CHAPTER 6

SMALL AIR CLEANING UNITS

6.1 Introduction

This chapter discusses the installation of internal components, primarily high-efficiency particulate air (HEPA) filters, in systems that require only a single filter per stage of each air cleaning unit. HEPA-filtered vacuum cleaning (HEPA-Vac) systems are not considered small air cleaning units and should not be utilized as such. The items described in this section should be manufactured under a quality assurance (QA) program that meets all the basic requirements of American Society of Mechanical Engineers (ASME) NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities*.[1] Although installation requirements are generally the same and should be tested similar to those for multifilter housings, the use of questionable practices in some older systems and the proliferation of commercially built off-the-shelf housings (side-access housings) make a separate discussion of this subject desirable.

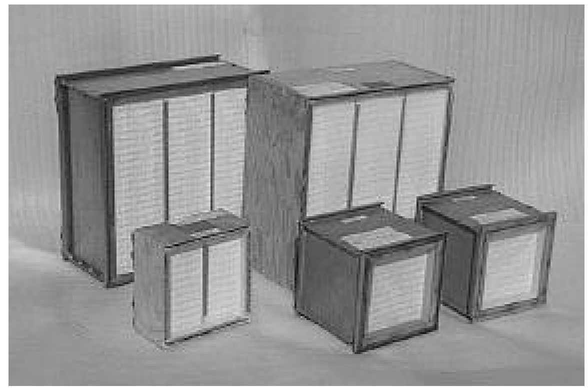

Figure 6.1 – Open-faced Rectangular HEPA Filters

Single-filter (nonparallel) installations are employed in the supply, exhaust, and recirculating air cleanup systems of rooms, gloveboxes, hot cells, chemical fume hoods, and other contained spaces; in the off gas lines of process vessels and radiochemical operations; and in other applications in which the airflow is 1,500 cfm or less. Single-filter installation for gloveboxes is a separate topic and is covered in Chapter 7. Although much of the discussion in this chapter focuses on installation of HEPA filters, it also applies to adsorber cells and other components, for which better than average installations are necessary.

Figure 6.2 – Open-faced Cyclindrical Flow HEPA Filter

The design of the filter (adsorber) installation is a function of the configuration of the filters (adsorbers) used. General HEPA filter configurations include open-faced rectangular (with wood or steel case and double-turned flanges on each face, as shown in **Figure 6.1**) and open-faced cylindrical flow (with molded-phenolic or metal case and with or without flanges on one or both faces (see **Figure 6.2**). The rectangular open-faced filter is most commonly used in both large-volume (multifilter) and low-volume (single-filter) applications; this chapter deals mostly with the low-volume, single-filter type. Another design approved by the U.S. Department of Energy (DOE) Standard 3020, *Standard for HEPA Filters used by DOE Contractors*,[2] is the radial flow HEPA filter shown in **Figure 6.3**. The radial flow design has a circular filter pack that is sealed into end caps and inner and outer grills. Under

Figure 6.3 – Radial Flow HEPA Filter

normal conditions, airflow is from the inside of the filter to the outside, although airflow from either direction is possible. Installation of cylindrical open-faced filters is discussed in Section 6.4.

Single-filter installations can be grouped into three broad categories: (1) in-wall (filter mounted in or to a wall penetration of a room, glovebox, hot cell, or other contained space); (2) in-duct (filter installed "in line" between two sections of duct, with or without transitions); and (3) duct-entrance (filter installed at the opening of the duct leading from a room, glovebox, hot cell, or other contained space). In-wall installations are generally employed to clean the air entering a contained space, to prevent backflow of contamination in the event the contained space becomes pressurized, or both. The filter may be installed bare (sides of case exposed) or in a partial enclosure. As in other installations, a prefilter is recommended upstream of the HEPA filter. Duct-entrance filters are strongly recommended to maintain the cleanliness of contaminated exhaust and air cleanup ducts. These filters should be mounted in or close to the entrance of the duct and, like the in-wall type installation, may be installed either bare, as shown in **Figure 6.4**, or in a partial enclosure.

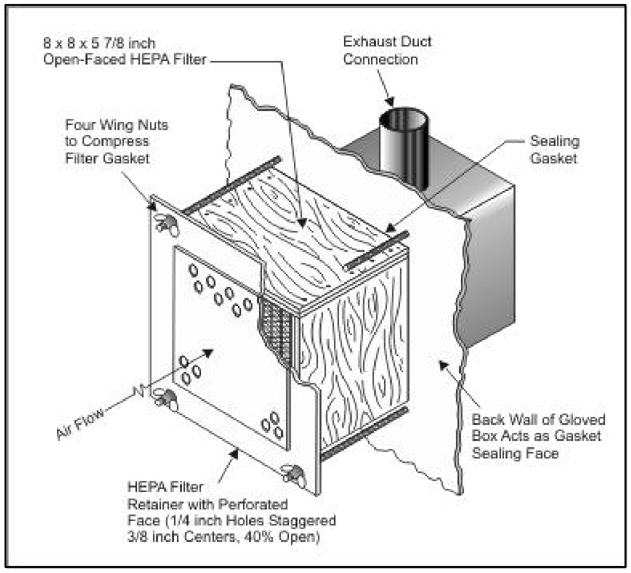

Figure 6.4 – Mounting of Duct-Entrance Filters

In-duct open-faced filters should be installed in totally enclosed housings or side-access housings, as shown in **Figure 6.5**. Taping or clamping the filter between two sections of duct or a pair of transitions with the case exposed is not recommended. Such installations provide no secondary confinement in the event of a breach of the filter case, gaskets, or tape seals, and (particularly for wood-cased filters) fail to meet the requirements of Underwriters Laboratory (UL)-181A, *Closure Systems for Use with Rigid Air Ducts and Air Connectors* [3] and National Fire Protection Association (NFPA) 90A, *Standard for the Installation of Air Conditioning and Ventilating Systems*.[4]

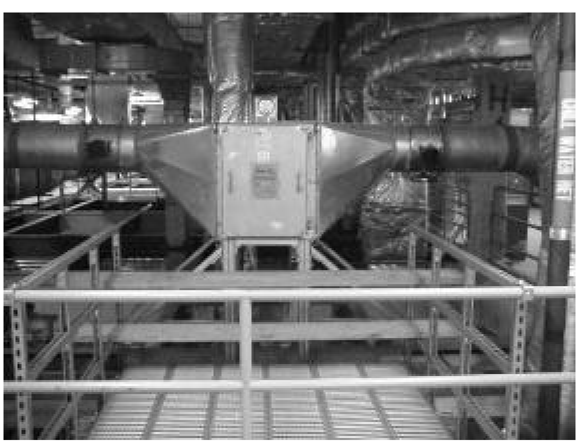

Figure 6.5 – Correct Mounting of In-Duct-HEPA Filter Housing

Enclosed filters are sometimes referred to as encapsulated (nipple-connected, closed-face, or self-contained) HEPA filters (see Chapter 3, Figure 3.8). They are not specifically recognized by applicable codes and standards and fail to meet all the requirements contained in DOE-STD-3020.[2] The uniformity of the velocity across the filter face is difficult to verify.

6.2 Housings

Housings for in-duct installations may be as small as the side-access housing for a 25-cfm HEPA filter or as large as the complete multistage air cleaning unit containing demister, prefilter, two stages of HEPA filters, and adsorber (**Figure 6.6**). Probably the most common single-component housing today is the bag-in/bag-out side-access type, which is commercially manufactured by a number of companies to a similar standard configuration.

Figure 6.6 – Complete Multistage Air Cleaning Unit

Commercially made side-access housings, like other air cleaning system components, are not items to be selected "on faith." Designers have been prone to look upon these as "black boxes," assuming that, because they are off-the-shelf items, they are adequately designed to be suitable for any nuclear application. This is not the case, and some users have been faced with replacing or upgrading many such commercial enclosures over the past several years. Features that must be checked carefully when purchasing standard commercial housings include the filter (component) mounting frame and clamping device, the rigidity of the box and its cover, the method of cover sealing and clamping, access to the installed component, the rigidity and construction of duct connections, and the materials of construction of all parts, including the component clamping mechanism. These same features are important in the design of one-of-a-kind shop-built housings. Provisions for in-place testing should be provided on all filter housings.

6.2.1 Component Installation

Requirements for installing components are basically the same as those for bank installations. These include structural rigidity, flatness, and accuracy of the sealing surface construction; positive, reliable sealing of the component to the frame; specification of and strict adherence to close tolerances in fabrication; and leaktight welded construction (see Chapter 4, Section 4.3.2). A minimum sheet-metal thickness of 0.078 inch (No. 14 U.S. gauge) is recommended for the sealing surface of commercially made and shop-fabricated housings. For gasket-sealed housings, the sealing surface must be seal-welded into the housing such that no warping of the filter (component) sealing surface will result. There should be a right-angle bend all around the seating surface to provide reinforcement and to ensure flatness. **Figure 6.7** shows a portion of the turned-angle filter sealing surface of a commercial housing, and **Figure 6.8** shows a schematic of the four-bar-linkage gasket seal clamping mechanism that is operated by means of a wrench (shown in **Figure 6.9**) from outside the housing. Other clamping systems are acceptable, so long as they provide the required amount of clamping force on the gaskets.

Figure 6.7 – Turned Angle, Gasket Sealing Filter Surface for a Commercial Housing (left-hand side of the photo) [Note: Right-hand side of this photo shows the four bar-linkage gasket.]

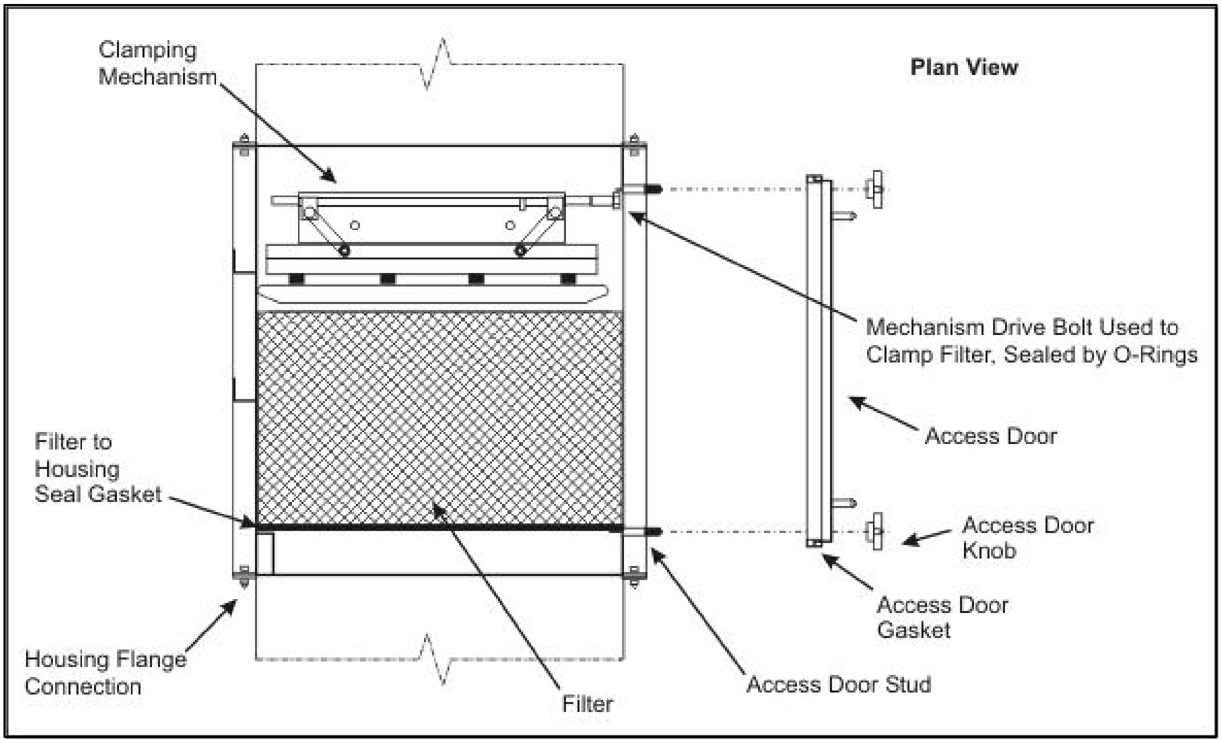

Figure 6.8 – Four-Bar-Linkage Gasket Seal Clamping Mechanism

The housing should be constructed to prevent leakage where the clamping mechanism penetrates to the outside. The structural requirements of the mounting frame will be met if 14-gauge steel is used, particularly if combined with the stiffening flange (right-angle bend).

Flat gasket-to-knife-edge seals are not recommended because they tend to leak excessively if the knife-edge is nicked or if the knife-edge and the filter face are not parallel. The compression set produced by a knife-edge in only a portion of the gasket also results in leakage if there is any degree of relaxation of the clamping device. The gel seal design does not require special tolerances and has been proven to create a very effective filter-to-sealing surface method.

Figure 6.9 – Using Wrench to Operated Four-Bar-Linkage Gasket Seal Clamping Mechanism

A nonwelded mounting frame consists of a single 0.25-inch plate sealed by gaskets between the flanges of the body and the transition of a field-assembled housing. The filter is clamped by bolts and installed through a hatch in the side of the housing. A gasket compression of at least 80 percent is needed to create a reliable seal between high-efficiency devices such as a HEPA filter or radioiodine adsorption cell. This requires a gasket loading of something over 20 pounds per square inch of gasket area for a total loading of over 1,400 pounds for a 24- × 24-inch filter; 1,050 pounds for a 12- × 24-inch filter; or 700 pounds for a 12- × 12-inch filter. Such loadings can be accomplished with the bolted clamping method. It is important for the designer to verify that the clamping mechanism of the commercial housing being considered can develop the loading required and is adjustable. All parts of the mechanism should be stainless steel to prevent rusting and seizing under operational conditions (including springs, which tend to break when rusted). The only exception to this rule is that, if nuts are used, they should be brass, bronze, or another material that will not gall in contact with the stainless steel male-threaded part (**Figure 6.10**). Clamping mechanisms should be on the clean side of the filter, and operator shafts, when required, must be sealed by O-rings or glands. A rest or guides, stops, or some other means for aligning the filter prior to clamping should be provided within the housing.

Figure 6.10 – Filter Locking Mechanism Drive Bolt Located at the Front Exterior of the Housing

For gel seal housings, the knife-edge sealing surface must be seal-welded into the housing so that warping of the filter (component) sealing surface will not result. There should be a right angle all around the knife-edge sealing surface to provide reinforcement and ensure alignment. **Figure 6.11** shows a portion of the knife-edged filter sealing surface of a commercial housing. The gel seal housing clamping mechanism is operated by hand from the side of the housing. All parts of the mechanism should be 300 series stainless steel to prevent rusting and seizing under operational conditions.

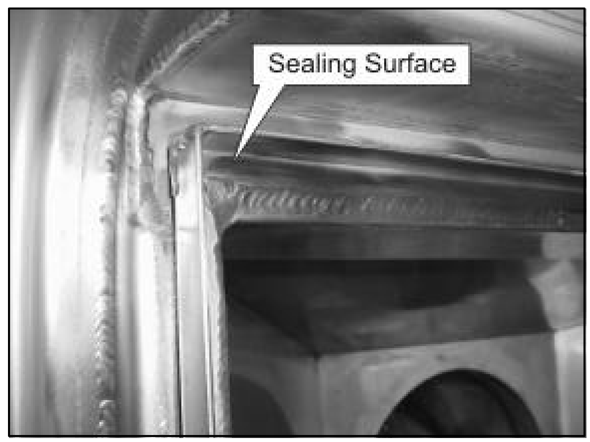

Figure 6.11 – Gel Seal Commercial Housing Filter Sealing Surface

The clamping pressure required to properly seal a gasket-sealed HEPA filter or adsorber cell must be both high and uniform, as noted in Section 4.4.6. However, this requirement is substantially relaxed when gel seal systems are used. As shown in **Figure 6.12**, the filter element has a groove filled with a non-Newtonian (i.e., nonflowing) gel. The filter is pushed against the knife-edged flange of the mounting frame so that the gel envelops the knife-edge, forming an airtight seal. The clamping pressure only needs to be sufficient to prevent the filter from backing away from the knife-edge (which would break the seal) under any foreseeable differential pressure across the filter in either normal operating or system upset conditions. The gel, a silicone compound, has been tested and found to be capable of maintaining an adequate seal under the fire and hot air conditions of UL-586, *Standard for High Efficiency, Particulate, Air Filter Units,*[5] and the radiation exposure requirement of ASME AG-1, *Code on Nuclear Air and Gas Treatment*, Section FC.[6] Either the flat-gasket-to-flat-flange or the gel seal are recommended.

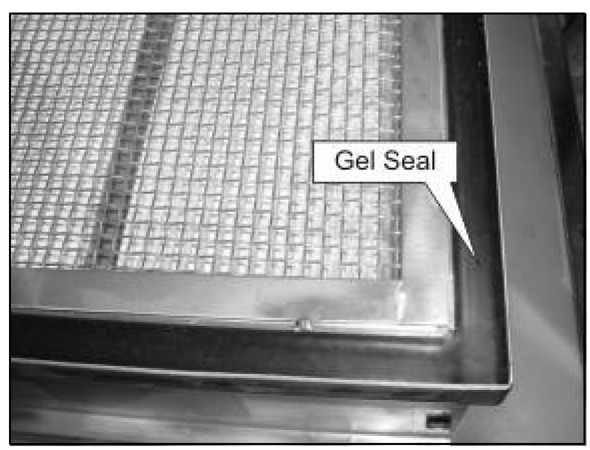

Figure 6.12 – Gel Seal System

6.2.2 Housing Construction

The walls of the housing must be sufficiently strong to prevent "oil canning" and overstressing under an alternating positive and negative pressure equal to at least 1.5 times the maximum gauge pressure to which the housing will be subjected under the most severe conditions for which it is intended. A minimum design pressure of 10 in.wg is generally recommended. In general, the recommended design features listed in Section 4.5.2 and the leaktightness recommendations of Section 4.3.4 are applicable to housings of these smaller dimensions. In purchasing commercial housings, the designer should check the details of construction to verify that the design proposed is fully adequate for the intended application, i.e., that the walls of the housing (or the cover) will not "oil can" and that stresses in the walls or clamping mechanism will not exceed a value of 0.7 times the yield strength of the material from which they are made under a housing pressure of 1.5 times the design pressure.

Many failures of commercial housings can be traced to corrosion. The filter housing is a common point where corrosives tend to condense, collect, and concentrate. When the filter housing is to be installed in a line that, under either normal or abnormal conditions, may contain corrosive fumes or vapors, stainless steel construction should be employed. In any event, all parts of the clamping device (including springs, but not nuts) should be stainless steel. Whenever housings are painted, the coating should comply with American Society for Testing and Materials D5144, *Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants*.[7] The designer should determine which coating has to be used and should be personally satisfied that it is adequate for the application.

Figure 6.13 – Access Door Hand Knobs

Hand knobs of the type shown in **Figure 6.13** should attach to the housing access door. Attachment of covers with machine bolts or nuts may be cheaper, but will be a constant problem to the user. Nuts get lost and threaded bolts get damaged under service conditions. The result is often an inability to seal the housing properly, and the need to remove and replace a large number of nuts or bolts inhibits access and proper service. For access door clamping, the door must have a 2-inch-deep lip or flange all around for stiffening (Figure 6.7). The cover must also be stiff enough or sufficiently reinforced so that it will not "oil can" under the pressure variations to which it may be subjected. The cover and the cover-clamping mechanism must be capable of sealing the cover opening whether or not a bag is in place.

6.2.3 Bagging

Most commercially manufactured and some one-of-a-kind shop-built housings are designed for bag-in bag-out filter replacement. **Figure 6.14** describes this procedure step-by-step. Shutoff dampers are needed upstream and downstream of the filter (or other component being replaced) to permit isolation of the housing during the change and to limit ballooning or sucking in of the bag when the access door is opened due to a pressure differential between the inside and outside of the bag. A small, valved, breather vent can be specified on the clean side of the filter to control pressure in the housing; a slight negative pressure (0.25- to 0.5-in.wg) helps ensure inward leakage in case the housing becomes pressurized due to pumping of the bag. When sealing change-out bags, two seals about 0.25-inches apart are usually made so that, when the bag is cut between them, both the housing opening and the enclosed filter are sealed from the room environment. The end user's safety officer will determine the method of sealing the change-out bag that best suits the facility.

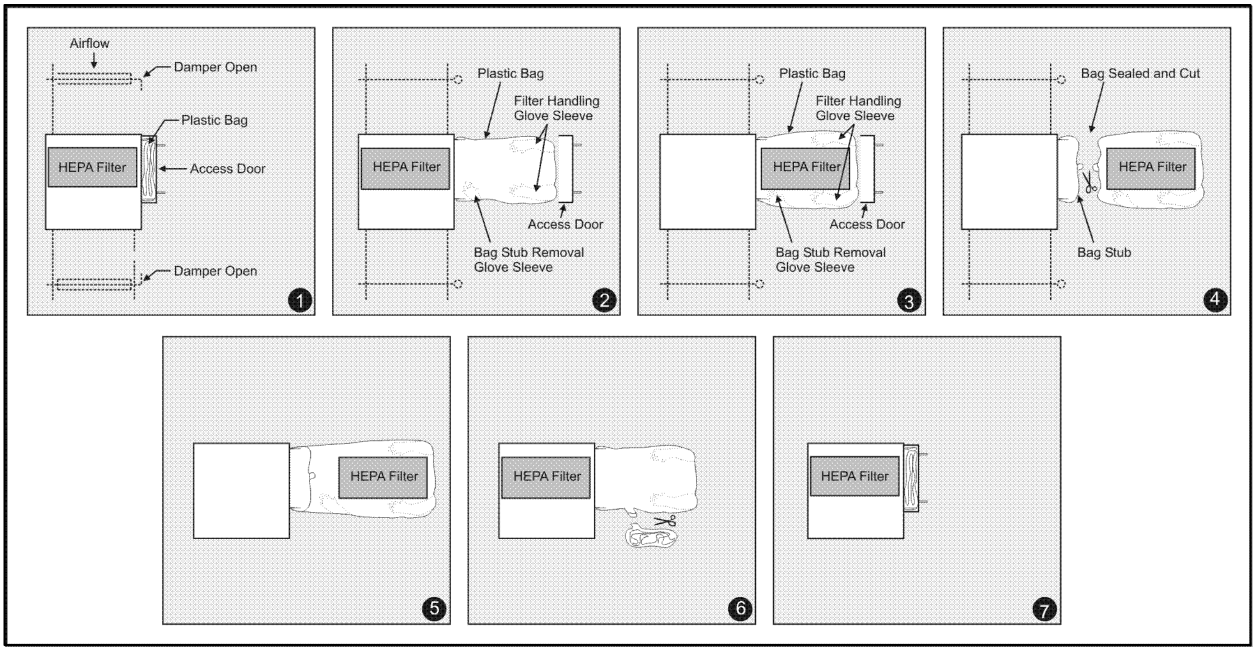

Figure 6.14 – Bag-In Bag-Out Filter Replacement

Bags should be clear plastic, typically polyvinyl chloride (PVC), to permit the worker to see what he is doing. In some housing designs, the worker has to manipulate the filter clamping mechanism through the bag as shown in **Figure 6.15**. Bagging materials are PVC or polyethylene. Radiation levels may limit the use of PVC. Bags should be a minimum of 0.008-inch thick. Thinner bags could tear, particularly when used with metal-cased filters or adsorbers. Care must be taken when carrying out the procedure with larger (24- by 24- by 11.5-inch) items. Housings should be installed in a location that can be isolated as a contamination or radiation zone in the event of a bag tear and resulting spill. The excess bag material that remains after a new filter is placed into the housing is folded carefully against the side of the filter element (shown in Figure 6.14) to prevent any portion from getting into the airstream or being pinched between the housing cover and bagging ring. After folding the bag within the filter housing, it must be isolated from system airflow on the clean side of the filter because the plastic can be damaged from continued exposure to the airstream. The covers of bag-out housings must be capable of sealing the housing with and without the bag installed and must be kept closed when the system is in operation to protect the bag that remains in the housing. Bagging should not be considered an automatic solution to the contamination hazard, and the user is cautioned to take proper precautions during filter changes. **Figure 6.16** shows possible dress for personnel engaged in a bag-out filter change when there is a possibility of high contamination levels (note the personal protection equipment). Again, the end user's Health

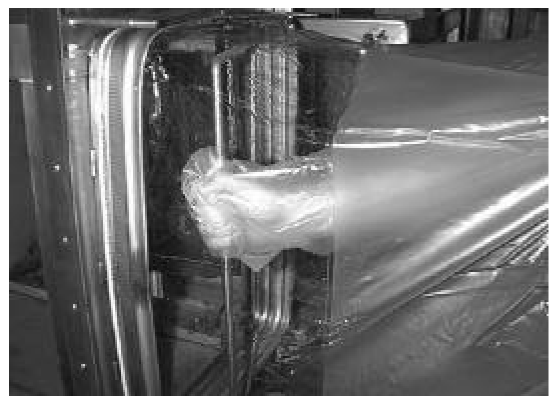

Figure 6.15 – Use of Clear Bags

Figure 6.16 – Personnel Dress for Bag-Out Filter Change

Figure 6.17 – Horizontal Filter Installation

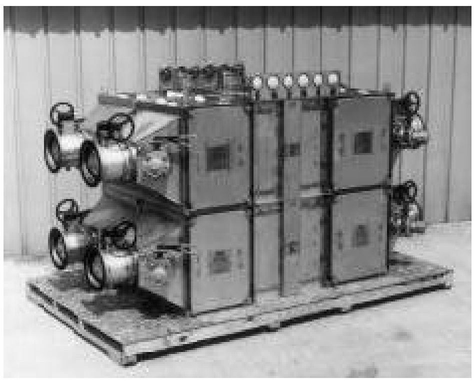

Figure 6.18 – Four Individual Housing Units Grouped as One Assembly

Figure 6.19 – Flexible Connection

and Safety/Radiation Protection personnel will determine the method of bag-out filter change that best suits the facility.

6.2.4 Housing Installation

Horizontal airflow with filter faces in a vertical position is recommended for large (24- by 24-inch face dimensions) HEPA filters. This recommendation is not so important for smaller filters designed with media support that is inherently sufficient to resist gravitational pull on filter core and collected dust. When vertical airflow (filter face in a horizontal position) is unavoidable, upflow design is recommended over downflow design because filter media sagging is offset to some extent by air pressure and because there is less chance of cross-contamination from the dirty side to the clean side of the system. With the downflow design, contaminated dust dislodged during a filter change can fall into the clean side of the system. A downflow design should be avoided where there is a potential for liquid to collect in the system. Liquid collected in the filter pleats of a downflow system will eventually seep through the media and carry dissolved contaminants into the clean side of the system. On the other hand, upflow systems may require withdrawal of contaminated filters into the clean zone. When horizontal installations must be used, filters should be designed to seal on the upper side of the mounting frame so that their weight will load rather than unload on the gasket or gel-sealing surface (**Figure 6.17**). Installation of the filter on the clean side (i.e., downstream) of the mounting frame is always recommended for single-filter installations.

For multistage installation, components may be installed in a single housing (as shown in Figure 6.17) or grouped as one assembly (**Figure 6.18**). Although bolted, gasketed joints are recommended, flexible connections (see **Figures 6.19 and 6.20**) are suitable for housings connected directly to a fan. Duct-taped seals between housings and ductwork are not acceptable. Multistage installations can create problems related to periodic surveillance testing of HEPA filters and adsorber cells. Even though a flange-to-flange installation (**Figure 6.21**) is undoubtedly the least expensive option when considering materials and space occupancy, sufficient room should exist between components to introduce a well-mixed test agent, to obtain a satisfactory upstream sample, or to probe for leaks on the downstream faces of the components. Careful planning of filter and adsorber test procedures before completion of installation design is essential, particularly for multistage installations. Although some housing specifications require and some vendors routinely furnish sample ports in the housing itself, such ports should not be automatically assumed to meet the requirement for preplanned and preinstalled test ports. As noted in Chapter 8, the test agent injection port must be located well upstream of the filter or adsorber to achieve good mixing of the air and test agent. Upstream samples must be taken from a point in the duct that is immediately upstream of the filter or adsorber. Downstream samples must be taken at a point far enough downstream to obtain good mixing of the air and test agent that penetrates the filter or adsorber. This point is at least 10 duct diameters downstream (or preferably downstream) of the fan. [Note: Fire protection is discussed in Chapter 10.]

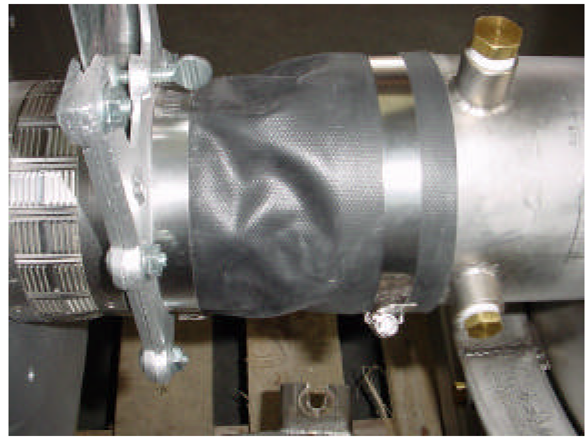

Figure 6.20 – Flexible Connection

To sidestep testing problems related to having 10 duct diameters upstream to inject the test agent and 10 duct diameters downstream to sample, in-place filter test sections are available. These test sections (shown in **Figure 6.21**) allow testing without requiring test personnel to enter the contaminated air space. The test sections should be the same height and width as the housing that contains the filter or adsorber being tested, and the length of the test sections should be 24 to 28 inches long.

Figure 6.21 – In-Place Filter Test Section

The in-place test sections should be designed, manufactured, and tested using the same criteria as the filter housing. The test housing will use apparatus and devices supplied as an integral part of the test section, including mixing devices and sample ports. The upstream and downstream test chambers must contain identical mixing devices to mix and disperse a uniform challenge air/aerosol ahead of the filter and the effluent from the filter being tested. Challenge aerosol inlet ports and upstream and downstream sample ports must be provided for each HEPA filter space and must be labeled for identification.

6.3 Enclosed Filter Installation

The enclosed HEPA filter design is not intended or recommended to replace or serve as a confinement housing.

6.4 Cylindrical Filter Elements

Cylindrical filters may be either cylindrical or radial flow. The cylindrical flow HEPA filter configuration frequently offers an ideal solution to certain installation requirements. One manufacturer makes a spiral of the filter material and a separator; the others make a conventional pleated-medium-and-separator core that is trimmed to a cylindrical shape. In both designs, the core is slipped into a molded or welded-seam cylinder (**Figure 6.22**) and sealed by catalyst-activated plastic foam or urethane. Cylindrical flow HEPA filters can be obtained with or without flanges on one or both ends. The filters with interference seals, but without flanges as shown in **Figure 6.23**, are used in push-through

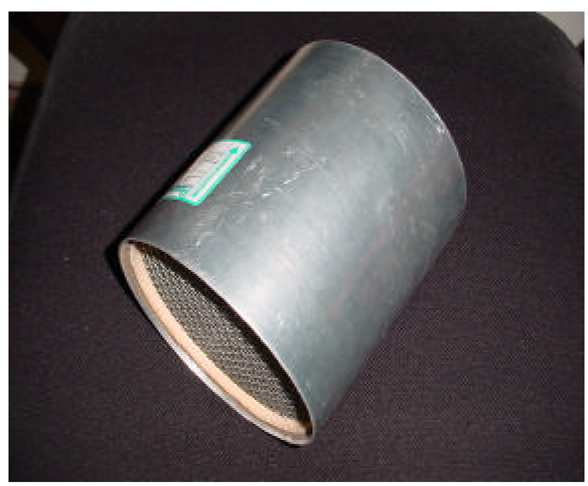

Figure 6.22 – Open-Faced Axial Flow Cylindrical HEPA Filter

Figure 6.23 – Radial Flow HEPA Filter

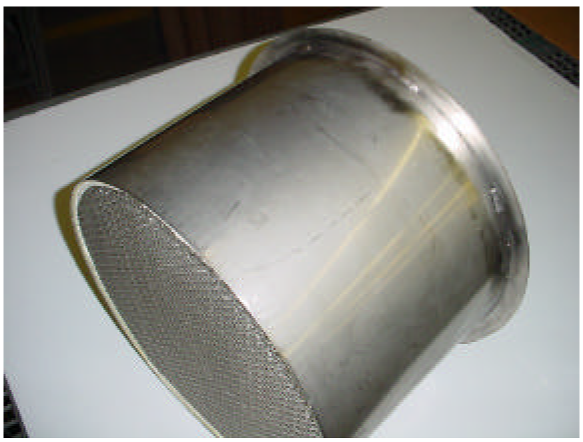

Figure 6.24 – Open-Faced Axial Flow Cyclindrical HEPA Filter with Flange

Figure 6.25 – Clearance Between Radial Flow Filter and Housing

(i.e., incessant) installations. The filters are sealed into a cylindrical opening with one or more half-round circumferential gaskets (fixed to the filter) that make a slight interference fit with the receiver. As the filters are often out-of-round and a reliable interference fit between filter and receiver is impracticable, push-through installations are often unreliable under system-upset conditions. Push-through filters are subject to being blown out of the receiver if pressure differentials become high. Flanged cylindrical HEPA filters (**Figure 6.24**) can be installed in pipe openings by bolting them to a flange on the pipe or by clamping the filter flange between mating pipe flanges. Conventional neoprene sponge gaskets are used for sealing (see Section 4.4.6). Because filter flanges and cases are characteristically made from light-gauge sheet metal with the flange seal-welded to the cylinder, these filters often leak at the flange-to-case weld. The flange often becomes deformed. Either condition results in an installation that is difficult to seal.

Cylindrical HEPA filters cost substantially more than rectangular HEPA filters of equivalent airflow capacity. There are no current standard dimensions or airflow capacities. No cylindrical filters are listed for axial or radial flow filters in any of the standard specifications for HEPA filters [e.g., DOE-STD-3020,[2] ASME AG-1,[6] Institute of Environmental Sciences & Technology (IEST)-RP-CC001.3, *HEPA and ULPA Filters*].[8] DOE-STD-3020[2] allows for the use of special filters in a footnote stating that HEPA filters not listed in Table 1 of the standard: "(e.g., round, rectangular, radial, etc.) which conform to the requirements listed in this Standard (5.2 Performance Requirements, 5.3 Materials Requirements, and 5.4 Filter Construction) are acceptable for use at DOE nuclear facilities."

There are two methods of installing cylindrical filters, one a duct-entrance design and the other a hot-cell exhaust design. In the hot-cell exhaust design, the mounting is sloped to permit runoff of any liquid accidentally spilled on the shield that protects the filter and to facilitate handling by the cell electromechanical manipulators. Where cylindrical HEPA filters are used, liberal clearance (at least 1/8-inch all around) between the case and receiver is necessary to accommodate the characteristic out-of-roundness (see **Figure 6.25**). The advantage of cylindrical filters is close conformance to round ducts and pipes, which can both permit the use of smaller, cheaper duct transitions and require less space. For inline installations, however, except where the filter has flanges on both faces and is installed as a spool piece, provision must be made to extract the filter from the duct or pipe after the connection is broken, thus risking loss of the space advantage over an equivalent open-faced rectangular filter. Spool-piece filters must have flanges and withstand the forces imposed by the duct or piping system and the flange bolting.

Cylindrical filters are often used in radioactive vacuum cleaners and portable air purifiers. The air purifier shown in **Figure 6.26** is a single-use device that is discarded when the contamination level or pressure drop of the collectors becomes greater than the pre-established design level.

Figure 6.26 – Cylindrical Filter Air Purifier

6.5 Installation

6.5.1 Human Factors

The recommendation to install filters vertically with horizontal airflow is discussed in Chapter 4. When practicable, single-filter installations should be located where they can be reached for service and testing without workers having to climb ladders or scaffolding. This requires consideration of human engineering factors. Analysis of the recommended weight limits indicates that handling a 1,000-cfm HEPA filter in the body positions often encountered in filter-change operations is at the upper range of personnel capability, and that handling of adsorber cells is well beyond the limits for one person.

Consideration must be given to the positions that a worker must assume to perform the required task. If the worker must hold his hands overhead for any length of time, fatigue may result. If crouching, bending, or squatting is required, the worker will soon become stiff, which will contribute to loss of efficiency. If a worker has to hold a heavy weight while performing a precision operation (e.g., supporting the weight of a filter or adsorber cell while trying to fit it between duct transitions or into a restricted opening), the stress of the combined task will become fatiguing and a mistake could occur.[9] All of these factors are compounded when the worker must wear protective clothing and respiratory protection. In addition, protective clothing adds to the worker's spatial requirements and limits mobility. For HEPA filter and adsorber cell installations, location of the filter or housing at an elevation between knee and shoulder height is recommended.

6.5.2 Fume Hood Filter Installations

The wide, often unpredictable variety of chemical operations conducted in laboratory fume hoods makes selection and installation of HEPA filters difficult and uncertain. Corrosive fumes may damage the filter and its mounting, and moisture and heat from hood operations may accelerate that damage. Operations that produce steam or moisture should be restricted to minimize condensation in the filter or the carryover of water and/or chemical droplets to the filter. The system should be designed so that any droplets will be vaporized prior to reaching the HEPA filter.

Some facilities install fume hood filters in the attic, usually directly above the hood served. Where this design is employed, the attic space should be designed as a confinement zone for easy cleanup in the event of a spill, and should not be used for extraneous purposes such as storage and experimental work when radioactive materials are handled in the hood.

Hood installations in which perchloric acid and certain other chemicals are handled should be provided with washdown facilities to permit periodic decontamination of the hood and ductwork (perchloric acid hoods should not be used for handling other materials because of the explosion hazard (see Chapter 11, Section 11.1.3, for more detail on perchlorates). Off gas scrubbers are often provided in hoods. Both washdown facilities and scrubbers generate substantial quantities of water droplets. Provision of demisters that meet the requirements given in Chapter 3, Section 3.6, should be considered to protect the filters and their mountings. Moisture collected in the demister should be conducted to a hood drain rather than permitted to fall into the workspace of the hood. Demisters should have adequate handling space and be easily accessible for cleaning, inspection, and replacement. Where incandescent particles or flaming trash can be released to the hood exhaust stream, a spark arrester may be needed to protect the HEPA filter. This arrester can be either a commercial flame arrester, a metal-mesh graded-density demister, or at minimum, a piece of 40-mesh metal cloth. In any event, it is recommended that the arrester be located at least one foot ahead of the HEPA filter and must have easily accessible for cleaning, inspection, and replacement.

Heat sources such as heating mantles, furnaces, and Bunsen burners are common equipment in laboratory fume hoods and should be planned for in the initial hood and exhaust system design. Designers should control heat-producing operations by limiting the size of heat sources, insulating furnaces, etc., or using air cooling methods. [Note: Chapter 10 discusses operational control for fire prevention and heat control in HEPA filter systems.]

6.5.3 Portable Air Cleaning Units

The use of portable HEPA filtration systems has become quite prevalent within the nuclear industry. Radiation protection standards stress the use of engineered controls, principal localized ventilation, and confinement as the primary means of controlling occupational exposure to airborne contaminants. Decontamination and decommissioning activities utilize supplemental ventilation to control the large amounts of dust generated by demolition activities, especially as existing facility ventilation systems are decommissioned. Portable air filtration systems pose their own unique challenges to both the designer and the end user. As with commercial side-access housing, well-designed portable filtration systems (shown in **Figure 6.27**) are much more than "black boxes." Careful evaluation of system requirements, selection and integration of components, and attention to construction methods are all required to ensure a functional, effective, user-friendly system. This process has been made somewhat more difficult, however, due to a lack of industry standards that specifically address portable HEPA filtration units.

Figure 6.27 – Portable Filter Unit

Most procurement specifications for portable HEPA filtration systems should be developed by using ASME AG-1[6] and the more recent ASME AG-1.[6] These standards address the in-place safety systems for nuclear facility ventilation. While many aspects of these standards are applicable to portable systems, wholesale application without consideration of the unique features and functionality of portable systems may result in unrealistic specifications that are difficult, costly, or impossible to meet. Compromises need to be made, but without sacrificing the overall functionality and safety of the equipment.

6.5.3.1 Operational Considerations

Certain operational considerations should be addressed when selecting or specifying portable HEPA ventilation units for use in environments where nuclear or another hazardous contaminant is present. Like any other ventilation system, a portable HEPA filtration system must be designed to move and effectively clean the appropriate amount of air, required to maintain adequate environmental conditions within the workspace. Unlike permanently installed facility systems, however, the ultimate applications of portable systems are rarely known. They may be used for ventilating confined spaces, providing general area air exchanging, or providing high, localized, capture velocity in support of cutting, burning, grinding, or other mechanical and maintenance processes. Unless the system is intended for "one time, one application" use, it must be designed and constructed with sufficient flexibility to perform well under a variety of operating conditions. Thought must be given to the anticipated use of the equipment, and some basic operational questions should be asked to better define the required features. Examples include:

- Is particulate the only contaminate of concern, or will gas adsorption also be required?
- Is the expected operating environment or contaminant corrosive, or does it contain other contaminants that might affect the construction materials?
- Will the unit be used indoors or outdoors?
- What will be the ambient and process air temperature extremes?
- Will the unit be used in areas where there is high relative humidity or entrained water?
- Will the unit be used in areas where potentially explosive concentrations of gases or dust will be present, requiring special hazard class electrical components?
- Does the process or contaminant warrant redundant (series) HEPA filtration for added protection?
- Will the unit be subjected to high system losses due to using long lengths of temporary, flexible ducting and/or multiple filtration stages?
- Is heavy dirt loading expected that might require larger, more robust prefiltration capacity?
- Does the relative hazard of the contaminant require the added protection of bag-in/bag-out filter changing?
- What power is available to run the equipment? (Low voltage and amperage as well as single-phase power supplies can severely limit the capacity of the ventilation system.)
- How much space is available to stage the equipment? Is a single larger unit supporting multiple exhaust points more workable, or are smaller units placed local to the work more appropriate?
- What is the duration of the project or operation that will be supported by the portable system? Is the unit intended for reuse many times over years, or is it a one-time application? (Durability and ruggedness of construction can be greatly impacted.)

- What sampling is expected from the unit?

Careful consideration of these types of questions will better define which compromises must be made in designing a usable system.

6.5.3.2 Component Considerations

Fan Assemblies

The fan forms the heart of the system. Portable systems typically use centrifugal fans. These relatively compact fans are available in a wide range of performance capabilities and construction materials. Cast aluminum housing and wheels are common, as well as fabricated steel. Fiberglass, PVC, and other nonmetallic fans are available for processing air with corrosive contaminants. Regardless of the type of fan used, it's performance should be matched with the intended application. A fan with high static capabilities at the required flow rate is needed for a portable system that will be expected to operate with high system losses (e.g., large amounts of flexible ducting on the inlet or discharge; periods of high filter loading). Likewise, if the unit is only intended to provide local recirculation without high system losses, a fan with lower static pressure capabilities is acceptable. Fan performance should be developed using Air Moving and Conditioning Association (AMCA) 210/American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 51[10] (both organizations now issue only one common standard).

Fans are typically direct-drive systems. Due to advances in motor and solid state controller design, speed control by variable frequency drive has become popular and cost-effective for three-phase motors. Motors with appropriate hazard class ratings should be specified to protect them from internal contamination. If frequent washdown with high-pressure water is expected, appropriate duty motors should be specified. Likewise, motors with appropriate hazard class ratings should be used in hazardous locations in accordance with NFPA-70-02, the *National Electrical Code.*[11]

Motor starters should be mounted on the unit. National Electrical Manufacturers Association (NEMA) enclosures should be selected for the intended service, and NEMA enclosures and liquid-tight conduit should be specified for units intended for outdoor application or where direct water wash of the unit is expected. Reference NEMA Publication 250, *Enclosures for Electrical Equipment (1000 volts max),*[12] for electrical enclosure testing requirements. Alternate enclosure testing standards such as International Electrotechnical Commission (IEC) Publication 60529, *Degrees of Protection Provided by Enclosures*,[13] are equally acceptable. The important point is that the electrical enclosures and wiring should be suitable for the intended operating environment, including any special NEC hazard class requirements. Overload protection is suggested for all electrical starters. Special attention should be paid to using three-phase motors and starters. Due to differences in wiring methods between the power supply and the portable systems, starter fan rotation can be easily reversed with three-phase motors.

Fan and motor assemblies should not be rigidly mounted to the system's cart or the filter housing/transitions. Vibration isolation should be used for the motor, and a flexible boot or other vibration-isolating connection should be placed between the filter bank and the fan. Vibration isolation will reduce noise significantly. The fan always should be mounted on the downstream side of the filters to ensure the filters and ductwork are at negative pressure with respect to the environment. All motor fan assemblies must have appropriate safety guards, including the fan inlet and outlet (if normally accessible), the shaft, the pulley, and the belts (if used).

Filters and Filter Housings

Any single, standard-sized, HEPA filter can be readily incorporated into a portable filtration system rated 1,500 cfm or less. HEPA filters should meet the requirements provided in Chapter 3, Section 3.2. Since the size of the portable system is quite important, small, non-standard-sized HEPA filters are more appropriate for low-volume ventilators. The same basic construction requirements described in Section 3.3.2 should be used for these filters as well. Gasketed and gel seal filters can both be used in portable systems, provided the clamping/holding mechanism stays engaged as the unit is moved.

One unavoidable consequence of the compromises made when constructing a portable air cleaning system is that the fan performance and filter ratings may not always match. A portable system designed to support a long length of ductwork and other system losses will move considerably more air when it is operated with lower system losses. The fan may be capable of moving air at a considerably higher rate than the filter's rated capacity. The portable air cleaning system should be able to maintain the rated flow through the HEPA filter as the differential pressure of the filter increases due to loading. As velocity increases, efficiency decreases. [Note: The rated flow of the HEPA filter must not be exceeded. A flow device should be included in the portable air cleaner, and the flow of the unit should be administratively controlled.]

The fan curve will indicate the system's maximum potential flow rate. The free airflow rate, or the flow at zero in.wg static pressure, is the maximum flow that most fans can develop. Since the fan is connected to a filter bank, some system losses are present, so the free air rate is not a good indication of maximum flow. The flow rate at the expected operating pressure is a better indication of the maximum flow that the fan/filter system can be expected to deliver.

The filter housing can be as simple as a side-access housing. A housing with bag-in/bag-out features provides added protection from high-risk contaminants or for units used outside. Depending on the contaminants present, the use of a side-access housing may not be warranted. Considerable size, weight, and cost can be saved with alternative filter-retaining methods. Filter sealing/housing arrangements or traditional side-access housings have been successfully used for many years. **Figure 6.28** depicts several portable system arrangements. Whichever method is used, the filter frame and clamping method should meet the standards previously discussed in Section 6.2. The sealing surface must be flat, square, fully welded, and ground smooth. The filter sealing surface must be fully welded to the pressure boundary of the filter housing. The clamps or latches retaining the HEPA filter should exert the recommended sealing force [20 pounds per square inch (psi) of gasket area], and should use a spring-loaded or tension method to ensure a positive clamping force is maintained (this is unnecessary when gel-sealed filters are used). Since portable systems are designed to be moved, the chosen clamping or housing method should adequately protect the filters and prevent unclamping or dislodging of the filter due to cart movement. The system's cart should be sufficiently rigid in construction to limit the amount of flexing seen in and by the filter frame and housing. When the filter is exposed, only metal-cased HEPA filters should be used.

Figure 6.28 – Typical Portable Systems

Prefiltration should be integral to the portable system. Prefilters should be accessible independent of the HEPA filter and should not require unclamping of the HEPA filter during change-out. Additional inline prefiltration may be needed for heavy dirt loading applications such as concrete-cutting and abrasive blasting. [Note: A spark arrester must be added to the prefilter for plasma arc cutting or any other type of sparkproducing activity.] Moisture separation also may be required. This can be addressed using either demisting pads that are integral to the portable system or supplemental dehumidifiers in line.

Adsorber beds can be configured on portable carts as well. The carbon cells can be adapted as part of the portable filter system or as a separate stand-alone assembly that is interconnected with the filter unit on an as-needed basis.

6.5.3.3 Construction

Portable equipment used in an industrial setting is subject to abuse. As such, construction of a portable filtration system needs to be rugged and suitable to a harsh industrial environment. Transitions and housing pressure boundaries should be fully welded. Properly designed gasketed and bolted connections, especially on transition to and from the filter, are necessary to avoid loosening over time. Assembly should allow access for decontamination purposes. Construction materials should be compatible with the operating environment. Stainless steel is highly recommended, especially for those components that come directly in contact with the contaminated airstream.

Quality wheels and casters should be used on wheeled equipment. At least one set should have a brake or some other means of securing the cart in place. Wheels should be compatible with the surface where the equipment will be used. Hard wheels are suitable for indoor use and are more readily decontaminated, while large pneumatic wheels may be more appropriate for outdoor applications. Wheel design should allow replacement if the wheel becomes contaminated or damaged. On larger units, channels for fork truck lifting or lifting eyes will facilitate handling. Lifting points should be conspicuously marked. A stout push handle is a desirable feature. Tow bars can be used for larger skids, allowing the cart to be pulled like a trailer.

Flow control dampers should be incorporated into the unit, especially on systems with multiple connection points. Dampers located in the ductwork close to the work area may be advantageous if frequent flow adjustments are necessary. Dampers should include a positive lock to ensure that the damper will not move once the desired flow balance is achieved. Blast gates, quadrant control, and butterfly styles are all suitable for flow control dampers on portable systems. If possible, dampers should be installed so that in the event of a failure, they fail in place or open, thus preventing a sudden loss of flow in the event of damper failure.

Tapered transitions add considerable length to a portable system, so abrupt transitions are frequently used on portable systems where size is a concern. If abrupt transitions (e.g., no taper) are used, a plenum space of at least 4 inches should be left in front of and behind the HEPA filter. This space will allow for airflow expansion, thereby reducing air velocity prior to entering the filter.

Duct connection points should be undersized to allow connection of flexible ducting. Allow 1/8 inch less than the nominal size of the flex ducting used. For example, a 7 7/8-inch outside diameter connection would be required if 8-inch diameter flex ducting were used. A roll bead, round bar, or other protrusion fabricated into the duct connection point will help secure the duct when a hose clamp is installed behind it. **Figure 6.29** shows a typical duct connection with a roll bead.

Differential pressure (DP) gauges should be installed to monitor dirt loading on the HEPA and prefilter. Individual gauges for both stages of filtration are desirable. Since the flow rate through a portable system can change significantly depending on ductwork routing and damper adjustments, the user must be aware that observed changes on the DP gauge may not be due to dirt only, but may instead reflect a change in the air velocity through the filter element. For this reason, it is necessary to ensure that, when assessing dirt loading on the filters over time, DP readings are taken under the same flow conditions. Alarms that indicate high filter DP, as well of loss of airflow (which can be indicated by a very low filter DP), are also good features. The same general caution about the affect of air velocity on filter DP would apply to these alarms as well.

6.5.3.4 Portable HEPA Filter Systems Testing and Inspection


Figure 6.29 – Duct Connection with Roll Bead

Portable air cleaning units require a great deal more periodic inspection and in-place leak testing than permanently installed systems. This is due to the inherent fragility of portable units and lack of stringent manufacturing standards for them. The rough handling and shock they can be expected to experience during transport makes careful inspections and functional tests, including in-place leak testing, mandatory prior to each use at installation. Also, anytime these units are moved or jarred after they are put into service, careful inspections and functional tests—including in-place leak testing—must again be performed. The testing of these units is covered in Chapter 8. Temporary, portable ductwork is fragile and may be subject to degradation, especially if exposed to sunlight, chemical vapors, or heat. It should be inspected and checked for leakage frequently, depending on the application, a daily or weekly schedule may be appropriate.

6.5.3.5 Vacuum Cleaning Systems

HEPA-Vacs are most commonly used to control friable particulate before it becomes airborne. They are also used to control airborne particles and liquids in and around work areas and to locally control 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.


Figure 6.30 – HEPA Filter Vacuum

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 and steerable wheels for portability and control during use. The power module consists of a fan 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 head-to-tank seal that depends on the vacuum force to provide a positive seal (i.e., many commercially available shop vacuums) should not be used (Figure 6.30 and 6.31).

Some vacuum cleaners are equipped with controllers that allow the worker to regulate the flow. This works well in providing negative ventilation in small glovebags. 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.

Figure 6.31 – HEPA Filter Vacuum

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 constructed by welding two pipes into a spare drum lid. As each drum is filled, the lid can be swapped to a new drum and a regular lid can be installed on the full drum. Personnel radiation exposures 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 prior to use at the site. This is necessary as these units are usually transported to the site in pick-up trucks and are dragged up flights of stairs and along rough floors and walkways. This is an invitation for filter leakage so careful handling is important. 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 simple and should be performable 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 in DOE STD 3025[14] and ASME AG-1.[6] 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 Filter Test Facility.

Operation

HEPA-Vacs are used to cleanup radioactive debris in the work area. 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 criticality 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:

- Maintaining control of HEPA-Vacs.

- Ensuring that HEPA-Vacs are tested on a frequency consistent with their use. This frequency should not exceed 1 year. 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 that the health physicist is contacted before the HEPA-Vacs are opened.

HEPA-Vacs used in contaminated areas should be equipped with HEPA-filtered exhausts or with exhausts that are directed to installed systems 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.

Testing and Periodic Maintenance

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. Testing of HEPA-Vacs is covered in Chapter 8.

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