CHAPTER 8

TESTING

8.1 Introduction

The rationale behind high-efficiency particulate air (HEPA) filter specifications was developed by Humphrey Gilbert, a Manhattan Project safety engineer who coined the term, "HEPA filter." The heart of the filter is the media (paper), originally the same filter paper used in World War II (WWII)-era military gas mask canisters. As a result, the HEPA filter inherited many of the same specifications used for gas mask military standards, most of which were developed during WWII and have remained largely intact to the present. For example, HEPA filters are tested for efficiency using aerosols with a 0.3-micrometer (μm) particle size because academics in the 1940s calculated that a particle of that size would be the most difficult to capture or filter. Modern technology has proven this calculation relatively accurate.

The specifications of in-place testing, sampling and laboratory testing of adsorbents also evolved from the WWII-era of military gas mask canisters to application in the nuclear industry. Chapter 1 discusses the history and use of adsorbents for nuclear power reactors, radiochemical processing, fuel processing plants and noble gas control.

Testing of high-efficiency nuclear air cleaning systems is required to achieve and maintain high performance and continued safe operation of nuclear facilities. In nonreactor nuclear facilities throughout the U.S. Department of Energy (DOE) complex, HEPA filters in confinement ventilation systems can be constantly challenged with radioactive aerosols. Nonreactor nuclear facilities comprise the bulk of DOE nuclear facilities, and failure of their air cleaning system components can lead to uncontrolled release of radioactive aerosols. Thus, maintaining nuclear facility operability depends on the performance of these air cleaning components.

At the same time that HEPA filters and adsorbers were being developed for nuclear applications, methodologies were being developed to assure their performance. These methodologies eventually evolved into a performance assurance program with three major components: (1) design qualification of individual components through destructive testing, (2) quality assurance (QA) of individual components through nondestructive testing, and (3) performance assurance of nuclear confinement ventilation systems through in-place testing. This overall performance assurance program was designed to be hierarchical because components were built on a foundation laid down by preceding components. Design qualification assured that filters produced according to a manufacturer's design met specific performance criteria for normal and off-normal operation. Ideally, performance criteria were directly related to a facility's design basis. In fact, however, this often was not the case, making it difficult to impossible to crosswalk between facility operation requirements and material/design qualification test criteria.

Once a manufacturer's design was qualified, the filter model number was put on a qualified products list (QPL) maintained by the Department of the Army. It was mandated that only QPL-listed manufacturers could be used for HEPA filter procurement. The nuclear industry adapted the QPL for use in procuring HEPA filters. Standard test procedures and equipment available from the American Society for Testing and Materials (ASTM), the Technical Association of the Pulp and Paper Industry (TAPPI), and others were referenced in the documentation of QPL products. Numerous organizations have issued consensus standards incorporating major provisions of the military specification and qualification standards. Those holding the most interest for nuclear service applications are the publications prepared by a standards writing group sponsored by the American Society of Mechanical Engineers (ASME) Committee on Nuclear Air and Gas Treatment (CONAGT), with participation from DOE and the U.S. Nuclear Regulatory Commission (NRC). Upon withdrawal of the U.S. Department of Defense (DoD) Military Specifications MIL-51079,

Filter Medium, Fire Resistance, High Efficiency, (1980)[1] and MIL-51068, *Filter Particulate, High Efficiency, Fire-Resistant,* (1981),[2] the MIL standard requirements were incorporated verbatim into ASME AG-1, *Code on Nuclear Air and Gas Treatment*, Section FC.[3] The Army no longer publishes the QPL.

HEPA filters for nuclear service now undergo four tests: (1) a design qualification test performed by a qualified laboratory, (2) quality control testing at the manufacturer, (3) a DOE-required acceptance test, and (4) and a system leak test at the facility where the filter will be used. Manufacturers submit prototype filters for design qualification testing. This testing examines areas such as media penetration and resistance to airflow, rough handling, pressure, heated air, and spot flame. The filter medium receives the most rigorous and extensive control and evaluation. At present, the U.S. Army's Edgewood Arsenal in Maryland is the only facility available to perform this qualification testing. This testing is required to be repeated every 5 years. Manufacturers receive a letter stating whether their filter designs passed the qualification tests.

After qualification of a filter design, manufacturers are eligible to sell their HEPA filters for use in nuclear applications. Before the filters are supplied to DOE, however, ASME AG-1[3] requires manufacturers to perform quality control testing including penetration testing and resistance to airflow.

DOE-STD-3020[4] requires further acceptance testing of HEPA filters that will be used in DOE nuclear facilities. This testing must be performed at a DOE Filter Test Facility (FTF). Manufacturers are required to submit their HEPA filters to the DOE FTF. This 40-year-old requirement was reestablished by the Secretary of Energy in a letter dated June 4, 2001, and reconfirmed in a letter dated July 11, 2003[5]. At the FTF, filters must pass a rigorous visual inspection by trained inspector personnel and various flow tests (penetration, resistance to flow, etc.). Filters that fail a visual inspection are not subjected to flow tests. There has been a 40-year history that suggests a failure rate of 3 to 5 percent for visual inspections and approximately 2 percent for performance. This persistent failure rate forms the basis for performing both the manufacturers' tests and having them independently verified at the FTF in order to obtain a HEPA filter with an efficiency of at least 99.97 percent. The FTF tests and the manufacturers' tests are based on: (1) uniform aerosol concentration, (2) uniform flow, (3) qualified sample locations, (4) capability for 100 percent and 20 percent flow, and (5) a challenge aerosol of 0.3 µm. This particle size represents the size of maximum penetration through the filter. Only filters that pass the FTF tests are forwarded to a DOE nuclear facility. Filters that fail are returned to the manufacturer, typically without cost to the buyer.

After being installed at a DOE nuclear facility, an in-place leak test is done to ensure the performance of the confinement ventilation system. Unlike bench tests for new filters that are designed to determine filter quality via a penetration test utilizing an aerosol containing a substantial fraction of particles in the range of the minimum filterable size, in-place tests are designed to reveal the presence of defects in the filter unit that result from such things as rough handling during transportation, paper and gasket damage during installation, inadequate pressure against intact gaskets, and penetrations through the housing to which the filter units are attached. Aerosol penetration during an in-place test in excess of established limits is assumed to indicate defective installation and/or filter damage. Procedures are conducted to locate and correct the defects. Such procedures include increasing gasket compression; examining gaskets for breaks and tears; replacing broken filters (repairs are not permitted for nuclear service in the United States); and welding closed any unauthorized penetrations, cracks, and open seams in the filter house and mounting frames (patching with caulking compounds is not permitted for nuclear service in the United States). Following each repair, the system must be retested until it meets the established criteria for leak tightness.

The performance of the periodic/surveillance in-place test cannot be overemphasized. The in-place leak test described by ASME N-510 is used to conduct a periodic surveillance to reconfirm the performance of the filter system. The in-place leaks test confirms the safety basis assumptions "system efficiency." The final result is a measure of efficiency that forms the basis for removal efficiency assumed in the safety bases. The in-place test results may also be credited by the RadCon and air emission permits for removal of respirable particles. Unlike the filter penetration test which validates the filter design assumption using a mono-disperse aerosol test, the in-place leak tests uses a poly-dispersed (0.7 mean diameter) and determines the system efficiency where the system components (i.e., gaskets, frame, housing, etc.) are challenged. The test is

performed under actual conditions and at operational airflow. The criteria for the in-place leaks tests are typically provided by the safety basis or other operating licenses/permits. The test results may also be used as a service life indicator.

Each of the components of this vigorous performance assurance program is described in this chapter.

8.2 Proof of Design – HEPA Filter Design Qualification Testing for Nuclear Service

As discussed previously, the U.S. Army's Edgewood Arsenal tests prototype HEPA filters to qualify the designs for use in DOE nuclear facilities (this testing is required to be repeated every 5 years). ASME AG-1, Section FC,[3] requires quality product qualification testing for efficiency, airflow resistance, rough handling, overpressure, heated air, and spot flame. The following subsections discuss each design qualification test and associated acceptance criteria.

8.2.1 Penetration (Efficiency)

The performance of a HEPA filter may be expressed either as a particulate collection efficiency (percent of particulate concentration stopped by the filter) or as a penetration. Penetration where the total aerosol penetration through the filter medium, frame, and gasket of a filter that has been encapsulated shall be no greater than 0.03 percent of the upstream concentration at rated airflow and at 20 percent of rated airflow. The reason for the 20 percent flow test is to increase sensitivity for pinhole determination. Concentration may be given by particle count per unit air volume (emphasizing the smallest particles present), particle weight per unit air volume (emphasizing the largest particles present), ionizing radiation intensity per unit volume of air (particle size effect is indeterminate), or light-scattering intensity per unit air volume (emphasizing small particle sizes). Sometimes filter penetration is expressed as a decontamination factor (DF), the ratio of the untreated air concentration to the treated air concentration (e.g., 99 percent collection efficiency is the same as a DF of 100 and is equal to a penetration of 1.0 percent). The DF descriptor is used most frequently when ionizing radiation is the concentration descriptor.

8.2.2 Airflow Resistance

The resistance of a filter to airflow, often called "pressure drop" and "back pressure," is usually given as the height of a water column (measured in in.wg) that exerts an equal pressure. The characteristic flow regime through HEPA filter media is aerodynamically described as laminar. For this reason, the airflow resistance of these filters changes in direct proportion to changes in air volume even though the air approaching the filter may be turbulent. Resistance to airflow at the rated airflow of the filter shall be no greater than 1.0 in.wg for filter sizes 4 and 5, and 1.3 in.wg for filter sizes 1, 2, 3, 6, 7, 8, and 9. See ASME AG-1, Section FC[3] for filter definitions.

The test protocols used to qualify HEPA filters for nuclear service are described below. Bench testing of all new filters intended for U.S. nuclear service is conducted with a test aerosol in a tester called a Q107 aerosol penetrometer (**Figure 8.1**). This device was designed by the U.S. Army Chemical Corps during the 1950s, and its construction and operation are described in MIL-STD-282 *Military Standard Filter Units, Protective Clothing, Gas Mask Components, and Related Products: Performance/Text Methods*,[6] Method 102.9. The complete penetrometer consists of a monodisperse test aerosol generator, an instrument that measures the size and uniformity of the particles formed, a clamping device to seal the filter under test into the test fixture, a total scattering photometer to measure test aerosol penetration, and a manometer to measure filter resistance at rated airflow rate.

8.2.3 Test Aerosol Test

The basic apparatus and procedure is described in detail in Military Standard MIL-STD-282[6] and DOE-STD-3025.[7] Room air is drawn through filters and split into three streams. One stream of 85 cubic feet per

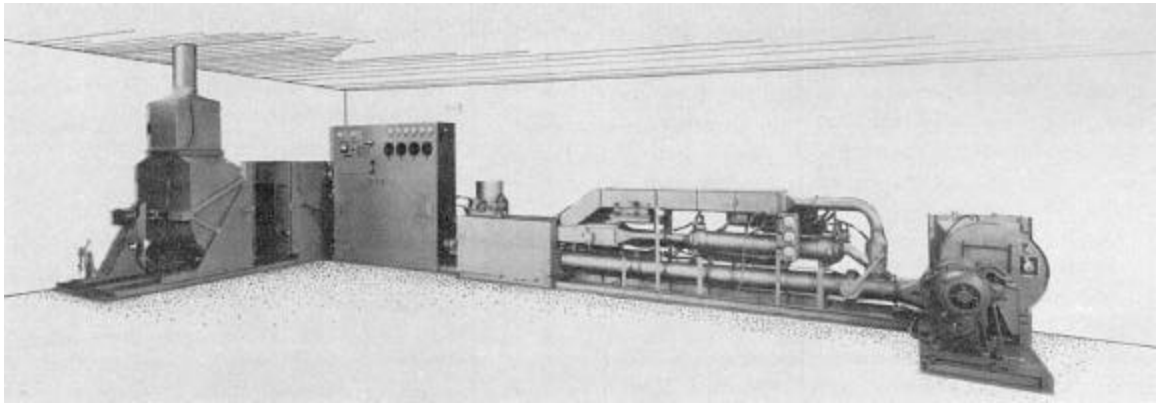

Figure 8.1 – Q107 Penetrometer for Efficiency Testing of HEPA Filters (Equipment contains a thermal DOP generator capable of producing a monodispersed aerosol)
(Photo provided by ATI)

minute (cfm) is heated to 365 degrees Fahrenheit and is passed over liquid test aerosol heated to 390 ± 20 degrees Fahrenheit. As the heated air passes over the surface of the hot test aerosol, it becomes saturated with aerosol vapor. Traditionally the test aerosol of choice was dioxytl phithalate (DOP). When the test-aerosol-saturated air contacts the second airstream (265 cfm held at approximately 71 degrees Fahrenheit), the condensation aerosol is formed. The third stream of diluent air (850 cfm) is introduced in a mixing chamber to dilute and disperse the aerosol-laden air. A forward light-scattering photometer is used to measure test aerosol penetration, and a manometer is used to measure filter resistance at rated airflow rate. Modern penetrometers that use jet impactors to obtain the same aerosol without heating the test aerosol liquid are commercially available.

The size of the test aerosol is determined by passing a sample through an optical particle-sizing instrument called an OWL[8] and noting the degree of polarization of a light beam. A polarization angle of 29 degrees indicates a particle diameter of 0.3 µm when the aerosol is monodispersed. The brightness and number of red bands produced when the beam is rotated 360 degrees indicates the uniformity of the particles. However, when the aerosol is not precisely monodispersed, the polarization angle read by the OWL represents an average diameter that is not the same as for a precisely monodispersed aerosol.[9] For example, a test aerosol with a count median diameter of 0.232 µm and a geometric standard deviation of 1.15 (perfect uniformity is a geometric standard deviation of 1.0) would give a polarization angle of 29 degrees, whereas a 0.3-µm aerosol with the same degree of size dispersion would give a polarization angle of 45 degrees.[9]

In the early 1980s, DOE issued a contract to the Los Alamos National Laboratory (LANL) to review HEPA testing practices. In the subsequent study, LANL highlighted the pros and cons of the MIL-STD-282[6] testing methodology, and recommended looking at modern technology to develop an alternative. This alternative system became known as the High Flow Alternative Test System (HFATS) and is currently used by some HEPA filter manufacturers and the DOE FTF located in Oak Ridge, Tennessee.

The HFATS uses the MIL-STD-282 Q-107 aerosol penetrometer blower, ducting, filter holding fixture (chuck) and some of the controls as a platform. The thermal monodispersed aerosol-generating components were disabled and replaced with the LANL-designed aerosol generator incorporating the standard Laskin nozzles and impactors. This combination generates a polydispersed aerosol that allows for penetration determinations at the particle size of maximum penetration (≅ 0.2 µm diameter) and at the traditional particle size of 0.3 µm diameter. The Q-107 aerosol monitoring and aerosol efficiency measuring instrumentation was disabled and replaced with a laser aerosol spectrometer, an upstream sample diluter, and a computer. A final report covering all the details is in LANL publication LA-10748[10] available from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

In summary, the HFATS eliminated several problems inherent with the MIL-STD-282 system and took advantage of state-of-the-art aerosol sizing instruments, which are capable of providing more detailed information regarding filter performance. It also allowed the use of liquids other than DOP and at a much lower concentration to test the filter. When using any test aerosol, consideration must be given to the flammability of the material.

8.2.4 Resistance to Rough Handling Qualification Test

The rough handling tester (**Figure 8.2**) was designed by the U.S. Army Chemical Center (Edgewood Arsenal) to subject a carbon filter to vibration to determine whether carbon channeling would occur during shipping and handling. If channeling occurred, then toxic gases would have a bypass path around the carbon, allowing penetration of the filter. The HEPA filter inherited this test to determine its capability of being transported across country by commercial carriers. It was quickly determined that transportation by rail led to unacceptable failure rate. [Note: This test does not actually test the HEPA filter according to the way it is shipped; a commercial vibrating machine designed for this purpose should be used to test the filter. In addition, the filter should be tested in its packaging exactly as it will be shipped, not laid down horizontally and bolted to a table.]

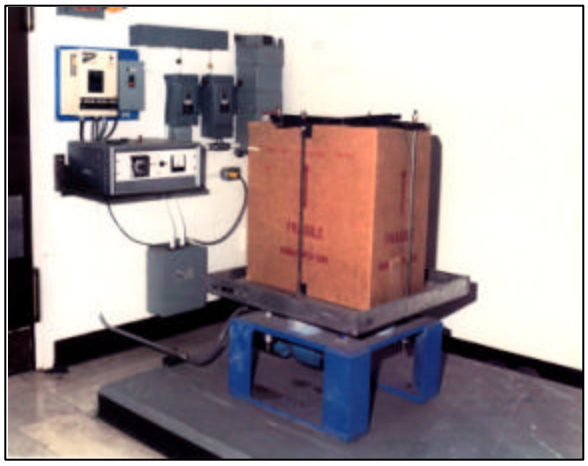

Figure 8.2 – Rough Handling Machine

In accordance with Method 105.9 of MIL-STD-282,[6] new, unused test filters (at least 2 of the size and design to be qualified) must undergo rough handling for 15 minutes at a total amplitude of 0.75 inches (using sharp cut-off cams that result in both a slow and an instantaneous 0.75-inch drop) and a frequency of 200 Hertz (Hz), with pleats and filter faces in vertical orientation. The filters must withstand this treatment without visible damage (cracked or warped frames, loose corners or joints, cracked adhesive, loose or deformed medium) or a decrease in filtration efficiency from 99.97 percent, as determined with nominal 0.3 µm test aerosol at full and 20 percent flows.

8.2.5 Moisture and Overpressure Resistance Qualification Test

The overpressurization tester (**Figure 8.3**), which tests HEPA filters at high humidity and at 10 in.wg, also came from a military standard for testing carbon filters that was applied to the HEPA filter. At least four new, unused filters of the type to be qualified must be aged a minimum of 24 hours under static conditions at 95 ± 5 degrees Fahrenheit and 95 ± 5 percent Relative Humidity (RH), after which they must be installed in a wind tunnel that has been modified to permit the introduction of water spray. After conditioning, the filters must withstand a spray of 1.25 pounds per 1,000 cfm, adjusted to produce a 10-in.wg pressure drop across the filter, and a flow environment of 95 degrees Fahrenheit. The minimum test duration under these specified conditions is 1 hour. After the test and the filters are dried out, there must be no visible evidence of failure. Within 15 minutes after completion of the pressure test and while still wet, the 0.3-µm test aerosol efficiency at full and 20 percent rated flow

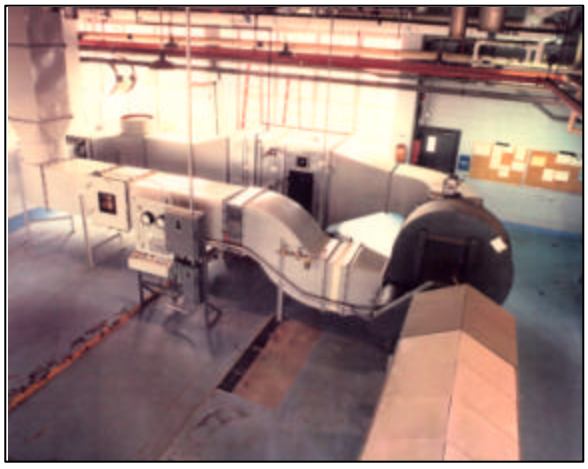

Figure 8.3 – Overpressure Resistance Tester

must be a minimum of 99.97 percent. By indirect reference, this qualification test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC).[3] This is the most stringent test an assembled HEPA filter will undergo and is limited to a 10-in.wg pressure drop. Some new HEPA filters have had difficulty meeting this requirement. For this reason, HEPA filters should never be rated for services at greater than 10 in.wg and should never be used above half this value.

8.2.6 Fire and Hot Air Resistance Qualification Test

The high-temperature test came from the nuclear industry as a result of a catastrophic fire at the Rocky Flats site. Related research work also was done at Lawrence Livermore National Laboratory (LLNL). The 700 ± 50 degrees Fahrenheit point of the test was selected in laboratory experiments. Since industry consensus standards did not come into vogue until the late 1950s and early 1960s, the HEPA filter inherited many then-current military standards and specifications.

New, unused filters must be exposed to heated air in a wind tunnel at 700 ± 50 degrees Fahrenheit for 5 minutes **(Figure 8.4)**. After exposure to heat, the filters must be cooled down and tested in-place, with the filter remaining in the heated air tester. An aerosol generator and photometer may be used for the aerosol test. The penetration at equal to or greater than 40 percent of rated flow must be less than 3 percent. By indirect reference, this test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC).[3]

Figure 8.4 – Heated Air Tester

8.2.7 Spot Flame Resistance

New, unused filters must be tested for spot flame resistance. In this test, the HEPA filter is inverted in a test duct and operated at its rated airflow. A gas flame from a Bunsen burner is directed against the upstream face of the HEPA filter. The Bunsen burner is adjusted to produce a flame with a blue cone 2.5 inches long with a tip temperature of 1750 ± 50 degrees Fahrenheit. The tip of this flame is applied so that it is not less than 2 inches from the filter face. The flame is applied for 5 minutes at each of 3 separate locations on the filter face. The Bunsen burner flame then is directed into the top corner of the filter unit so that the tip of the blue flame cone contacts the frame, filter pack, and pack sealant. The flame is applied for a period of 5 minutes. After the removal of the test flame at each point of application, there must be no sustained flaming (burning) on the downstream face of the unit. By indirect reference, this test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC).[3]

8.3 Manufacturer's Quality Control - Inspection and Testing of HEPA Filters

The manufacturer's qualification procedure involves two distinct phases: (1) a quality assurance/quality control (QA/QC) routine intended to ensure careful manufacture of a quality product, and (2) a series of tests to verify filter compliance with preset standards concerning the properties of components and the physical characteristics of the assembled filter, as well as a set of performance criteria related to collection efficiency and resistance to airflow. When all of these factors are within the tolerance limits set by the applicable standards, the manufacturer certifies that each delivered filter unit meets all acceptance criteria. The manufacturers required tests for HEPA filters are prescribed in ASME AG-1, Section FC.[3]

8.4 Filter Test Facility Acceptance Testing of HEPA Filters

HEPA filters are critical to the safety of workers and the public in the event of an accident at a nuclear facility. The greatest care is taken to ensure these filters perform both as designed and as assumed in the facility safety analysis. The U.S. Atomic Energy Commission (AEC) identified the need for QA testing of HEPA filters between 1957 and 1958. During this period, the AEC randomly selected filters from stock, and a significant number were found defective. In 1959, the AEC initiated QA testing at the Hanford and Edgewood Arsenal sites. Operations at the Oak Ridge FTF (ORFTF) and Rocky Flats FTF (RFFTF) followed in January 1963 and 1974, respectively. Historically, these FTFs have provided over 40 years of progressive QA testing and delivery of critical quality components. The ORFTF is the last of the three DOE HEPA FTFs remaining. DOE continues to perform 100 percent QA receipt inspection and efficiency-pressure drop testing on certain HEPA ventilation filters produced for use in DOE nuclear facilities. This is done to ensure that filtration efficiency reliably meets DOE specification requirements and that the last barriers of protection against the release of particulate radioactivity to the environment at DOE nuclear facilities are performing as they should. Historically, the rejection rate continues to fluctuate, as shown in **Table 8.1** below, with a high of 18.7 percent in 1996 decreasing to 1.6 percent in 1999, then increasing to 9.8 percent and 8.1 percent in 2000 and 2001, respectively. These significant reported rejection rates indicate that vendor testing alone is not sufficient to reliably produce a HEPA filter of at least 99.97 percent efficiency.[11]

Table 8.1 – Oak Ridge Filter Test Facility Testing Activities (Fiscal Year 1996 to 2003)

Fiscal Year	*Number Received*	*Number Accepted*	*Number Rejected*	*Resistance*	*Penetration*	*Manufacturing Defects*	*Does Not Meet PO and/or Spec*	*Shipping Damage*	*Percent Rejection Rate*
1996	2,643	2,150	493	371	70	35	17	0	18.7
1997	2,916	2,814	102	59	20	7	16	0	3.5
1998	2,305	2,237	68	1	28	3	34	2	3.0
1999	2,362	2,325	37	0	31	6	0	0	1.6
2000	3,597	3,241	356	0	44	36	270	6	9.9
2001	2,722	2,505	217	1	39	46	123	8	8.0
2002	2,110	2,008	102	0	20	42	32	8	4.8
2003	2,772	2,621	151	0	26	93	27	5	5.4
Total	21,427	19,901	1,526	432	278	268	519	29	7.1

The operating policy of DOE's filter testing program, contained in DOE-STD-3022-98, *DOE HEPA Filter Test Program*,[12] calls for testing all HEPA filters intended for environmental protection at a DOE-operated FTF (ORFTF). Delivery of certain HEPA filters to the FTF for QA review is mandatory for all DOE facilities. This service is also available to the public on a fee basis. The FTF test results are added to the information on the filter case. The test procedures at the FTF call for "penetration and resistance tests," "visual inspection for damage and visible defects," and other "visually verifiable requirements." Except for filters rated at less than 125 cfm, penetration tests are to be conducted at 100 percent and 20 percent of rated airflow capacity, and the maximum penetration of 0.3-µm particles at both airflow rates is 0.03 percent, in accordance with DOE-STD-3025-99.[7] Penetration tests may be conducted using a monodisperse aerosol and a total light-scattering photometer or a polydisperse aerosol with a single particle counting and sizing instrument. A QA program for the DOE FTF is contained in DOE-STD-3026-99, *Filter Test Facility Quality Program Plan*.[13] Specifications for HEPA filters to be used by DOE contractors are contained in DOE-STD-3020-97, *Specifications for HEPA Filters Used by DOE Contractors*.[4]

Visual Inspection

Immediately prior to installing new HEPA filters in a system they should be thoroughly inspected visually by a trained inspector for any damage to the filter frame, filter pack, and gaskets or fluid seal.

Visual inspection is an integral and vital part of every acceptance or surveillance test. A careful visual examination should be made of each internal and external component prior to installation to verify that the items have been received in satisfactory and serviceable condition. After installation, the system should be checked as part of the acceptance test procedure to make sure that all required items have been properly installed. A suggested checklist is provided in Section 5 of ASME N510,[14] which may be used to verify that system design and construction are in accordance with ASME N509.[15] ASME AG-1 also provides guidance for visual inspection in Section 5.0 and Appendix 1 of Section AA.[3] Preparation of the proper visual checklist is the most important part of the test procedure. The checklist should cover all major potential problems without further testing, including the relevant items identified in Section 5.0 of ASME N510,[14] and also should incorporate the field observation checklist items listed in Appendix C of ASME N509[15] where applicable. Certain items listed in the recommended checklist in ASME N510[14] are only observable prior to installing the components. Experienced field test personnel should be, and have been, able to find bank leak paths of a few tenths of a percent by visual examination, as well as many other potential problems not identified by the actual leak test procedures. Appendix B of this Handbook provides guidance and a sample checklist for HEPA filters used at DOE facilities that must meet DOE-STD-3020.[4]

8.5 In-Place Component Tests and Criteria

System tests fall in two broad categories: (1) prestartup acceptance tests to verify that components have been installed properly and without damage and that the system can operate as intended, and (2) surveillance tests made periodically after the system has been placed in operation to demonstrate its ability to continue performing its intended air cleaning function. Surveillance tests are leak tests of the HEPA filter and adsorber installations. To provide guidance for the preparation of test procedures, details of acceptance and surveillance tests are given in ASME N510,[14] and ASME AG-1.[3] In all cases, tests should be preceded by careful visual inspection, as previously discussed in Section 8.4.

8.5.1 Component Acceptance Testing

Acceptance tests also fall into two broad categories: (1) those that relate to the permanent elements of the system, ducts, housing, mounting frames, and location of test ports, and (2) those that verify the installation and condition of the primary air cleaning components (HEPA filters and adsorbers). Acceptance tests of HEPA filter and adsorber installations are identical to the surveillance tests of those elements and are covered in Section 8.6. Tests in the first category include leak tests of ducts, housings, and primary-component mounting frames; airflow capacity and distribution tests; gas residence time tests for systems containing adsorbers; duct-heater tests for systems containing heaters; and air-test aerosol mixing-uniformity tests. The acceptance test program for a particular system may contain any or all of these tests, depending on the nature of the system and its importance (i.e., the potential consequence of a failure of, leakage from, or release from the system).

NRC Regulatory Guides recommend the full battery of acceptance tests for engineered safety feature (ESF) systems, and the requirements for testing safety-related nuclear air treatment system components are covered by NRC Regulatory Guide 1.52.[16] In addition, requirements for testing of non-safety-related nuclear air treatment system components are covered by NRC Regulatory Guide 1.140.[17] Neither the ASME N510[14] standard nor the two regulatory guides are consistent in their requirements, and a coordinated version and further clarification are long overdue. The new 2001 revisions of both regulatory guides incorporate references to AG-1[3] in an attempt at consistency. While not perfect, they are a big improvement over the previous versions. Lesser systems may not warrant such stringent testing. On the other hand, these tests, which are conducted only once when a new or rebuilt system is accepted, provide an assurance of system reliability that cannot be obtained in any other way. The ASME CONAGT (responsible for ASME N510[14]) recommends that these tests be considered for any high-reliability system.

The original standard for nuclear air cleaning component testing was developed by the American National Standards Committee's N45.8.3 ad hoc group which was incorporated into the first version of *Testing of*

Nuclear Air Cleaning Systems, (ANSI N510-1975)[14] was later revised to ANSI/ASME N510-1980,[14] then ASME N510-1989.[14] This standard was updated by the ASME CONAGT Group, and a final version for acceptance testing was issued as ASME AG-1,[3] Section TA, "Field Testing of Air Treatment Systems." (Note: Section TA of AG-1 addresses the acceptance field testing of the system and its components. The standard for routine field surveillances is still under development. The seventh draft revision of the standard is entitled, ASME N511-2003, *Standard for In-Service Testing of Nuclear Air Treatment, Heating, Ventilating, and Air Conditioning Systems*. The basic precepts of ASME N510[14] and ASME AG-1,[3] Section TA, are listed below).

- All components (prefilters, mist eliminators, HEPA filters, adsorbers, etc.) are qualified and tested as individual components. Their original efficiency is established, and "as-installed" tests do not require further "efficiency testing." Only the in-place test is conducted to ensure the integrity of components is maintained and that no bypass exists.
- The housing is of the desired strength and integrity, which can be measured by isolating the unit envelope housing and leak testing under the specified pressure differential conditions.
- The framework integrity (framework holding critical components such as HEPA filters and adsorbers) can be measured by using blank off plates and pressure differential leak tests.
- When critical components are installed, the in-place leak test measures only the quality of the installation of the components.

The standard writers assumed that the components are well designed and that pyramiding of the four above-listed precepts will realistically measure the adequacy of the installed operating air cleaning unit.

For clarity, it must be reiterated that the definition of the "Air Cleaning Unit" is an assembly of components that together comprise a single subdivision of a complete air cleaning system, including all the components necessary to achieve the air cleaning function of that subdivision. A unit includes a single housing, with the internal components (filters, adsorbers, heaters, instruments, etc.) installed in or on that housing.

Acceptance tests are outlined in Table 1 of ASME N510[14] and in ASME AG-1,[3] Section TA. Before assembly, personnel should assure that all components meet the specified criteria. Typical QA acceptance only assures that paperwork is available. This paperwork should be checked both for original supply and for replacement parts. Before installing components, personnel should perform the following tests:

- Visual Inspection,
- Duct Leak Test,
- Housing Leak Test, and
- Mounting Frame Leak Test.

During and immediately after installation of components, personnel should perform the following tests:

- Visual Inspection,
- Airflow Capacity and Distribution Test,
- Air/Aerosol Mixing Uniformity Test,
- In-Place Leak Test HEPA Stage,
- Remove Adsorbent and Perform Laboratory Testing (to establish baseline carbon efficiency),
- In-Place Leak Test Adsorber Stage, and
- Duct Damper Bypass Leak Test (if required).

The tests listed in ASME N510,[14] Table 1, include:

- Visual Inspection – Section 5 (to ensure that components are properly installed and are not damaged);
- Duct and Housing Leak and Structural Capability Test – Section 6 (to ensure the installed housing has leakage and structural integrity);
- Mounting Frame Pressure Leak Test – Section 7 (to ensure that no bypasses exist at welds, etc.);
- Airflow Capacity and Distribution Tests – Section 8 (to ensure that desired flows can be achieved with clean and dirty filters, and also that velocities through components are in the narrow range where the components were qualified individually;
- Air Aerosol Mixing Uniformity Test – Section 9 (to ensure the test aerosol injection and sampling ports are located properly to perform testing of the HEPA filter bank or adsorbent stage);
- HEPA Filter Bank In-Place Test – Section 10 (to establish that the HEPA filters are properly installed and were not damaged before or during installation);
- Adsorber Bank In-Place Test – Section 11 (to establish that the adsorbers were properly installed and that there is no major settling and/or channeling of the adsorbent);
- Duct Damper Bypass Test – Section 12 (to qualitatively assess leakage through bypass dampers in the system);
- System Bypass Test – Section 13 (to ensure that all filter banks and potential bypass leakage paths are assessed in the leakage test). All negatively pressurized portions to the flow discharge can be important and are frequently overlooked, e.g., fan shaft seals, damper control linkage, sample ports. The importance of the amount of bypass leakage is increased as the credit for removal of the contaminant increases in the system;[18]
- Air Heater Performance Test – Section 14 (to ensure that the heaters used for humidity control are capable of achieving the desired RH); and
- Laboratory Testing of Adsorbent – Section 15 (to quantify the efficiency of the carbon media for its ability to adsorb radioiodines).

Two critical items have to be understood in the use of ASME N510.[14] First, the standard is considered a test method for air cleaning systems designed according to ASME N509.[15] However, ASME N510[14] was initially issued in 1975, and ASME N509[15] in 1976, years when a large number of U.S. power reactors were already designed, and even many later, facilities were designed with only with limited adherence to common sense engineering practices or the requirements of ASME N509.[15] The second critical item is the potential for misinterpreting the Scope section of ASME N510,[14] which states that it is a "basis for the development of the test programs and detailed acceptance and surveillance test procedures," and "that it be rigorously applied only to systems designed and built to ASME N509."[15]

In spite of this rather clear scope definition, many facilities established their test methodology by either generally claiming that, "testing shall be in accordance with ASME N510,"[14] even when their systems were not designed for it (or according to NRC Regulatory Guide 1.52[16] or 1.140,[17] which refer to ASME N509[15] and N510[14] requirements). Some never developed a specific test program for each unit and system to modify the basic N510[14] procedures to ensure achievement and maintenance of the desired result (complete system integrity). The treatment of issues related to air cleaning unit and system testing here is based on ASME N510.[14]

If all of the referenced tests are performed sequentially every time and the airflows are well balanced from a specified intake point to a specified discharge point, then the test series may be considered a system test. However, if only parts of it are performed, it is not a system test—only an installed component section test (i.e., a HEPA filter bank or adsorber stage bank test).

8.5.2 Duct and Housing Leak Test

The level of duct and housing leaktightness (and therefore the acceptance criterion for the test) is based on the type of construction and the potential hazard (consequence) of a leak. Recommended maximum permissible leak rates for various duct and housing constructions are given in AG-1, Section TA.[3] The designer may specify tighter requirements based on the confinement requirements of the system.

Duct leak tests may be conducted by testing the entire ductwork system at one time or by testing one section at a time and blanking off the ends of the section under test. The second method is more practical for larger systems. When segmented, the permissible leak rate for the individual sections is based on the proportionate volume of that section. The apparatus and procedure for leak testing levels 1 and 2 ducts are described in the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) *HVAC – Duct Design.*[19] Using the described procedures outlined in ASME N510,[14] duct leak tests can also be developed with some modifications. The ASME N510 standard offers two test methods for housing leak test: the Pressure Decay Method (the most convenient for larger duct and housing systems) and the Constant Pressure Method (the most effective for smaller volumes).

Test methods for level 3, 4, and 5 ducts and for housings are described in Section 6 of ASME N510.[14] If the specified leak tightness cannot be met, leaks are located, repaired, and retested by one of the methods described in Section 6 of ASME N510.[14]

When performing the unit housing leak test, it is important to follow the normal procedures (door closing, etc.) and thereby avoid creating a once-in-a-lifetime condition that does not resemble normal operating procedures and conditions. The test is supposed to demonstrate that the unit housing will maintain the specified leaktightness during its operating life. Based on experience, this is an unrealistic expectation. There is always some deterioration of door gaskets, or occurrence of sprung doors, damaged threads on closures, and leaks due to maintenance work on the unit. To ensure the leak integrity of the housing is maintained, personnel should perform periodic retesting (every 10 years). However, the risk of spreading contamination does not warrant this test on ventilation systems that are in continual use in contaminated or potentially contaminated applications. Surrogate methods such as acoustical monitoring or tracer gas monitoring may be appropriate when entry into the housing is precluded.

8.5.3 Mounting Frame Pressure Leak Test

This test is performed to ensure the installed HEPA filter/adsorber mounting frame is installed with no leak paths through the structure. This is considered an optional test because the same evaluation is done after the filters are installed, and an in-place leak test is performed on the bank. However, this test may be useful for determining gross leakage prior to filter installation. Any repairs required must be done before installation of any HEPA filter/adsorber. This test is also the first check for any other leak paths through conduits, drains, etc., which communicate between the upstream and downstream side of a single bank of HEPA filters or adsorber banks. Realistic test performance requires the unit housing leak test to be performed and the specified leak criterion to be met. The acceptance value set in the specifications should always be realistic.

These tests are conducted to verify there are no leaks through the HEPA filter and adsorber mounting frames or through the seal between the mounting frames and the housing. The tests also verify there is no bypassing of the mounting frames through electrical conduits, drains, compressed air connections, and common anterooms of the housing, or other inadvertent leak paths. Familiar sources of leaks are weld cracks and incomplete welds. A properly designed mounting frame should have no penetrations (via conduits, piping, or ducts), and lighting, drain, and other ancillary systems should be designed so that no bypassing of the HEPA filters and adsorbers can occur. Nevertheless, unauthorized modifications are often made in the field. The purpose of this test is to disclose such occurrences, as well as any leaks caused by poor workmanship or shipping damage. The test is recommended for any installation, whether duct and housing leak tests are performed or not, but it is particularly necessary when subsequent in-place tests of the HEPA filter and adsorber stages will be performed using a shrouded method.

This test is conducted by first blanking off all openings for filters and adsorbers and closing or blanking off all openings in the housing, then conducting a soap-bubble or spray test aerosol leak test around all welds and other potential leak paths (as described in Section 7 of ASME N510).[14] After all leaks have been repaired, individual chambers of the housing should be checked by a pressure leak rate test to verify there are no bypasses that were not disclosed by the leak detection check. It is unnecessary to perform these tests from the upstream side of the mounting frame, and it is quite acceptable to test two mounting frames simultaneously by blanking off the openings of both and pressurizing the space between. Because the mounting frame pressure leak test is a chamber-by-chamber test of the housing, it can replace the need for a housing leak test.

8.5.4 Airflow Capacity And Distribution Test

This test is used: (1) to verify that the specified volume flow rate of the air can be achieved with the installed fan under actual field conditions at maximum and minimum filter pressure drop, and (2) to verify that the airflow distribution across each HEPA filter or adsorber stage is within the specified uniformity at the designed volumetric flow rates. ASME N509[15] and N510[14] require an airflow capacity of ±10 percent maximum deviation from design flow. This value is not well correlated to the assumption of NRC Regulatory Guide 1.52[16] and the radioiodine test methods specified in ASTM D3803.[20] The variation of ±10 percent in velocity through the adsorbent bed results in a very high variation of the methyl iodide-131 removal efficiency. Recent parametric testing for radioiodine removal efficiency showed that even the ±4 percent flow variation permitted in ASTM D3803[20] is too high to obtain good reproducibility. To ensure proper correlation of the results used to justify the potential performance of the adsorber stage, the volumetric flow through the adsorber stage should result in not less than a 0.25-sec residence time (for a 2-in.-thick bed). Therefore, a design flow of +0, -20 percent is much more realistic than the design of ±10 percent permitted by ASME N509[15] and N510.[14] Similarly, ASTM D3803[20] should require a velocity corresponding to 0.25-sec residence time and +4, -0 percent to achieve adequate reproducibility and to err on the conservative side. The procedure for airflow capacity testing recommends making pitot tube traverses of the ducts. However, the following values must also be considered.

Duct Size	*Number of Readings*	*Precision of Measurements*
<150 mm	1	±20 percent
400 < 150 mm	4	±12 percent
950 < 400 mm	8	±10 percent
>950 mm	12	±5 percent

mm = millimeter

ASME N510[14] is unclear about how the precision of the measurement should be used to achieve the ±10 percent specified flow capacity. Due to the convoluted design of the air cleaning system inlet and outlet ducts, it is often impossible to find an adequate duct location that is, as required by the American Conference of Governmental Industrial Hygienists (ACGIH) *Industrial Ventilation – A Manual of Recommended Practices*,[21] 10 duct diameters downstream and 5 duct diameters upstream of points where turbulence is induced in the airflow (e.g., elbows and junctions), which further subtracts from the precision of the velocity measurements. The location where the acceptance airflow capacity test was performed should be tagged (indicating the date, method used, etc.) to ensure that future tests are made at the identical location. For example, LLNL places test fittings at the locations used. The test fittings are about an inch in diameter to permit turning equipment 90 degrees after insertion and are capped. This makes them both durable and easier to find. ASME N510,[14] Table 1, requires this measurement to be an acceptance and surveillance test. However, experience shows that changes in airflow capacity occur in intervals as short as 18 months due to damper adjustments, pressure conditions at inlet points, duct disassembly and reassembly either upstream or downstream of the unit, etc. Therefore, this measurement should be a routine surveillance test item each time a unit or system surveillance test is made.

The actual text of ASME N510,[14] Section 8, indicates via a note that only the air distribution test is an acceptance test (presuming the airflow capacity is both an acceptance and a surveillance test, as it should be). The unit should be operated for 15 minutes prior to the test to achieve steady-state conditions. The airflow distribution test leaving the HEPA filter banks is required by ASME N510.[14] In many existing units, there is inadequate space to perform the test downstream of the banks. Any test performed on the entry side of these banks must be more conservative for the HEPA filter banks because of the flow-straightening characteristics of HEPA filters. Therefore, if such a test meets the criteria, it should be acceptable. [Note: The currently permissible separate airflow distribution uniformity of ±20 percent on top of a ±10 percent airflow capacity and a potential test error of ±10 percent results in permissible residence times in the adsorber section might be less than that presumed for the iodine-131 DF used to establish the authorization basis of the facility.]

8.5.5 Air-Aerosol Mixing Uniformity Test

The purpose of this test is to verify that the aerosol or challenge gas is introduced in order to provide uniform mixing in the airstream approaching the HEPA filter bank or adsorber stage to be tested. No safety credit should be claimed for HEPA filters or adsorbers that are not tested regularly to verify they continue to meet performance requirements. Although individual filter units and adsorber cells are tested by the manufacturer, in-place testing after installation is essential because of the damage and deterioration that can take place during shipping, handling, installation, and service. Therefore, an important phase of acceptance testing is verification that HEPA filter and adsorber installations can be tested satisfactorily. The design of many older systems permitted an acceptance test of the HEPA filters, but made testing after the system began operation nearly impossible. Some systems were designed to be so cramped that quantitative testing of the kind specified in ASME N510[14] was impossible due to poor airflow distribution or ducts that had unreachable portions of cross-sectional area. Such designs are not acceptable in high-reliability applications.

The test method described here includes tests to establish the adequacy of the test aerosol injection and upstream sampling port locations, but does not generate data reflecting the adequacy of the downstream sampling port location. Undoubtedly, the test should be a prerequisite for performance of any in-place test of a HEPA filter bank and adsorber bank stage. The verified locations of injection and upstream sample ports should be documented, and the locations should be tagged to indicate the date, method used, etc., as well as the tests to be conducted. All other ports found to be unsatisfactory should be tagged to prevent later accidental use of incorrect injection or sampling ports.

The aerosol/vapor injection point for the first HEPA bank and the adsorber stage should always be ahead of any unit or system bypass line, and the downstream sampling point for the second stage HEPA filter bank and for challenge aerosol/vapor should always be downstream of the return of the bypass line into the main duct.

Good testability requires provision of permanent test aerosol injection and sample ports or other planned and pre-established means for injecting the test aerosol and for taking reliable, well-mixed samples. Details of the air-aerosol mixing test are described in Section 9 of ANSI N510.[14] It is essential that the air and test agents mixture challenge to the filters (adsorbers) is thoroughly mixed so that the concentrations entering all points of the filters, including the upstream and downstream sample points, are essentially uniform. Adequate mixing upstream usually can be obtained by introducing the test aerosol at least ten duct diameters upstream of the filters or adsorbers, or by introducing it upstream of the baffles or turning vanes in the duct. When neither of these methods is practical, a Stairmand disk located four to six duct diameters upstream will provide satisfactory mixing. A Stairmand disk is a plate with the same geometric shape as the duct section that blocks the central half of the duct area. Air flowing past the disk creates vortices on the leeward side that compel turbulent and thorough mixing. The disk is placed into the duct for testing. At other times it is either removed, swung out of the way, or turned on a pivot so the long axis is parallel to the direction of flow. When duct arrangement makes it necessary to introduce the test aerosol directly into the filter housing, a design such as that discussed under multistage housings (Section 8.7) may be required. Extraction of the downstream sample at a point several duct diameters downstream of the fan will usually provide a well-mixed sample. Fan-shaft leakage should be considered in sampling downstream of the fan. Since leakage at the

shaft will be in-leakage, sufficient air to dilute the downstream sample can be drawn in if the shaft annulus is large (yielding a low downstream concentration reading), or dust may be drawn into the fan to provide a high downstream reading (which may be particularly prevalent during construction). Application of a shaft seal, or at least a temporary seal, is recommended during testing. If this is not practical, a photometer leak reading should be taken with and without the aerosol generator "on" to establish shaft seal leakage.

The second aspect of testability—access—requires space for personnel and equipment; space to manipulate equipment without damaging filters or creating hazards for personnel; passages for getting personnel and equipment where they are needed; means of providing power (electrical, compressed air) to the equipment; access to both faces of the filters and adsorbers; adequate lighting; viewports; and other features that facilitate safe testing. Space also will be needed later during filter replacement for: (1) temporary storage of removed filters/adsorbers and their replacements, (2) crew movements required to effect the change (such as bagging in/out), (3) placement of tools, and (4) personnel, including both the filter technicians and any associated safety staff or radiation monitoring technicians. Consideration should be given to making the area easy to decontaminate if necessary by making the floor and area as free of cracks, crevices, and hard to clean/reach places as practical.

8.5.6 Duct Damper Bypass Test

Section 12 of ASME N510[14] requires testing of potential bypass leakage paths, through closed dampers or valves, to ensure that radioactive gases or particulates do not escape treatment through the HEPA and/or adsorber banks. This test allows testing of the potential leak path during the test aerosol or Halide test on the HEPA/adsorber banks, assuming the injection sample ports are located such that the potential bypass is included in the test envelope. Otherwise, the bypass (damper) may be tested using conventional pressure-testing techniques.

8.5.7 System Bypass Test

Section 13 of ASME N510[14] requires challenging of all potential bypass leakage paths and all portions of the nuclear air treatment system (including the housing stages) during the test sequence, which could potentially defeat the purpose of high efficiency nuclear air treatment components. All potential bypass leakage paths around the HEPA/adsorber banks must be included as a single overall leak test of the sum of the individual tests on the separate banks. In dealing with a series of HEPA or adsorber banks, each bank must be tested individually to ensure that contaminated air does not bypass the filter banks or escape treatment. Small system bypass leakage may be very significant for systems that have multiple HEPA banks with greater than 99.8 percent assigned efficiency per bank[18] (per the authorization basis).

8.5.8 Duct Heater Performance Test

Section 14 of ASME N510[14] requires the humidity control system for the carbon adsorber bank (which prevents water buildup on the carbon) to be tested to ensure satisfactory performance. For example, the voltage always has to be checked to make ammeter readings meaningful. The temperature should be checked sufficiently upstream and downstream of the heater to ensure an adequate rise in air temperature. The readings obtained also should be evaluated by a cognizant individual to ensure the desired RH can be achieved with the potential minimum and maximum environmental temperatures in the inlet stream.

8.6 Surveillance Testing

There are three types of surveillance tests: (1) in-place leak tests of HEPA filter banks using an accepted test aerosol, (2) in-place leak tests of adsorber stages using a slightly adsorbable gas such as the fluorocarbon Refrigerant-11, and (3) laboratory tests of samples of adsorbent withdrawn from the system to establish its remaining adsorption capacity. These tests are also employed as part of the acceptance procedure for new installations, with the exception that laboratory tests are made on samples of adsorbent taken from batch material as furnished.

Surveillance tests of HEPA filter and adsorber systems should be made at regular intervals after installation to detect deterioration and leaks that may develop under service conditions. Regular in-place testing of standby systems is necessary because deterioration can take place even when the systems are not being operated. Aside from component damage, frequently discovered causes of failure to meet in-place test requirements include loose clamping bolts; inadequate clamping devices such as C-clamps; foreign material trapped between gaskets and mounting frames, rough or warped mounting frame surfaces; cracked welds; unwelded joints in mounting frames; incorrectly installed components (e.g., HEPA filters installed with horizontal pleats); inadequate seals between mounting frames and housings; poorly designed mounting frames; and bypasses through or around conduits, ducts, or pipes that penetrate or bypass the mounting frames.

In-place tests should be made by introducing a test aerosol upstream of the bank to be tested. [Note: The upstream aerosol introduction should never be swapped to the downstream side. This actually occurred at one DOE facility where upstream introduction was a physical impossibility.] The concentrations of test aerosol upstream and downstream (upstream concentration is considered 100 percent) should then be determined, and penetration should be calculated from the ratio of concentrations. The reliability of this test is determined by: (1) the ability to properly introduce the test aerosol and obtain representative samples, and (2) the availability of physical access to the banks being tested. The first can be verified by an air-aerosol mixing test. This test should be made once, at the time of acceptance testing, and its satisfactory completion is required before both acceptance and future surveillance in-place testing of HEPA filters and adsorbers.

8.6.1 In-Place System Leak Test, HEPA Filter Banks

Section 8 and 9 of ASME N510[14] are prerequisites for the HEPA filter in-place system leak test. In cases where there are multiple series or parallel HEPA banks and associated bypass leakage paths, the guidance outlined in Section 13 of ASME N510,[14] "System Bypass Test," should be followed. The proper procedure to be used with dual HEPA filter banks is to introduce a test aerosol at the predetermined qualified location (the test port) upstream of the first bank, and then determine a downstream reading of the first filter bank between the first and second filter bank. If this determination is satisfactory, then while injecting at a point (or through a manifold) upstream of the second HEPA filter bank (between the banks), readings should be taken downstream of the second HEPA filter bank, preferably downstream of the fan.

There are three major types of in-place system testing methods. The first test method uses a light-scattering photometer with a polydispersed aerosol. The second method uses a shroud and/or scanning test technique, and the third uses a laser spectrometer in lieu of the forward light-scattering photometer. Due to differences in the designs of HEPA filter plenums throughout the DOE complex, as well as corresponding differences in testing techniques, the Defense Nuclear Facilities Safety Board recognized a need to standardize methods for in-place system testing at DOE sites. To address this need, a conference was held at the DOE Savannah River Site (SRS) to exchange information about the sharing of in place system testing technology among DOE contractors.[22] The conference concluded that all DOE sites basically used the same type of penetrometer, with the exception of LANL, which uses the laser spectrometer. In-place system tests of HEPA filter installations are made with a polydispersed test aerosol consisting of droplets with a light-scattering number mean diameter (NMD) of 0.7 µm and a size range of approximately 0.1 to 3.0 µm.[14] This range should be compared to the test aerosol used for efficiency testing by manufacturers and DOE's Filter Test Facility (ORFTF) which is a monodispersed aerosol with a light-scattering NMD of 0.3 ± 0.03 µm. The in-place system test is made by challenging the upstream side of the filter or filter bank with test aerosol smoke, then measuring and comparing (using a light-scattering photometer) the test aerosol concentration in samples of downstream (filtered) and upstream (unfiltered) air (**Figure 8.5**). If the system exceeds the specified maximum permissible penetration value, the downstream faces of the filters and mounting frame can be scanned with the photometer probe to locate localized high concentrations of test aerosol, indicating leaks. Figure 8.5 illustrates the basic equipment and a schematic of a standard test arrangement. [Note: Figure 8.5 is not intended to depict an actual system.] The instrument shown is a forward-light-scattering photometer with a threshold sensitivity of at least 10^{-3} µg/L for 0.2- to 1.0-µm particles, and a sampling rate of at least 1.0 cfm is recommended.[4] The instrument should be capable of measuring concentrations

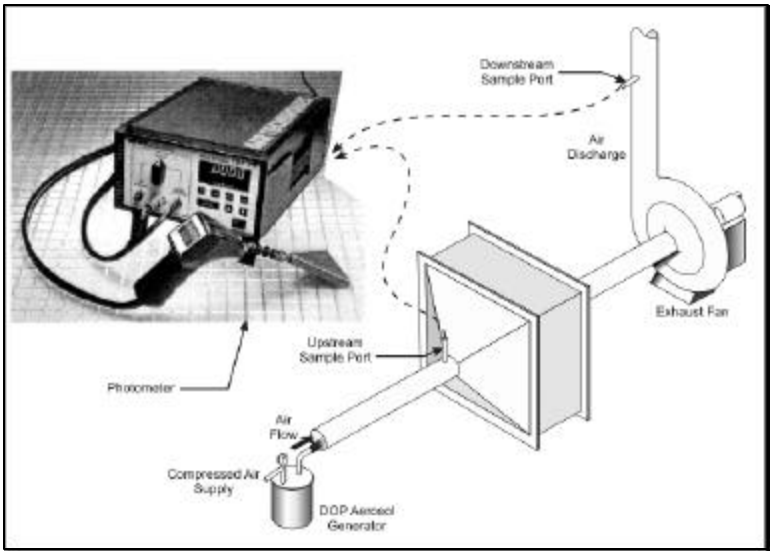

Figure 8.5 – Equipment Arrangement, In-place Testing of HEPA Filters

10^5 times the lower detection limit. An upstream concentration of 20 to 100 µg/L is desirable. Compact self-contained instrument packages are commercially available (**Figure 8.6**). Polydispersed aerosol may be generated thermally or by compressed air. Compressed-air generators are widely used for testing small systems. They are commercially available or can be "homemade" in sizes from 1 to 24 nozzles, as shown in **Figure 8.7**. Care must be taken in selecting the aerosol test agent, as some replacements for DOP have made a flame-throwing device out of the generator (see Chapter 10.6.2.1). A rule of thumb for determining generator capacity is not to exceed one Laskin nozzle per 500 cfm of installed filter capacity. Compressed-air generators are suitable for systems up to about 3,000 cfm; above this size they become cumbersome. Although gas-thermal generators are generally used for testing systems of 6,500 cfm installed capacity and larger, they have too much output for small systems (Figure 8.7). The engineer must not confuse this type of generator with the mono-dispersed test equipment used by filter manufacturers or the DOE ORFTF for determining the particulate efficiency of HEPA filters. The gas-thermal generator produces a polydispersed aerosol of about the same NMD and size range as the compressed-air generator. It is also small and can generally produce enough aerosol at a concentration of 40 to 50 µg of test aerosol/L to test banks up to 30,000 cfm installed capacity. Nitrogen must be used with some thermal systems to avoid a potential fire hazard.

Figure 8.6 – Commercially Available Packaged Forward-light Scattering Photometer for HEPA Filter In-place Testing

A detailed description of the procedure for conducting an in-place test of HEPA filters is given in Section 10 of ASME N510[14] and in ASME AG-1, Appendix TA.[3] A prerequisite of the test is a demonstrated ability to achieve good mixing of the test aerosol and air at the upstream and downstream sample points (Section 9, ASME N510).[14] For systems in which good mixing cannot be achieved, multipoint sampling and averaging may be used, in accordance with Section 11 of ANSI N510.[20]

An acceptance criteria of 0.05 percent maximum leakage for the in-place system test is recommended for systems that are designed in accordance with this handbook.

For the shroud/scan in-place test method (**Figure 8.8**), ASME N510 (1980),[14] the photometer, generator, and test aerosol are the same as those used in the standard test method described above.

A manifold is installed in the upstream and downstream shroud. The upstream shroud must be placed over a filter, and the generator turned on. It is important to verify that the aerosol mist is filling the shroud using an upstream sample/challenge manifold located in the shroud. When the 100 percent upstream concentration is obtained, the meter is set to 0 and the downstream reading is taken. If the downstream shroud method is used, the sample tube must be connected to the downstream shroud manifold, and the downstream shroud must be placed against the frame of the filter to be tested for a minimum of 15 ± 5 seconds as determined by the photometer operator. If the downstream scan method of testing is used, each filter and gasket must be probed. The photometer is then read, and the highest leak rate reading is recorded "as found." The final leak rate readings are recorded.

To calculate leak rates, the leak rate readings from the data are added together and the sum is recorded. This total is then divided by the number of filters in the filter stage, and the result is recorded, as expressed below.

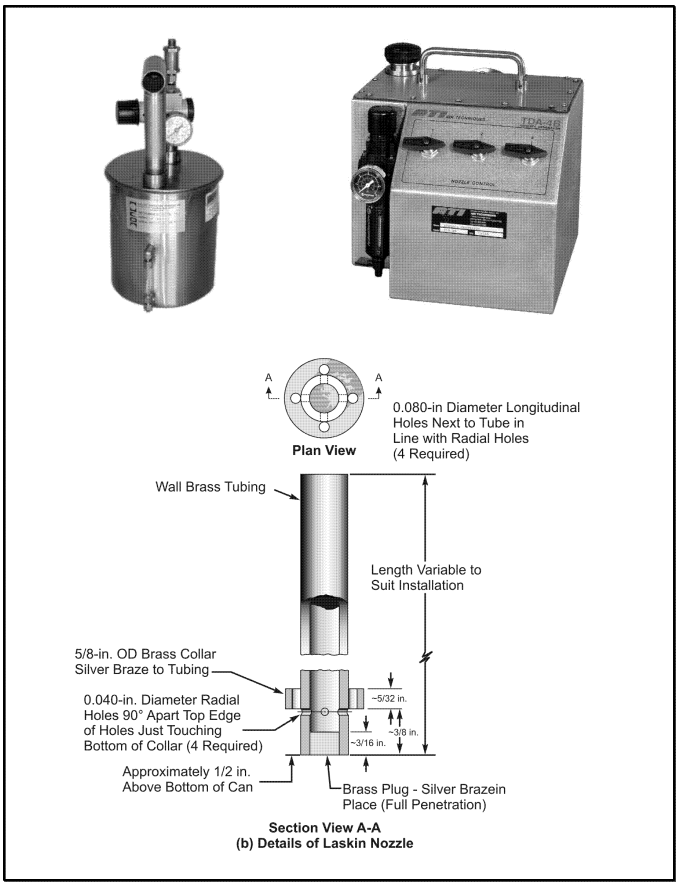

Figure 8.7 – Compressed Air-Operated Aerosol Generator

$$\frac{Sum(As\ Found\ or\ Final)}{Total\ Number\ of\ Filters} = Overall\ (As\ Found\ or\ Final)\ Leak\ Rate$$

Overall efficiency is determined by subtracting the overall leak rates ("as found" and "final") are subtracted from 100 percent and recording the result, as expressed below.

100 percent – Overall ("As Found" or "Final") Leak Rates = Overall (As Found or Final) Efficiency

A third test method, the single-particle particle-size spectrometer, was implemented at LANL using the guidelines of NE F 3-41T.[24] This modified procedure uses a laser particle size spectrometer with the capability of counting single particles downstream of two filter stages where DF of the first stage and overall system effectiveness are established. DF measurements as high as 10 were obtained,[25] indicating a high level of sensitivity that can be used on single-stage filters. The advantage of the single-particle particle-size spectrometer method is that it provides information on system performance relative to the most penetrating particle size of the filer system being tested. The downside is that the instrument is prone to malfunction, being a laboratory-type instrument, and is heavy, cumbersome, and expensive.

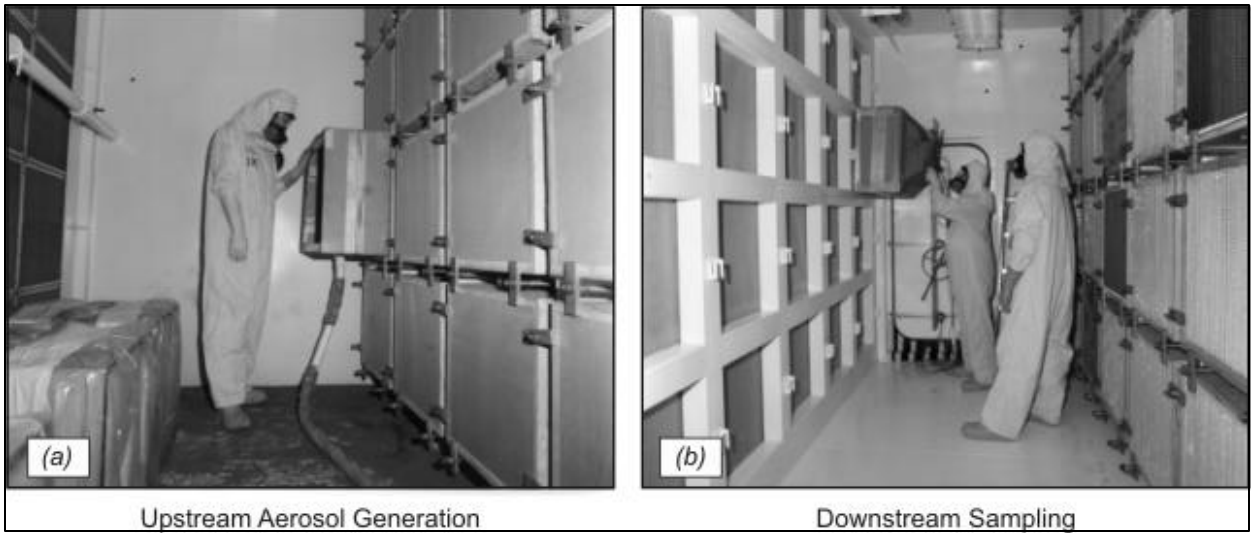

Figure 8.8 – Shroud Test

8.6.2 In-place Testing for Adsorbers

The in-place leak test of the adsorber bank (stage) measures bypass (mechanical) leakage around or through the installed adsorber bank. This test may be performed: (1) as an acceptance test to verify system design function following initial field installation; (2) after an abnormal incident, replacement, repair, or modification that may affect design function; or (3) as a periodical in-service (surveillance) test to monitor system condition and operational readiness.

Bypass leakage around the adsorber bank (stage) may result from mounting frame weld degradation, damaged or poorly compressed gaskets, common drains between housing compartments, common electrical conduits between housing compartments, and inadequately dampered bypass ducts. Bypass leakage through the adsorbent media may be due to poor adsorbent filling technique and subsequent settling from system vibration and air or gas pulsation.

Since the in-place leak test only provides a measure of bypass leakage, this test is often performed in conjunction with the laboratory test of the adsorbent media. Assuring that the adsorber bank meets bypass leakage acceptance criteria and the adsorbent media itself performs adequately provides the necessary information required to determine whether the adsorber bank is performing as designed.

There are two methods commonly used for in-place leak testing of the adsorber bank stage. One uses a fluorocarbon refrigerant gas or an alternative tracer gas. The other uses a radioactive tracer gas (iodine or methyl iodide). The first method, developed by Savannah River Laboratory,[25] is the most frequently used, particularly in commercial applications. The second method involves the use of radioactive isotopes and personnel licensed to handle them. This test should not be confused with a laboratory test of adsorbent media. Radioiodine tracer methods were developed primarily for DOE installations.[26, 27] Both in-place tests are leak tests designed to measure bypass leakage, and they must be supplemented with laboratory tests of samples taken from the adsorbers at the time of the in-place test to determine system leak tightness and the radioiodine removal efficiency of the adsorbent media. For commercial nuclear power plants, typical bypass leakage acceptance criteria for the adsorber bank (stage) range from 1.0 percent to 0.05 percent, depending on specific plant license bases. The current NRC Regulatory Guide 1.52 [16] requires that in-place leak testing for adsorbers be performed: (1) initially; (2) at least once each 24 months; (3) following the removal of an adsorber sample for laboratory testing if the integrity of the adsorber section is affected; (4) after each partial or complete replacement of a carbon adsorber in an adsorber section; (5) following detection or evidence of penetration or intrusion of water or other material into any portion of an ESF atmosphere cleanup system

that may have an adverse effect on the functional capability of the adsorber; and (6) following painting, fire, or chemical release in any ventilation zone communicating with the system that may have an adverse effect on the functional capability of the system. The Regulatory Guide further specifies that the in-place leak test should be performed in accordance with Section 11 of ASME N510-1989[14] and the in-place leak test should confirm a combined penetration and bypass leakage quantity around or through the adsorber of 0.05 percent or less of the test gas at system rated flow of ± 10 percent.

8.6.2.1 Nonradioactive Tracer Gas Test

The first test, commonly referred to as the Freon™ test, is made by challenging the upstream side of the adsorber with a slightly adsorbable and readily desorbed fluorocarbon gas [usually Refrigerant-11, trichloro mono fluoromethane], then determining the concentrations immediately upstream of the adsorber bank and at a point downstream of the adsorber bank where satisfactory mixing with air occurs. Bypass leakage is calculated from the ratio of downstream-to-upstream reading, as follows.

Percentage Bypass = Reading Downstream/Leakage Reading Upstream

Since it is the *ratio* of concentrations that matter, the units may be expressed in terms of peak height or some other measure directly related to tracer concentration, although the measure may not necessarily reflect the actual volumetric or mass tracer concentration.

Refrigerant-112 was originally used, but is no longer produced. Refrigerant-112 was more strongly adsorbed by the adsorbent bed than Refrigerant-11 and allowed testing of banks under conditions of high RH or elevated adsorbent moisture content. With the introduction of ASME AG-1,[3] alternative, substitute tracer gases are allowed (permitting tracer gases with stronger adsorption potentials than Refrigerant-11), providing the selection is made in accordance with the AG-1,[3] Appendix TA-C, selection criteria. Noncommercial installations have successfully used alternative tracer gases.[28] When the carbon beds nondestructive test was developed, testing equipment consisted of a pump to draw upstream and downstream air samples from the adsorber system, two identical gas chromatographs with electron-capture detectors for measuring refrigerant gas concentrations, a timer, and several rotameters for determining sample dilution factors. The chromatographs had a linear range of about 1 to 100 parts per billion (ppb) (by volume) for detection of the refrigerant gas. Since the upstream concentration exceeded the linear range of the instrument, the sample was diluted with a known volume of air to bring it within the detection range of the chromotograph. Calibrated rotameters were used to determine the dilution factors. Currently, two types of equipment are used to perform this test. Traditional, noncontinuous chromatographs have been developed specifically for in-place leak testing, eliminating the need for rotameter dilution and providing microprocessor-based leak rate calculation. Modern chromatograph-based equipment used for the adsorbent in-place leak tests is shown in **Figure 8.9**. Continuously monitoring detectors are also used as shown in **Figure 8.10**. **Figure 8.11** shows a schematic of the test setup. Prefilters and HEPA filters in housings have no effect on the nonradioactive

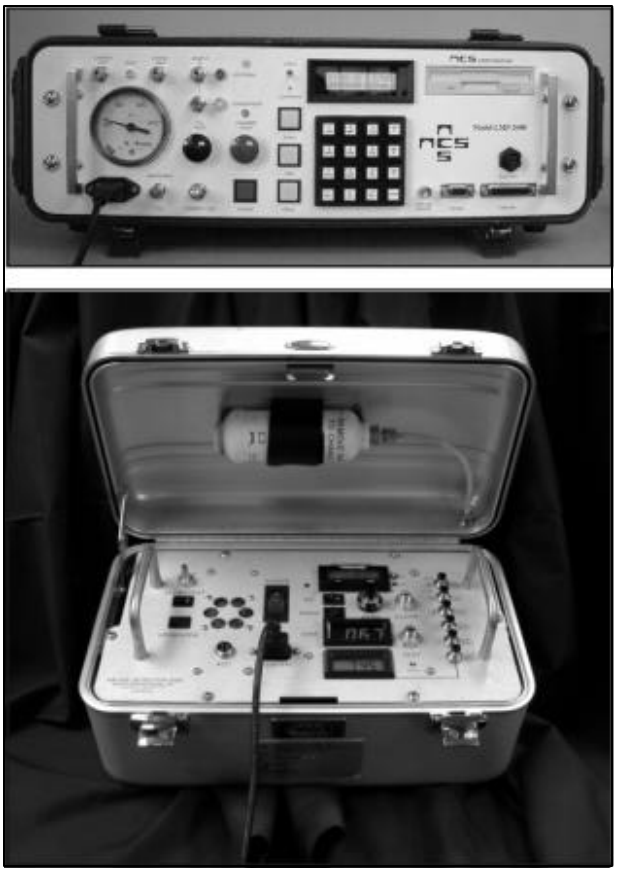

Figure 8.9 – Modern Chromatograph-Based Equipment

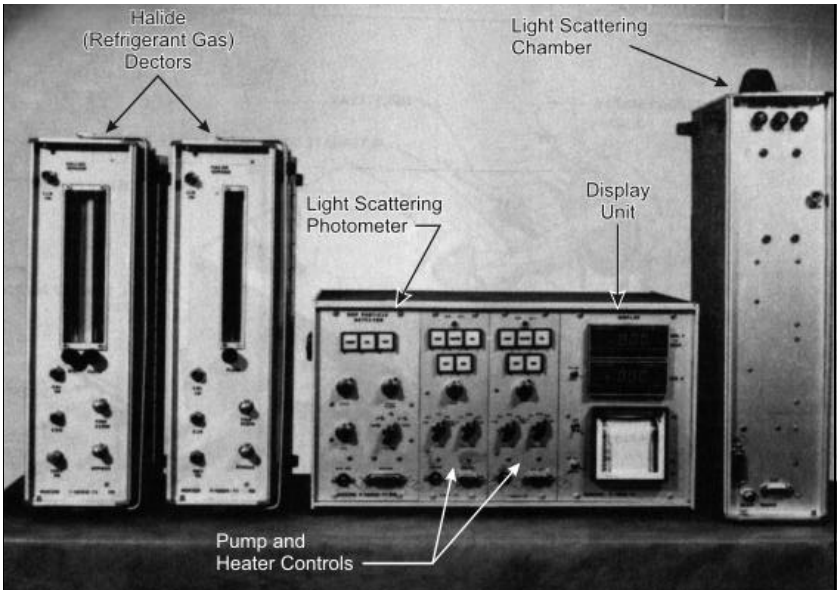

Figure 8.10 – Continuous Monitoring Charcoal Testing Equipment

tracer gas test. The test should be performed by experienced, trained personnel, and should be conducted in accordance with prescribed procedures (ASME N510,[14] Section 11). Use of the mixer shown in Figure 8.11 is not necessary if samples can be taken from an area that assures good mixing, e.g., downstream of the fan or downstream of duct bends or transitions that introduce turbulence into the airstream. Where good mixing cannot be achieved, temporary or permanently installed sampling manifolds constructed in accordance with ASME N509,[15] Appendix D, may sometimes be used.

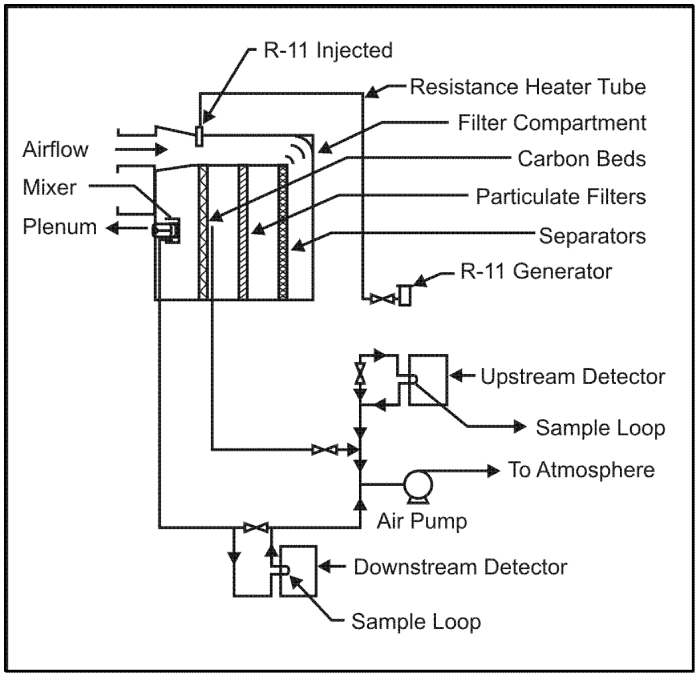

Figure 8.11 – Schematic of Charcoal Testing Setup

8.6.2.2 Radioactive Iodine Tests

These tests are currently used for routine adsorber-bank testing at Oak Ridge National Laboratory (ORNL) and the Hanford (Richland, Washington) facilities of DOE. Two tests are used, one with radioactively traced elemental iodine, and the second with radioactively traced methyl iodide. Equipment requirements for controlling the injection and sampling flows during elemental iodine testing include an iodine injection tube (**Figure 8.12**), two sampling units (**Figure 8.13**), a sample extraction pump, and two calibrated flowmeters. The sampling units are filled with charcoal of known efficiency for elemental iodine. The test gas is iodide-127 containing the iodide-131 tracer. A combination of injected radioactivity (in microcuries), sampling rate, and counting technique (usually dictated by the kind of counting equipment available) must be developed to give the required test precision. At ORNL, a combination of sampling and injection rates is selected which, with available counting equipment, will produce an upstream sampler radioactivity count between 8×10^5 and 5×10^6 counts per minute. These are not rigid limits, but are instead convenient target values with considerable latitude. Satisfactory tests have been made with sampling rates as low as 0.03 percent of the system flow rate, but sampling rates of about 1.0 cfm per 1,000 cfm (0.1 percent) of rated adsorber capacity are recommended.

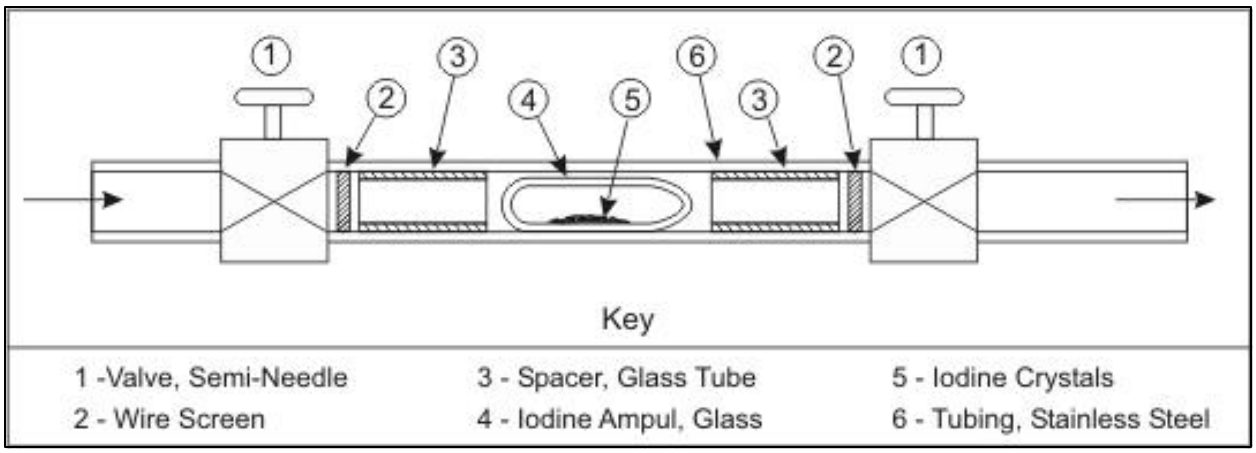

Figure 8.12 – Injector Tube for Radioactive Tracer Test

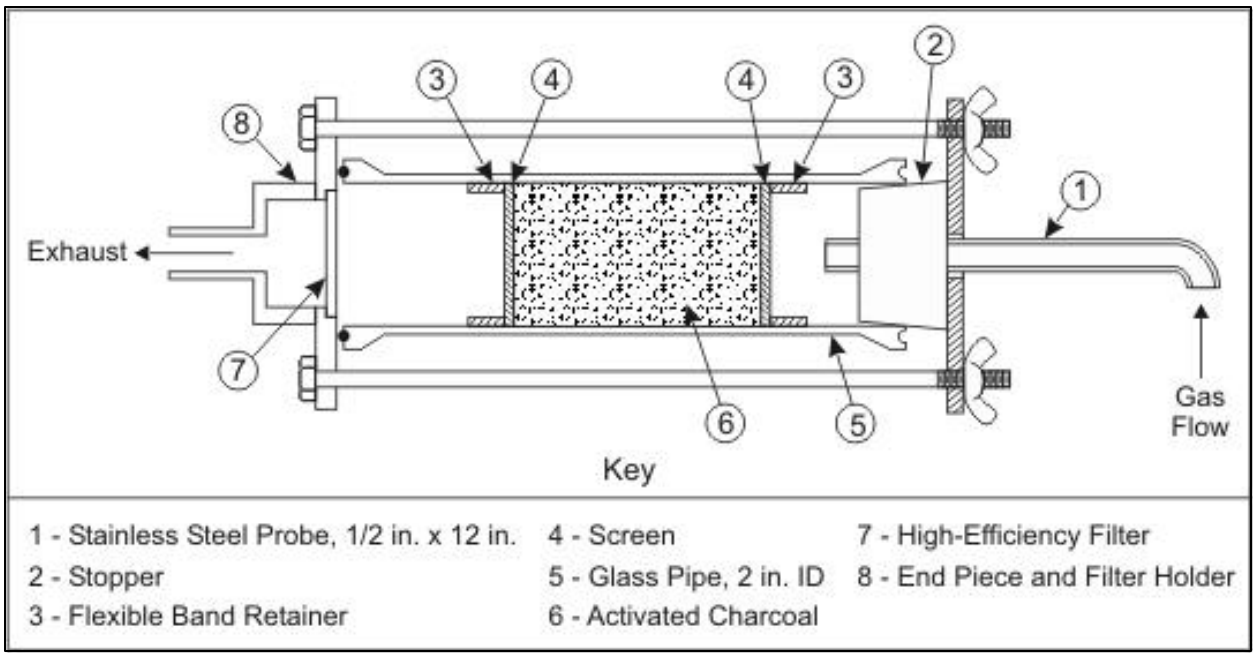

Figure 8.13 – Sampling Elements for Radioactive Tracer Test

The amount of iodine required and the size of the injector tube are not critical. The amount of iodide-127 is invariably 100 mg in the ORNL tests, although this amount may be doubled if excessive plateout in the upstream duct or housing occurs. The amount of iodide-131 tracer must be adjusted to give the radioactivity count noted above. The radioactive iodine source is prepared by mixing the required quantities of iodide-127 and iodide-131 as sodium iodine, precipitating the iodine fraction of palladium iodide by treatment with acidified palladium chloride, then decomposing the palladium-iodide under vacuum. The liberated iodide-127 and iodide-131 is collected in a liquid-nitrogen-cooled U-tube and transferred to a glass ampule that is installed in the injector (Figure 8.13). Preparation of the iodine and loading of the injector must be carried out in a laboratory equipped for handling radioactive materials. To inject iodine during the test, the injector tube is crushed, breaking the ampule and releasing the iodine vapor. Heat may be applied to the injector tube prior to its being crushed and also during the test to assist in vaporizing the iodine source. Compressed air is passed through the tube at a carefully controlled rate for 2 hours.

Figure 8.14 shows a typical in-place radioiodine-tracer test setup. After system flow and background radioactivity levels are established, iodine is injected far enough upstream to ensure adequate mixing with the

main airstream, and samples are withdrawn simultaneously through the upstream and downstream sampling units. Injection of iodine is continued for approximately 2 hours, but system airflow and downstream sampling are continued for another 2 hours to catch any iodine that may desorb from the beds, in addition to that which penetrates immediately. Exhaust air from the sampling units is usually dumped back into the upstream side of the main system. The iodine content of the carbon in the samplers is determined by direct gamma spectroscopy, and the bypass leakage is determined from the following equation.

$$E = \left(1 - \frac{C_d}{C_u - B}\right) \qquad (8.1)$$

Where

E = efficient, percent

Cd = iodine content of downstream unit, dis/min

Cu = iodine content of upstream unit, dis/min

B = background due to impurity iodine is charcoal, dis/min

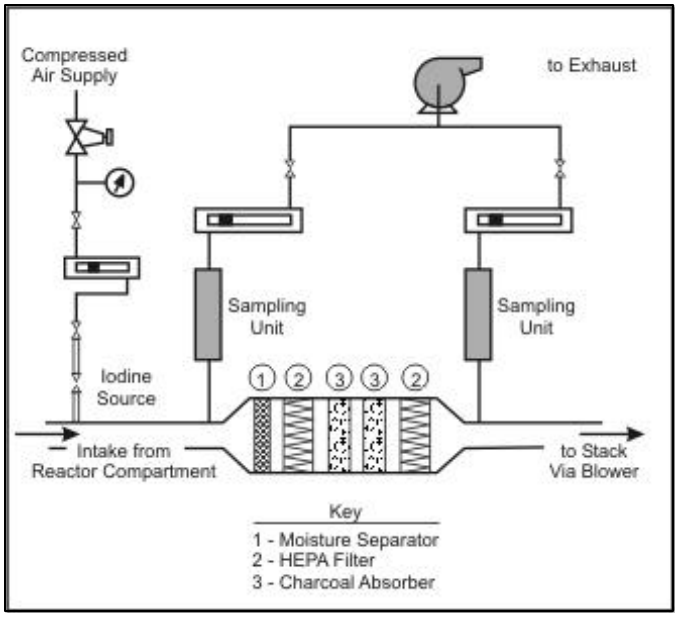

Figure 8.14 – Test Setup for Radioiodine Tracer Tests

The methyl iodide test for determining the efficiency of adsorbers for organic radioiodine compounds is similar to the test for elemental iodine and uses the same equipment, except for the injector. The injector used for the methyl iodide test is a U-tube and a vapor expansion chamber. Sampling and analytical procedures are the same as those for the elemental iodine test. The test vapor is methyl iodide-127 containing methyl iodide-131 tracer. Because the methyl iodine test determines a different property of the adsorbent and depends on a different sorption mechanism, it cannot be used in place of the elemental iodine test. Therefore, both tests are required for a complete evaluation of impregnated charcoal adsorbers. Both of these tests suffer from the limitations of using radioactive tracers in the field and from the number of variables that must be controlled to achieve reliable results.

8.6.3 Test Sequence and Frequency

The recommended test sequences and frequencies in both ASME N510[14] and NRC Regulatory Guides 1.52[16] and 1.140[17] are inadequate to ensure that an air cleaning system is maintained in an acceptable operational condition. ASME AG-1,[3] Section TA, provides updated guidance on testing sequence and frequency.

Surveillance Tests are outlined in Table 1 of ASME N510,[14] and are repeated in **Table 8.2**.

Additionally, due to the potential for unauthorized flow adjustment and duct damage, all air cleaning system airflows should be rebalanced at least every 5 years. Regularly scheduled testing and air balancing properly verifies the safe, effective operation of air cleaning systems and ensures that design parameters are being met and systems are operating within specified acceptance criteria. ASHRAE STD 111, *Practices for Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilating, Air Conditioning and Refrigeration Systems*[29] should be followed.

Table 8.2 – Surveillance Tests

Test	*Recommended Frequency* [a]
Visual Inspection	Before each test series [b]
Duct Leak Test	Acceptance [c]
Structural Capability Test	Acceptance [c]
Housing Leak Test	Acceptance and at least once every 10 years [c]
Mounting Frame Pressure	Optional Leak Test [d]
Airflow Capacity/Distribution	Acceptance [c] Surveillance [e]
Air-aerosol Mixing Uniformity	Acceptance [c] Test
In-place System Leak Test - HEPA	Acceptance after each HEPA filter replacement and at least once each operating cycle (every 12 months for DOE sites as a basis or more/less frequency, as determined by a technical evaluation) [c, f]
In-place System Leak Test - Adsorbers	Acceptance after each adsorber replacement and at least once each operating cycle [c, f]
Duct Damper Bypass Test	Acceptance and at least once each operating cycle [c, f]
System Bypass Test	Acceptance and at least once each operating cycle (See HEPA above) [c, f]
Air Heater Performance Test	Acceptance and at least once each operating cycle [c]
Laboratory Test of Adsorbent	Acceptance before each adsorber replacement, and at least once each operating cycle [c, g, h]

Notes:

[a] Field test of motors, valve and damper actuators, and fire protective systems are not covered in ASME N510.[14]

[b] The frequency of verifying loop seals and traps must be evaluated by the owner to assure integrity at all times.

[c] Acceptance tests must be made after completion of initial construction and after any major system modification or repair.

[d] The mounting frame leak test is a recommended, but optional, test that identifies the mounting frame leakage that would be included as a part of total bank leakage during HEPA filter bank and adsorber bank in-place leak tests. In many cases, a thorough visual inspection of the mounting frame ensures the mounting frame leakage component of total bank leakage will be minimal (significant leak paths can be visually located). It is left up to the owner to determine whether a mounting frame leak test is warranted based on the visual examination.

[e] Airflow capacity checks for surveillance purposes must be performed prior to any in-place leak test.

[f] Periodic in-place leak tests of systems located within reactor confinements and used only for recirculation are not recommended by the NRC.

[g] Adsorbents must be tested before installation or replacement to establish efficiency. Samples for laboratory testing should be taken before routine in-place testing of the installed system to verify the condition of the adsorbent.

[h] Adsorbent must be sampled and laboratory tests must be conducted to confirm performance at intervals not exceeding 720 hours of system operation for any system immediately following inadvertent exposure to solvent, paints, or other organic fumes or vapors that could degrade the performance of the adsorbent. The 720-hour requirement may be modified based on laboratory test history.

8.7 In-Place Testing for Multistage Systems

HEPA filters are sometimes used in series to increase system reliability or to reduce the effluent air concentrations released from transuranic materials-handling operations. Two questions of importance arise when HEPA filters are employed in series: (1) how can they be tested in place, and (2) what will be the ultimate DF?

With a lower size detection limit at 0.1 µm and excellent analytical characteristics, laser spectrometer counting and sizing instruments have been proposed as a feasible and satisfactory method for testing two or more HEPA filters in series when it is not possible to test each individually. Some uncertainties, however, remain. To have an adequate number of particles downstream for a statistically reliable penetration measurement, high upstream particle concentrations are required; this, in turn, calls for an accurate aerosol dilution device to reduce the particle concentration entering the laser spectrometer to a point where coincidence counting becomes insignificant. This often calls for a reducing concentration by 2 to 4 orders of magnitude, a difficult procedure. In addition, overall tests fail to indicate the status of individual filters in the series. This is important because there are no agreed-upon criteria for permissible penetration through two or more filters in series.

Systems that contain two or more HEPA filter stages and/or two or more adsorber stages in series in the same housing give special problems because of the difficulty of obtaining a representative single-point sample downstream of the first bank and the difficulty of introducing the second-stage test aerosol at a point where good mixing can be achieved. Some series banks are too close, so neither of these objectives can be achieved in the normal manner. Because of the high collection efficiency of the first-stage elements, sufficient test aerosol cannot be introduced upstream of the first stage to permit effective testing of the second stage. It has been shown that accepted test aerosols have no adverse effect on activated carbon or other adsorbents when used for testing nuclear air cleaning systems, and the refrigerant gases used to date have no adverse effect on HEPA filters.

Figure 8.15 – Recommended Scanning Pattern

8.7.1 First-stage Downstream Sample

The first-stage downstream sample can be obtained by using a multiple sampling technique. For testing multistage HEPA filter banks, scanning the downstream face of the stage to be tested is an approved technique, in accordance with the procedure outlined in Section 4 of Institute of Environmental Sciences and Technology (IEST) RP-34.1.[30] The recommended scanning pattern for each filter in the bank is shown in **Figure 8.15**. Prior to starting scanning, the upstream side of the stage is challenged with test aerosol and the photometer is adjusted to read 100 percent. A high concentration will always exist directly downstream of a leak. During the downstream scan, the relative magnitude of each leak is determined by turning the scale shift knob of the instrument until a reading about halfway between half and full scale is obtained. The reading is recorded, and the leak flow for that point is calculated from the following equation.

$$\frac{Leak - probe\ meter\ reading\ (percent)}{Upstream concentration\ (percent)} \times probe\ flow\ rate = leak\ \ flow \qquad (8.2)$$

where probe flow is the airflow capacity of the instrument.

The percent penetration of the total bank is calculated from this equation.

$$penetration = \frac{\sum n\ leak\ \ flows}{total\ \ flow} \qquad (8.3)$$

Defective filters must be replaced and installation deficiencies must be corrected before the final test is conducted. This method is considered more sensitive than the usual method of HEPA filter testing, and is recommended for multistage systems with plutonium or transuranic element source terms.[31]

8.7.2 In-Place Testing for Multistage Adsorber Systems

Systems containing two or more adsorber stages in series in the same housing pose the same problems as multistage HEPA filters. The same techniques can be used for gas injection and testing as used in the aerosol HEPA filter systems described above. Additionally, since any tracer gas injected upstream of the adsorber bank is only temporarily adsorbed, additional difficulty with desorption interference may be encountered when attempting to test subsequent adsorber stages. Normally, it is advantageous to start with the downstream bank when testing series adsorber banks to minimize desorption interferences. It may be possible to perform individual bank leak testing of series adsorber banks by using temporary or permanently

installed sampling manifolds or by providing a temporary jumper duct to bypass airflow around the second stage to either the system fan or to a temporary auxiliary fan.

8.7.3 Test Aerosol/Gas Injection, throughout Second-Stage Upstream Sample

When the test aerosol/gas is introduced through an auxiliary duct, the upstream sample can be taken any place in the auxiliary duct (upstream of the bank to be tested), assuming the auxiliary duct is long enough to ensure good mixing and prefilters are not installed. When using an auxiliary blower, a downstream sample can be taken downstream of the blower. Another method of ensuring proper mixing of the test aerosol/gas with air is to shroud adjacent filters (adsorbers) and introduce the agent to each filter element (adsorber cell) individually by using a multiple discharge distributor, as shown in **Figure 8.16**. The upstream sample is taken downstream of the perforated distribution plate. The downstream sample is taken with a multipoint sampling probe (**Figure 8.17**). The penetrations of the individual filters (adsorbers) are averaged to find the gross bank penetration. This method requires that a mounting frame pressure leak test be made, usually at the time of acceptance testing,[32] and that the air-containing test gas be passed through a unit (filter or adsorber cell) or group of units one at a time. This method has the advantage of substantially reducing the total quantity of test aerosol/gas introduced to the system if scanning is required to locate leaks; however, it requires more time than the usual method of taking single-point upstream and downstream samples. The vapor test gases have no adverse effect on HEPA filters, and it is possible to inject the gas upstream of the HEPA filters when testing adsorbers. [Note: Shroud testing is rarely performed in the commercial nuclear plant environment.]

Figure 8.16 – Adsorber Tray Mounting Frame. "X" Cross Units Are for Test Gas Injection

Modern air cleaning systems should be designed to eliminate back-to-back series adsorber elements within a single housing. Gasketless deep-bed adsorbers or series adsorbers contained in separate, testable housings may be used when the design requires bed depths in excess of the standard two inches.

8.7.4 Adsorbent Sampling and Laboratory Testing

8.7.4.1 Sampling

The effectiveness of the adsorbent may be impaired due to aging, weathering, and/or poisoning by chemical contaminants. The charcoal ages as a result of oxidation of the adsorptive sites at the adsorbent surface.[33] Aging may occur in the drum (static) or in the operating air cleaning system (dynamic). Weathering typically occurs during system operation when the adsorbent is exposed to normal atmospheric, low-level contaminants in the airstream, e.g., oxides of nitrogen and sulfur and outgases from plant materials and equipment. Poisoning generally refers to an acute exposure of the adsorbent to chemical compounds that temporarily or permanently impair its ability to remove radioiodine and radioiodides. Periodic sampling of the adsorbent provides a means of providing a representative sample of adsorbent for radioiodine testing. The radioiodine laboratory test, together with the in-place adsorber leak test, provides a means of assessing overall adsorber system health.

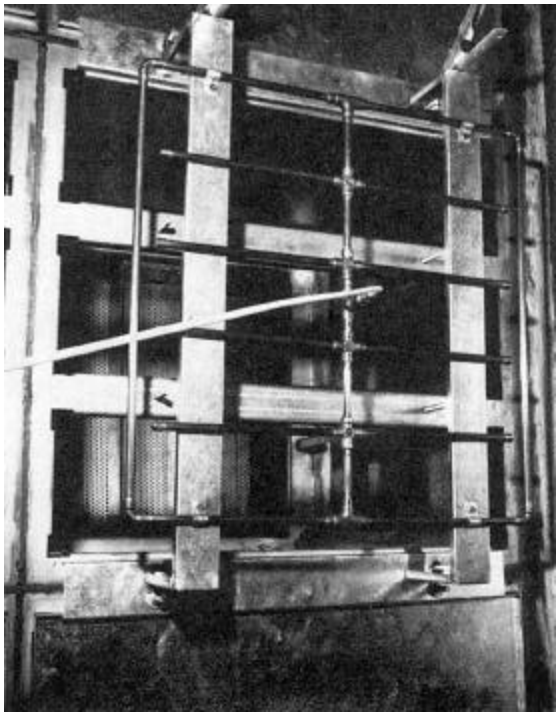

Figure 8.17 – Multiple Point Sample Probe

Figure 8.18 –Multicell System

Flow-through cartridges must be provided and installed in an area of the bank where air will flow through them, and not in obvious low-flow areas such as the outside edge of the mounting frame. If sample cartridges are not provided, other means of sampling are necessary. In a multicell system such as that shown in **Figure 8.18**, samples can be obtained by removing and emptying a cell, taking a sample of the loose adsorbent, refilling the cell (using a qualified filling procedure), and reinstalling it in the bank. For some adsorber systems, it may be possible to take a "grain thief" sample.[34] In small adsorber installations, when considering the cost of the tests and labor involved in obtaining the sample, it may be beneficial to simply replace the adsorbers or adsorbent. Some users have found it more economical to replace the adsorbent at the stipulated sampling frequency rather than making surveillance sample tests.

NRC Regulatory Guide 1.52,[16] Revision 3, currently requires that sampling and analysis be performed: (1) after each 720 hours of system operation, or at least once every 24 months, whichever comes first; (2) following painting, fire, or chemical release in any ventilation zone in communication with the system that may have adversely affect the functional capability of the carbon media; and (3) following detection of, or evidence of, penetration or intrusion of water or other material into any portion of an ESF atmosphere cleanup system that may have adversely affect the functional capability of the carbon media.[3]

When using a "grain thief" for sampling Type II (cartridge) or Type III (deep bed) adsorbers, multiple samples should be taken from all sections of the adsorber bank. For deep bed adsorbers, it is important to sample from below the tops of screens so that carbon from the overfill is not commingled with the service carbon. In filters with a bed thickness greater than two inches (50.8 mm), samples should be taken from the center of the bed. Samples taken from the inlet side of a carbon bank will show more radioiodine penetration than samples taken from the exit side. Therefore, samples should be taken symmetrically from the exit screen side, the entrance screen side, and the middle of the bed. After using a grain thief to sample a Type II adsorber, the tray should be "topped off" with new carbon (assuming the tray is to be reused), and then marked as "Not Representative for Future Sampling."

When sampling Type II adsorber trays, the entire tray should be emptied and the contents mixed to yield a homogeneous composite sample. A smaller, grab sample may be taken from the tray contents for laboratory testing. If the bank is not being replaced, a new tray must be installed in the bank and marked as "Not Representative for Future Sampling."

Sample canisters may be used to take a representative carbon sample from the adsorber bank. Sample cartridges must be provided in sufficient numbers to permit taking samples at specified intervals for the life of the adsorbent. Sample cartridges must be designed so that bed depth, airflow, and pressure drop across the cartridges are the same as for the adsorber stage. For this reason, the zero-flow hang-on cartridges shown in **Figure 8.19** are not acceptable. Properly designed sampling canisters should have a minimum diameter of 2 inches (50.8 mm) and should have the same bed depth as the main bank. Sampling canisters should be mounted vertically so that any bed settling within the canisters will not create a mechanical bypass of the carbon media.

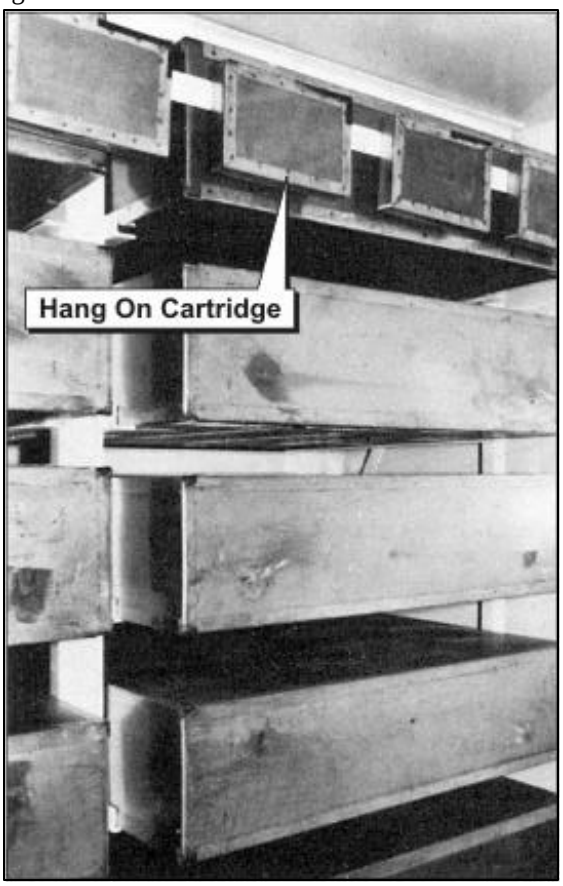

Figure 8.19 – Zero Flow Hang on Cartridges

All samples taken from an adsorber bank must be representative of the main bank. Any method used for sampling (grain thief, sample canister, dumping) must yield representative composite samples. One method of confirming that a sampling procedure is acceptable is to compare the radioiodine testing results from the sampling procedure with the radioiodine testing results from a representative sample of the main bank taken after the carbon is removed from the system. After a bank has been emptied, all of the carbon is accessible for sampling, allowing a true representative to be taken. If the test results obtained from a homogenized sample taken when the entire bed has been emptied are consistent with the results from in-situ sampling, then the sampling procedure is acceptable.

Carbon samples taken from the adsorber bank should be thoroughly mixed and packed into vapor-tight containers such as a plastic bottle. At least 125 ml of carbon for each two inches of bed thickness are required for the laboratory test. All samples that are to be sent to a testing laboratory must be marked with the following minimum information:

- Utility/Company,
- System Identity,
- Sample Date,
- Purchase Order Number,
- Test Standard (ASTM D3803-1989),[20]
- Test Temperature,
- Test Humidity,
- Face Velocity,
- Adsorbate (methyl iodide),
- Pressure,
- Bed Thickness, and
- Contact Person/Telephone Number.

Test results for samples sent to a laboratory for radioiodine penetration analyses must be available within 30 days of their sampling date.

8.7.4.2 Laboratory Testing

Most radioiodine laboratory testing on activated carbon samples taken from safety-related filtration systems installed in U.S. commercial nuclear power plants are conducted in accordance with ASTM D3803-1989.[20] This requirement was made mandatory by NRC Generic Letter 99-02,[31] issued in 1999. Other test standards that can be used for non-safety-related systems include ASTM D3803-1979[20] and 1986,[20] as well as RDT-M16-1T 1973.[34]

Table 8.3 Standard ASTM D3803-1989 [21] Testing Conditions

Temperature	54 degrees Fahrenheit
Humidity	95 percent
Face Velocity	12.2 m/min (40 fpm)
Pressure	29.91 in. Hg.
Methyl Iodide	1.75 mg/m3 Concentration
Equilibration Time	120 minutes
Pre-equilibrations	16 hours
Loading Time	60 minutes
Post Sweep	60 minutes
Bed Thickness	50 millimeters

Radioiodine penetration analysis is conducted in the laboratory using the ASTM D3803-1989[20] standard test method. Testing is conducted in sophisticated environmental chambers that are capable of precisely controlling the temperature and humidity. The activated carbon sample is loaded into stainless steel testing canisters, one canister for each two inches of adsorber bank bed depth. Along with two more canisters containing new carbon, the canisters with the activated carbon sample are assembled into a canister stack for testing. The canister stack is placed into the environmental chamber and plumbed into the testing system. The system environment is adjusted to the required temperature and humidity, normally 86 degrees Fahrenheit and 95 percent RH. All test parameters are monitored by a computer monitoring system for the duration of the test. After an initial thermal equilibration period, humid airflow is started through the carbon beds for the duration of the pre-equilibration and equilibration periods. The loading period begins with the introduction of methyl iodide into the airstream. The methyl iodide is fed into the system for a period of 60 minutes, called the loading period. After completion of the loading period, the injection of methyl iodide is stopped, and the humid air continues for an additional 60 minutes. This is called the "post sweep." The carbon canisters are then disassembled and carbon from them is loaded into plastic counting canisters for analysis. Each carbon sample is counted in a gamma spectrometer to determine the amount of radioactivity contained in each carbon canister. Knowing the amount of radioiodine present in each carbon canister allows calculation of the radioiodine penetration in percent penetration.

Detailed descriptions of the penetration measurement may be found in ASTM D3803-1989.[20] Radioiodine laboratory testing on activated carbon samples taken from safety-related filtration systems installed in U.S. commercial nuclear power plants are conducted in accordance with ASTM D3803-1989.[20] Previous versions of ASTM D3803 (1979 and 1986) and RDT M16-1T-1973[34] are still specified for non-safety-related adsorber systems. However, for future licensees, currently applicable documents include NRC Regulatory Guide 1.52,[16] Revision 3, (safety-related) and 1.140,[17] Revision 3, (non-safety-related). Both of these Regulatory Guides now reference ASTM D-3803-89.[20]

Acceptance criteria for radioiodine penetration are described in the facility technical specifications for safety-related systems. For other systems, pertinent information related to system design performance may be found in vendor design documentation or the facility Final Safety Analysis Report.

8.7.4.3 Frequency of Testing

The following test schedule (**Table 8.4**) is suggested for both continuous and intermittent online adsorber systems designed in accordance with this Handbook.

Table 8.4 – Test Schedule for Adsorbers

Application	*Frequency*
All systems.	Before system startup, following any major system repair or modification, and following each filter (adsorber) replacement.
Radiochemical plants, fuel reprocessing plants, and laboratory fume hoods.	Semiannually or quarterly where high moisture loadings or high temperatures are involved. In some systems, frequent (even monthly) testing is often specified where the environment is particularly severe. The frequency may be reduced if experience indicates a lesser frequency is satisfactory.
Reactor post-accident cleanup systems and post-accident cleanup systems of fuel reprocessing plants.	Annually or 720 hrs of system operation, whichever comes first (as specified in NRC Regulatory Guide 1.52).[16]
Zone III or tertiary confinement [a] areas of facilities that handle radioactive materials.	Annually.
Zone II or secondary confinement [a] areas of plants and laboratories that handle radioactive materials.	Annually.
Zone I or primary confinement [a] areas (glovebox lines, hot cell exhaust, etc.) of laboratories and plants that directly handle moderate to large quantities of radioactive materials.	Semiannually unless experience indicates that annual testing is sufficient. If filters (adsorbers) are replaced at short (less than 6-month) intervals to limit exposure of personnel to radiation during a filter (adsorber) change, or to permit contact maintenance of the system by limiting the amount of radiation that can be collected in the filters (adsorbers), systems should be in-place [i.e., leak-tested following each filter (adsorber) change]. Laboratory testing of adsorbents may not be necessary if the adsorbent is replaced frequently.
Systems that are continually on standby, but are operated occasionally during plant maintenance to ventilate the system.	At least biannually.

[a] Zones and confinements are found in Chapter 2, Section 2.2.9.1.

8.8 Testing of Deep Bed Sand Filters

Deep bed sand filters are not true HEPA filters, although their efficiency approaches that of a true HEPA filter when tested for aerosol penetration using the test method described in Chapter 8 of this Handbook; a physical description is found in Chapter 9. This method, which is the same method used to leak test HEPA filter systems, uses a poly-dispersed aerosol with a light scattering mean diameter of 0.7 micron. Many experts believe this method of testing sand filters tends to over rate the filtration calculated efficiency, so it may be prudent to use another method of testing to confirm test data. One method of doing this is to measure the quantity of radioactive particulate in the airstream before and after it passes through the sand filter and compare them to the aerosol test result.

Aerosol should be injected into the system as far upstream of the sand filter as possible for good mixing. An Air-Aerosol Mixing Uniformity Test, as described in ASME N 510,[14] should be performed to determine the best injection point and sample points. A perforated dip tube designed and installed per ANSI N 13.1[32] should be used upstream and downstream of the sand filter to further ensure a representative sample of the aerosol concentration is used. The upstream and downstream concentration of background aerosols (dust test) that may interfere with the test results should be performed prior to the introduction of aerosol into the system. The background test is performed by setting the aerosol photometer's internal calibration feature to

reference the instrument to a concentration equivalent of 100 micrograms of aerosol per liter of air. The background concentration is then measured upstream and downstream (upstream first) and recorded. The background levels should be stable and allow for detection of aerosol penetration smaller than the maximum allowable penetration. The aerosol should be injected into the sand filter for a period of 15 to 30 minutes, depending on the size and cfm of the sand filter, prior to the test sampling to allow time for distribution of the challenge aerosol throughout the sand filter.

8.9 Areas for Continuous Improvement

8.9.1 Qualified Products List

The QPL for qualification of HEPA filters, which was once maintained by the military, needs to be re-established and maintained. With the military's elimination of the QPL for HEPA filters, ASME Code AG-1[13] specifies that qualification may be performed by independent laboratories. The problem is that, with the exception of Edgewood Arsenal, no laboratories have the equipment or inclination to qualify filters. Review and updating of the qualification test protocol is required. Changes may be needed in the heated air, moisture overpressure, environment cycle, or rough handling tests. Additional tests may be needed.

8.9.2 Suggested Improvements and Testing Standardization

Improved field-testing methods and equipment require the adoption of testing standards to ensure consistent testing and results. Although commercial nuclear applications apply the ASME N510[14] and ASME AG-1[13] standards, DOE contractors require clarification of the applicable parts of these referenced standards. An in-place testing conference held at the DOE SRS recognized that standardization of DOE contractors' in-place testing procedures for DOE applications was in order. The group also identified the following areas for improvement:[23]

- Referencing ASME N510[14] for testing of DOE filter systems results in auditing confusion and problems in demonstrating compliance with the referenced requirements.
- Filter specification (ASME/DOE) clarification is needed.
- Improvements are needed in the areas of standards, procedures, training requirements, and certification for filter test technicians.
- A DOE guidance document or standard for testing unique filter systems at DOE sites should be developed.
- Guidance on filter service life should be developed.
- The challenge test aerosol used by DOE contractors should be standardized.
- Mandatory/optional requirements for the in-place test procedure should be standardized.
- More stringent receiving inspection/QA requirements need to be developed and more training of personnel in this area is needed.
- QPL requirements for cylindrical filters should be developed.
- A decision is needed concerning whether FTF QA testing will continue, and which facility will perform the qualification tests.
- A decision is also needed to establish the testing protocol for HEPA filter vacuums and portable ventilation units.

8.10 Review of In-Place Filter Testing at Selected DOE Sites

In 1992 and 1993, LANL performed a 2-year review[35] of the HEPA filtration systems at seven different DOE sites:

- Paducah Gaseous Diffusion Plant;
- Portsmouth Gaseous Diffusion Plant;
- LANL, Area 200 of FP4, Technical Area 55;
- Plutonium Fuel Fabrication Facility and Plutonium Experiment Facility at SRS;
- High Flux Beam reactor and Medical Research Reactor at Brookhaven National Laboratory;
- Buildings 38 and 50 at Mound Plant (Mound); and
- ORNL, High Flux Isotope Reactor, Radiochemical Engineering Development Center and Isotope Enrichment Facility.

Although significant differences among the sites were found, there were also several issues common to all seven. The observations were divided into four areas:

Policy Development. (Includes filter shelf life, filter service life, role of HEPA acceptance and in-place filter testing and system oversight.) The goal should be to provide a technical basis for setting maximum storage and service times after which filters must be discarded or replaced.

Testing Multi-stage Systems. (Includes overall system and individual stage testing.) Requirements in this area include clarification for the use of acceptance-testing filters, the need to test intermediate stages of multiple stage systems, appropriate requirements for testing filters used with gloveboxes, and the types and degree of administrative oversight and record-keeping necessary when HEPA filers are part of exhaust and air emission control systems.

Guidance on In-place Filter Testing and System Supervision. Includes testing practices, test equipment maintenance and calibration, special concerns of older systems, measurement uncertainty, pass/fail decisions, frequency of routine testing, analysis and reporting of testing results, and technical support and training of testing personnel.

Uncertainty in In-place Filter Testing Results. The issue of how such results are affected by measurement methods, system characteristics, and system abnormalities needs to be studied.

Two principal conclusions emerged from these reviews. First, there was an immediate need to develop information on how filter mechanical integrity decreases with time, and to use this information to establish limits on filter service life. Second, there was a general need to ensure the validity of in-place filter testing results and to improve testing practices. A mathematical framework for describing the effects of abnormal system features on testing results was proposed as an aid in understanding the uncertainty in in-place filter testing results.[37]

8.11 Testing Portable HEPA Filtration Systems

8.11.1 General Testing and Periodic Maintenance Considerations

Problems with operating portable HEPA filtration systems (PHFS), i.e., systems that can move and are often not visually observable or detectable by onboard instrumentation. Therefore, filter replacement and testing are important to the continued safe operation of the unit. In-place testing is designed not only to validate the HEPA filter, but also to verify the integrity of associated seals, gasketing, ducting, and housings regarding leakage.

All HEPA filters used in the system should be tested by the DOE FTF before initial use. In addition, the device should be leak-tested after installation at the site and prior to operation. Most importantly, a thorough leak test should be conducted anytime the unit is jarred, bumped, or moved. Leak tests are conducted by first injecting an aerosol challenge into the inlet of the PHFS and measuring the aerosol challenge concentration at the inlet to establish a 100 percent baseline. Then the detector samples particle free air to establish a 0.000 percent baseline. With these two baselines, created samples of the PHFS outlet can be sampled to measure any aerosol leakage.

Any entry into a PHFS must be consistent with local radiological controls, which is normally controlled by a radiological work permit. Radiation and contamination surveys should be performed periodically for PHFS in use, and the labels on these units should be updated. The frequency of radiation surveys should depend on the specific use of the unit.

PHFS tend to be overlooked when it comes to maintenance and testing. Many standards and procedures address maintenance and testing of permanent Heating, Ventilating, and Air Conditioning (HVAC) HEPA filtration systems. However, no national standards and procedures are available for PHFS. Worse, because of their size and portability, personnel assume they are functioning correctly. Ironically, these units are capable of discharging contamination over the specific areas of the work site they are supposed to be protecting if filter bypass leakage is occurring.

These units by their very nature are prone to leakage. This is mainly because they are small and portable, and thus are transported from workplace to workplace in the back of trucks and are subjected to substantial rough handling by workers. This action creates leaks in units that were previously tested, giving personnel a false sense of security. For this reason, these units should be tested anytime they are transported to another workplace. When testing PHFS, test personnel should apply the same rigorous procedures outlined in ASME N510[14] and ASME AG-1[3] for the permanent HVAC HEPA filtration systems. After all, PHFS perform the same functions and have essentially the same components as the permanent HVAC systems.

8.11.2 Reasons For Testing PHFS

- Poor PHFS design.
- Poor workmanship and inadequate quality control by the PHFS manufacturer.
- Leaks in the filter media itself.
- Leaks due to failure of the adhesive bond between the filter media and its frame.
- Leaks between the filter frame and cabinet sealing frame seals.
- Leaks between the cabinet main frame and the cabinet housing.
- Leaks in the cabinet or housing due to damage in transit or handling.
- Leaks from misalignment or misassembled components of the PHFS.
- Leaks resulting from incorrect or inadequate maintenance.
- Leaks resulting from improper installation and operation of the PHFS at the work site.

[Note: Many of the above items may not be applicable to units constructed and certified to ASME AG-1[3] criteria.]

8.11.3 Portable Filtration Systems Testing Applications

There are two basic designs for these systems: those that "pull" air through the HEPA filter and those that "push" air through it. Therefore, some units locate the HEPA filter upstream of the motor/blower assembly,

and others place the HEPA filter downstream of the motor/blower. The advantages and disadvantages of each design concept are summarized in **Table 8.6**.

Table 8.6 – Downstream/Upstream HEPA Filter Locations in PHFS

(+) Advantages	*(-) Disadvantages*
Type A DOWNSTREAM HEPA	Type B UPSTREAM HEPA
(+) Easier access to HEPA filter for scanning or leak testing	(-) Difficult access to HEPA filter for scanning or leak testing
(+) May not require mixing chamber to assure uniform mixing of test aerosol	(-) Requires mixing chamber to assure uniform mixing of test aerosol
(-) Motor/blower may become contaminated	(+) Motor/blower should stay uncontaminated unless filter leaks
(-) Cabinet interior may become contaminated	(+) Cabinet should stay uncontaminated unless filter leaks

Design, materials, specifications, and quality of construction vary widely among PHFS. These variables have a tremendous impact on overall performance and effectiveness. In particular, the cabinet material must remain rigid and undistorted during shipping, handling, and the rigors of daily operation to prevent the contaminated air from bypassing the HEPA filter. The type and gauge of metal fabrication methods, braces, holes, cracks, fasteners, welds, gaskets, and seals must be designed, specified, and assembled with potential leakage, durability in service, and maintenance in mind. [Note: Many of the above items may not be applicable to units constructed and certified to ASME AG-1[3] criteria.]

8.11.4 Testing Problems and Special Considerations

Some of the designers and manufacturers of PHFS have not put much thought or effort into creating units with integrity leak tests in mind. Not only do they unintentionally "design in" leaks, but they also often overlook the inclusion of features that allow access to areas that are critical for leakage testing. Access to the downstream face of the HEPA filter for the purpose of scanning is virtually impossible in most units where the blower is downstream of the HEPA filter. A mixing chamber with baffles is necessary at the inlet of this type of unit to provide adequate challenge aerosol mixing. Downstream measurements of the exhaust airstream can be subject to error due to channeling—the opposite of mixing. The aerosol from a specific leak may simply remain concentrated in a segment of the exhaust airstream. Therefore, sampling must be done at various points across the face of the exhaust air outlet, in effect a "scanning" of the opening. A single-point sample is usually not representative of what is in the exhaust airstream because the leak becomes diluted with the particle free air. The same considerations are included in making air velocity measurements across the exhaust opening or duct in accordance with ANSI/ASTM 41-2 (1987).[36] A single-point reading is not representative as discussed in ACGIH *Industrial Ventilation – A Manual of Recommended Practice*.[21]

8.12 Testing HEPA Filter Vacuum Cleaners

HEPA filtered vacuum cleaners (HEPA-Vacs) are most commonly used to control particulate before it becomes airborne. They are also used to control airborne particles and liquids in and around work areas and to provide localized control of loose debris when work operations could potentially spread contamination. When used in the nuclear industry, HEPA-Vacs are commonly referred to as nuclear or radiological vacuum cleaners.

8.12.1 Description of Radiological Vacuum Cleaners

Radiological vacuum cleaners are generally well-constructed, well-sealed devices with a HEPA filter on the exhaust. They are normally mounted on a cart with a comfortable handle and lockable, steerable wheels for portability and control during use. The power module consists of a blower powered by an electric motor and controlled by an onboard switch. The filter module consists of a positively mounted and sealed HEPA filter protected by a prefilter. All units should have a positive plenum (tank)-to-vacuum head seal. Vacuums that

have latches but provide a loose tank-to-head seal that depends on the vacuum force to provide a positive seal (as in many commercially available shop vacuums) should not be used.

Some vacuum cleaners are equipped with controllers that allow the worker to regulate the flow. This works well in providing negative ventilation in small glove bags. Using HEPA filtered vacuum cleaners can significantly improve how contamination is controlled.

An inline HEPA filter can be installed in the suction hose to collect radioactive material before it reaches the vacuum cleaner. Fittings can be made to connect the vacuum cleaner hose to the HEPA filter. As debris is sucked into the hose, it is deposited on the inline HEPA filter instead of the HEPA filter inside the vacuum cleaner. Temporary shielding should be installed around the inline filter before operation, as the filter becomes highly radioactive.

If a large amount of debris will be collected, installation of a waste drum in the suction hose should be considered to ensure the debris collects in a waste drum and not the vacuum cleaner. Commercial systems are available, or one can be made by welding two pipes into a spare drum lid. As each drum is filled, the lid can be installed on a new drum and a regular lid can be installed on the full drum. Personnel doses are reduced because the debris is collected directly into the waste drum instead of the vacuum cleaner.

Vacuum cleaners should be constructed of a material that is easily decontaminated without damage to components. Units that use silicone-based material to prevent leakage should not be used. All hose connections should provide positive seals and should be constructed of a material that will not be damaged by repeated use or rough handling.

HEPA filters should have a positive seal and pass in-place leak testing. The filter holddown clamps should provide the required force (20 pounds per square inch) to seal the filter and prevent dislodging during rough handling and repeated use. They should be constructed of a material that will not warp or bend with repeated use.

The HEPA filter replacement method should be both simple and achievable in minimum time to reduce exposure and the chance of radioactive contamination. The vacuum cleaners should be designed to ensure HEPA filter integrity under all conditions of use and to prevent unauthorized or accidental access to the inner surfaces of the vacuum. Units should be constructed with no sharp edges or burrs that could injure personnel or damage protective clothing.

HEPA filters used in HEPA-Vacs should meet the efficiency and construction requirements for HEPA filters listed in DOE -STD- 3025[7] and ASME AG-1.[3] The maximum flow rate of the device should not exceed the flow rate at which the HEPA filter was efficiency-tested. The HEPA filters should be certified at the DOE FTF.

8.12.2 Operation

HEPA-Vacs are used to cleanup radioactive debris. Improper use of HEPA-Vacs may result in generation of airborne radioactivity, loose surface contamination, or high dose rates. HEPA-Vacs used for radioactive material should be marked, “For Radioactive Service Only.” A nuclear safety review must be performed and documented prior to use of a HEPA-Vac for fissile material.

HEPA-Vacs must be appropriate for the type and amount of radioactive material involved. The health physicist is responsible for determining the levels of filtration required on the exhaust. Programmatic organizations are responsible for the following items:

- Maintaining control of HEPA-Vacs.
- Ensuring that HEPA-Vacs are tested semi-annually. (HEPA-Vacs must be retested if the integrity of the filter media or the sealing surface of the HEPA filter is compromised, if the HEPA filter is exposed to water or high levels of water vapor, or if the HEPA-Vac is transported to another area or site.)

- Ensuring that HEPA-Vacs are properly labeled, controlled to avoid improper use, and serviced or emptied only by individuals trained to do so, and also that the health physicist is contacted before they are opened.

HEPA-Vacs used in contaminated areas should be equipped with HEPA-filtered exhausts or with exhausts that are directed to installed systems that are equipped with HEPA filters. Such provisions may not be necessary when these systems are used in areas where only tritium or radioactive noble gases are present or when the material to be vacuumed is wet enough to prevent the generation of airborne radioactive material or removable surface contamination. Extended use of air handling equipment may cause a significant buildup of radioactive material in the ductwork and filters. Periodic sampling of the exhausted air and surveys of the accessible surfaces of the equipment should be performed to assess the radiological impact of equipment operation. While use of the devices discussed above has been proven effective in reducing contamination spread and associated decontamination costs, these benefits must be weighed against the potential costs. Use of engineering controls may require expenditure of worker doses to set up, work in, maintain, and remove the device. There may be financial costs associated with device purchase or manufacture, worker training, possible reduced productivity, and device or component maintenance and disposal.

8.12.3 General Testing and Periodic Maintenance Considerations

HEPA-Vacs operational problems are very similar to portable HEPA filtration systems discussed in Section 8.11.1. It is worthwhile to repeat those observations here. Problems with operating HEPA-Vacs are often not visually observable or detectable by onboard instrumentation. Therefore, filter replacement and testing are important to the continued safe operation of the unit. In-place testing is designed not only to validate the HEPA filter, but also to verify the integrity of associated seals, gasketing, ducting, and housings to leakage.

All HEPA filters used in HEPA-Vacs should be tested by the DOE FTF before initial use. In addition, the device should be leak-tested prior to initial use when units have been opened and/or transported to another site, as well as semi-annually. Leak tests are conducted by first injecting an aerosol challenge into the inlet of the HEPA-Vac and measuring the aerosol challenge concentration at the inlet to establish a 100 percent baseline. Then the detector samples particle-free air to establish a 0.000 percent baseline. With these two baselines accomplished, samples of the HEPA-Vac outlet can be taken to measure any aerosol leakage.

Any entry into a HEPA-Vac must be consistent with local radiological controls, and normally would be controlled by a radiological work permit. Radiation and contamination surveys should be performed periodically for HEPA-Vacs in use and the labels on these units should be updated. The frequency of radiation surveys should depend on the specific use of the unit.

HEPA-Vacs tend to be overlooked when it comes to maintenance and testing. Many standards and procedures address maintenance and testing of permanent HVAC HEPA filtration systems. However, for HEPA-Vacs, no national standards and procedures are available. To make matters worse, because of their size and portability, personnel assume that they are functioning correctly. Ironically, these units are capable of discharging contamination over large areas of the work site if filter bypass leakage is occurring.

These units are prone to leakage by their very nature—mainly because they are small and portable, and thus are transported from workplace to workplace in the back of trucks, and are subjected to substantial rough handling by workers. This action creates leaks in units that were previously tested, giving personnel a false sense of security. For this reason, these units should be tested anytime they are transported to another workplace. When testing these HEPA-Vacs, test personnel should apply the same rigorous procedures outlined in ASME N-510[14] and ASME AG-1[3] for the permanent HVAC HEPA filtration systems. After all, HEPA-Vacs perform the same functions and have essentially the same components as the permanent HVAC systems.

8.12.4 HEPA Filter Vacuum Cleaner Tests

Numerous suppliers manufacture HEPA-Vacs, and each supplier has several models available. This leads to unique characteristics that must be considered when performing in-place testing. As in the permanent HVAC systems, a thorough visual inspection by trained personnel of the unit to be tested should be performed before conducting the test. This inspection should be done using a checklist tailored to the specific make and model to be tested. These units should also be tested for proper flow and suction capabilities. Generally, a 4- to 6-in.-diameter duct or flex hose 8 to 10 feet long is used to introduce the challenge aerosol to the input of the HEPA-Vacs under test. An upstream probe can be fitted close to the end of the hose for transition to the inlet connector on the unit under test. The output of the aerosol generator should be directed to the other end of this hose. This configuration usually allows adequate aerosol-air mixing of the aerosol challenge.

The greatest challenge to testing HEPA-Vacs is obtaining a representative downstream reading. For most HEPA-Vacs, downstream air is discharged radially in all directions rather than through a duct (as in permanent HVAC systems). To accomplish this, test personnel usually fabricate a collection hood to collect all of the downstream air discharged from the unit under test and connect a duct or hose to the hood. The hose or duct can be fitted with a downstream probe located at least 10 diameters downstream of the hood. After the upstream/one hundred percent baseline and the 0 percent baselines have been established, a downstream reading should be taken both with and without the aerosol generator operating. This is done to verify whether there is a background leakage reading. Some HEPA-Vacs generate significant amounts of particles due to their design configuration. If a background reading is detected, it should be recorded and deducted from the downstream reading obtained with the aerosol generator operating.

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