or failure of the buyer to have filters timely retested and serviced will nullify or limit any warranties which might otherwise apply and may result in a compromised installation.

## Quality Assurance

Any industry that has dangerous process or exhaust gases and/or particulates has a vital concern for the health and safety of personnel. In addition to corporate concern, the United States Government has dictated that safety equipment meet minimum safety standards. Any equipment sold to meet these minimum standards has to be manufactured using accepted Quality Control procedures.

Flanders Corporation has developed a Quality Assurance program to assure that the product or service provided meets these standards. This program addresses the entire range of Flanders involvement, including the purchase of raw materials, the shortage of these raw materials, incorporation of these materials into a product or service, testing this product or service, and then shipping it to its destination.

The program of Flanders has been audited many times, and each time the program has been acceptable. An uncontrolled copy of the program manual is available with each request for Quality Assurance information. Like any dynamic document, the program is continually being revised to include recent issues of standards and specifications in order that Flanders/CSC may use the latest state-of-the-art methods in providing its products and services.

The Quality Assurance Program at Flanders Corporation has been audited and approved numerous times by the Nuclear Utilities Procurement and Inspection Committee, NUPIC. This committee was established by nuclear electric utilities to ensure that suppliers of goods and services can meet all applicable regulatory and quality requirements.

## Notes:

1 As part of our continuing program to improve the design and quality of all our products, we reserve the right to make such changes without notice or obligation.

2 Flanders, through its limited warranty, guarantees that the products described herein will meet all specifications agreed to by the buyer and the seller.

3 ASME N509 Nuclear Power Plant Air-Cleaning Units and Components.

4 ASME N510 Testing of Nuclear Air Treatment Systems.

5. ASME AG-1 Code on Nuclear Air and Gas Treatment

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