CHAPTER 4

HOUSING DESIGN AND LAYOUT

4.1 Introduction

This chapter discusses housing design and requirements for air cleaning units in which filters and/or adsorbers are installed (see Chapter 6, "Small Air Cleaning Units," for single filter housing design information). Two basic designs are addressed in this section: man-entry and side-access (see **Figures 4.1** and **4.2**). In addition, two side-access housing types are addressed—one utilizing square filters and the other radial flow/round filters (**Figure 4.3**). Both side-access designs are for housings with two or more filters and for system capacities greater than 2,000 cubic feet per minute (cfm). Single-filter inline housings, man-entry housings larger than 30 high-efficiency particulate air (HEPA) filters, and masonry/concrete housings are not considered here.

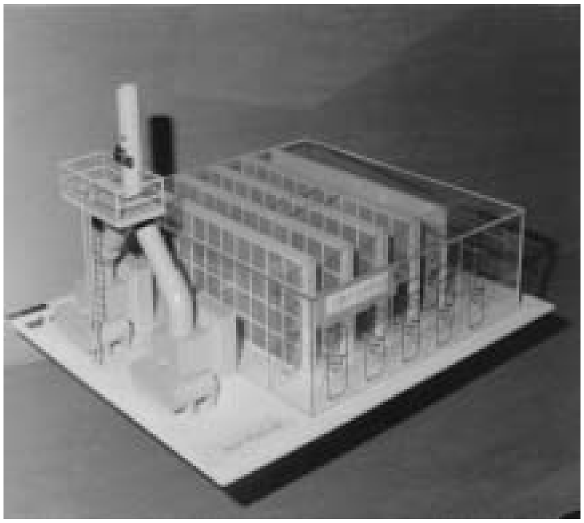


Figure 4.1 – Model of a Man-entry Plenum

4.2 Housing System Design

Large-volume air supply and exhaust requirements may be met by a number of side-access or man-entry filter housing installations operating in parallel, or in a single central system. Parallel housings have the advantages of: (1) greater flexibility for system modification; (2) minimum interference with operations during filter replacement because individual units can be shut down without affecting the remaining systems; (3) good overall ventilation control in the event of malfunction, fire, or accident to one or a few individual units; and (4) easy system testing and balancing.

4.2.1 Man-entry Housing System Design

The man-entry filter housing consists of a fabricated steel confinement room with one or more walls seal-welded in place. The walls have holes and hardware to mount HEPA filters or absorbers. The room has access doors providing entry at each side of the walls. Air is ducted into one end of the room; passed through the filters/absorbers mounted on the wall; and exits from the other end of the room. A wall with filters/absorbers mounted on it is considered a "stage" or "bank." The man-entry design is best used for housings with stages of 15 filters (5 across, 3 high) or more. As the number of filters/absorbers increases, consideration must be given to the ability to test the filters/absorbers and to the distribution of airflow. For larger systems (over 30 filters per stage), the designer should consider segmenting the system into two or more parts of equal airflow capacity, with each part in a separate, parallel housing. Isolation valves on each housing are desirable for convenient system control,

Figure 4.2 – Side-access Design (Square Filter)

isolation of individual units during an emergency, and maintenance or testing activities.

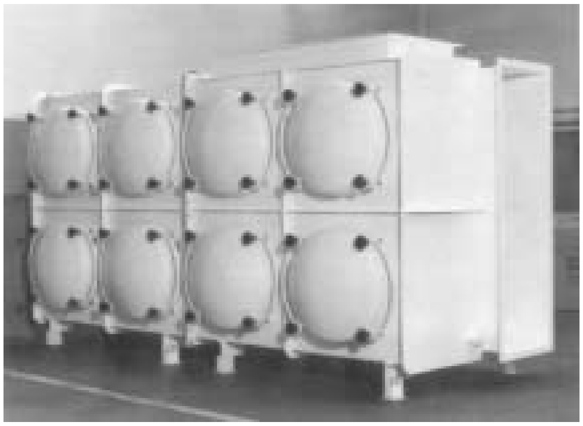


Figure 4.3 – Side-access Design Cylindrical (Radial Flow Filters)

4.2.2 Arrangement and Location

Maintainability is a major consideration when laying out filter housings. Although some systems may have only a single bank of HEPA filters, most will have at least one additional bank of prefilters, and many will have multiple banks of HEPA filters. Those systems in which contaminated gaseous releases must be controlled will also require one or more banks of adsorbers. Often a bank of demisters is required, resulting in as many as six or more banks of components in a single housing. There must be sufficient clear corridor space adjacent to the housing for handling filters during filter changes, as well as an adequate number of corridors to and from the housing. Dollies are often used to transport filters to and from the housing area. This practice results in safer operations that reduce the risk of both injury to personnel and spread of contamination from dropped filters. When dollies are used, space is required to move the dollies in and out, and for loading and unloading. Additional space is desirable for stacking new filters adjacent to the work area during the filter change-out process. Recommended clearances for housings and adjacent aisles or airlocks are given in **Figure 4.4**.

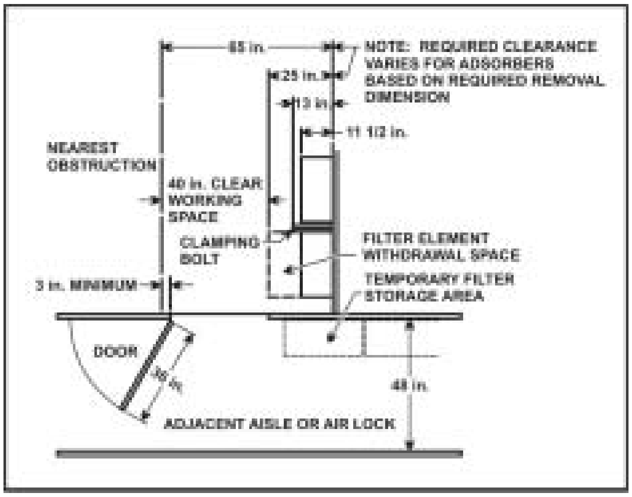


Figure 4.4 – Recommended Clearances for Man-entry HEPA Filter Banks

Proper access to the filter housing is sometimes overlooked. Too frequently, housings are situated among machinery, equipment, and ductwork where workmen are required to climb between, over, or under obstructions to get to the housing door, where they still have inadequate workspace. In some installations, it is necessary to carry filters one at a time over ductwork and then rely on rope slings to transfer them up to the floor above where the air cleaning system is located. It is essential to preplan the route for getting filters and adsorbers to and from the housing, and to provide elevators or cranes where they have to be hoisted to an upper level. Gallery stairways are also recommended in lieu of ladders. See **Figures 4.5 through 4.10**.

High-risk operations often require segmented systems with two or more housings ducted in parallel that exhaust from the same area and vent to the same stack. Each housing must have inlet and outlet isolation dampers to permit one to be held in standby or, when both are normally operated simultaneously, to allow one housing to be shut down for maintenance, testing, and emergencies.

Another important consideration in housing layout is uniformity of airflow through the installed components. This is especially important for adsorbers, since flow through those components must achieve the gas residence time required for efficient adsorption of gaseous contaminants. For large, multiple-filter housings that must operate in parallel, equalizing screens may be required in each filter unit to ensure uniform flow in housings. Long transitions are difficult, particularly in large housings. Nevertheless, every effort should be made to locate and design inlets and outlets to avoid stratification and to enhance the uniformity of airflow through components.

Special care must be taken in designing side-access housings to ensure uniform flow through all filter elements. It is recommended that manufacturers performance-test prototype side-access filter units in accordance with American Society of Mechanical Engineers (ASME) AG-1, Section TA,[1] to document uniformity of flow through side-access filter units before fabrication of production units. When high-activity alpha-emitters such as plutonium or transuranic elements are handled, it may also be desirable to compartmentalize the system, both in series, with separate housings for prefilters and HEPA filters, and in parallel for extra safety.

Figure 4.5 – Airlock Entry for Man-entry Plenum (Filters Above Doors are to Allow Pressure Equalization)

4.3 Component Installation

4.3.1 General

Proper installation of HEPA filters, adsorber cells, and demisters is critical to the reliable operation of a high-efficiency air cleaning system. HEPA filter and adsorber frames should be designed in accordance with the requirements of ASME AG-1, Section FG.[1]

4.3.2 Considerations

The following factors must be considered in designing HEPA filter and adsorber frames:

- Structural rigidity of mounting frames;
- Rigid and positive clamping of components to the mounting frame;
- Careful specification of and strict adherence to close tolerances on alignment, flatness, and the surface condition of component seating surfaces;
- Welded-frame construction and the welded seal between the mounting frame and housing;
- Ability to inspect the interface between components and the mounting frame during installation (man-entry);
- Adequate spacing between components in the bank (man-entry); and
- Adequate spacing in the housing for men to work (man-entry).

Figure 4.6 – Man-entry Two-Level Plenum (lower level) (Looking at Mist Eliminator Upstream Side of First HEPA Filter Stage)

Figure 4.7 – Man-entry Two-Level Plenum (Upper Level Looking at Upstream Side of First HEPA Filter Stage)

Figure 4.8 – Man-entry Plenum (Looking at a Ship Door Between HEPA Filter Stages)

4.3.3 Housing Construction

The components and mounting frame should form a continuous barrier between the contaminated and clean zones of the system. Any hole, crack, or defect in the mounting frame or in the seal between components and the frame that permits bypassing will result in leakage of contaminated air into the clean zone and reduced system effectiveness. A mounting frame that is not sufficiently rigid can flex so much during operation, particularly under abnormal conditions, that leaks may develop in the HEPA filters clamped to the frame (due to differential flexing of the filter case relative to the mounting frame). Cracks may also open between the filters and the frame, between frame members (due to weld cracking or fatigue), or between the frame and the housing. Insufficient attention to maintenance provisions in the original design can increase operating costs and reduce reliability of the system. Once the system is installed, defects are difficult to locate, costly to repair, and may even require rebuilding the system.

Mounting frames for HEPA filters and other critical components should be all-welded structures of carbon or stainless steel structural shapes. Carbon steel frames should be painted or coated for corrosion resistance. Galvanized steel is not recommended because of welding difficulties and because the zinc coating does not give adequate protection in the environments that may be encountered in a contaminated exhaust system. Aluminum is not recommended because of the high cost of surface preparation. Stainless steel is often the best and most economic choice for radiochemical plant applications. Suitable housing and mounting frame materials include the following (source references are listed at the end of this chapter as noted below):

- Stainless steel shapes, American Society for Testing and Materials (ASTM) A479, alloy UNS S30403, class C, annealed and pickled[2];
- Stainless steel plate, ASTM A240, alloy UNS S30403, hot-rolled, annealed, and pickled[3];
- Stainless steel sheet, ASTM A240, alloy UNS S30403, annealed and pickled, 2D or 2B finish[3];
- Carbon steel shapes and plate, ASTM A36,[4] A499[5];
- Carbon steel structural tubing, ASTM A500[6], and
- Carbon steel sheet, ASTM A1011-03.[7]

Information relating to fabrication includes:

- "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," *Manual of Steel Construction Allowable Stress Design*, American Institute of Steel Construction, New York, NY, 1989. [8]
- *Cold Formed Steel Design Manual and Specification for the Design of Cold-Formed Steel Structural Members,* American Iron and Steel Institute, 4th Edition, New York, NY, 1996. [9]
- *AWS Structural Welding Code-Steel,* AWS D1.1, D1.1M-02 American Welding Society, Miami, FL, 2002. [10]
- *Design of Welded Structures,* O. W. Blodgett, James F. Lincoln Arc Welding Foundation, Cleveland, OH, 1976.[11]

Figure 4.9 – Common Aisle Between Two Man-entry Plenums

4.3.4 Potential Housing Leakage

Contaminated filter housings must be leaktight to prevent contamination of adjacent service and operating areas. (Leak-testing of filter housings is covered in Chapter 8). The design of nuclear air cleaning system housings must consider the potential for leakage. By locating the filter unit in an appropriate plant location and locating the fan relative to the filter housing, leakage amounts (especially leakage of contaminated air) can be minimized.

A once-through contaminated exhaust filter housing may be designed with the exhaust fan located after the filter housing and the housing located in a space that is "cleaner" than the air entering the housing. The benefit of this system configuration is that the air cleaning system up to the fan is under a negative pressure. Leakage is into the housing, thereby minimizing the potential impact of contaminated leakage on plant personnel during system operation. This system configuration does not mean leakage should not be considered. It means that the leakage potential can be reduced by component location and that further reductions in personnel dose to levels as low as reasonably achievable (ALARA) are possible via housing construction.

If the space where an air cleaning system housing is located is more contaminated than the air entering the housing, it would be better to locate the fan on the inlet side of the housing. This arrangement would eliminate in-leakage of more contaminated air downstream of the filters.

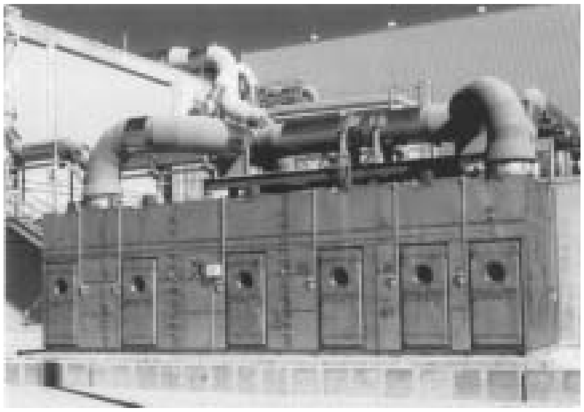


Figure 4.10 – Man-entry Housing Located Outside Building

For a habitability system where the housing is located within a protected space, the fan should be located downstream of the filter unit to ensure any potential in-leakage is "cleaner" air. If the housing in a habitability system is located in an area outside the protected space, then the fan should be located upstream of the filter unit to ensure potentially contaminated air does not bypass the filter unit.

The first step in determining housing leaktightness is to assess the relative contamination potential between the air entering the housing and the space where the housing is situated. Locate the fan accordingly, then determine the allowable leak rate to maintain: (1) the personnel dose within the requirements of 10 CFR 20[12] for inplant personnel, (2) the offsite dose per 10 CFR 100,[13] and (3) the ability of the system to maintain performance [e.g., direction of airflow, required pressure differential, air exchange (dilution) rates]. The latter item depends on the system design and margin. ASME N509-89[14] and ASME AG-1,[1] Section HA, "Housings," provide guidance on determining allowable leakage.

The allowable leakage should be considered when determining construction requirements. However, for filter housings, the structural design requirements for pressure and dynamic forces dictate that the housing fabricated of heavy platework (10-gauge to 3/16-inch-thick) can be seal-welded to join the transverse and longitudinal joints, instead of using bolts, without significantly increasing cost. This will result in a low-leakage installation.

4.3.5 Paints and Protective Coatings

Coatings and paint requirements must be consistent with the corrosion expected in a particular application and the size of the duct. Corrosion and radiation-resistant paints and coatings should, at a minimum, meet the requirements of ASTM D5144[15], *Standard Guide for Use of Protective Coatings in Nuclear Power Plants*. Unless special spray heads are used, spray coating the interior of ducts with an effective minimum diameter of 12 inches is often unreliable because it is difficult to obtain a satisfactory coating and inspection for defects and voids. The interior of ducts 8 inches and smaller cannot be satisfactory brush painted. Dip coating is recommended instead. Ducts to be brush painted should not exceed a length of 5 or 6 feet to ensure proper coverage.

Carbon steel housing interiors and mounting frames must be painted to protect against corrosion and to facilitate cleaning and decontamination. Surfaces must be properly prepared, and primer and topcoats must be applied in strict accordance with the coating manufacturer's instructions in order to obtain the necessary wet-film and dry-film thicknesses. Film thicknesses should be tested during and after application. Surfaces to be coated should be abrasive blasted to a profile of 1 to 2 mils in accordance with the Society of Protective Coating (SPC) SSPC-SP-5/NACE No. 1, *Near White Metal Blast Cleaning.*[16] The prime coat must be applied within 2 to 3 hours, but in no case more than 8 hours, after surface preparation.

For exterior carbon steel surfaces, either hand or power tool cleaning (SSPC-SP-2[17] or SSPC-SP-3[18]) is usually sufficient. For certain conditions, such as highly humid atmospheres, exterior carbon steel surfaces should be prepared in accordance with SSPC-SP-5/NACE No. 1 instead. Both ambient and metal surface temperatures should be 10 to 20 degrees Fahrenheit (6.6 to 12.2 degrees Celsius) above the dew point before starting to paint and there must be adequate drying time (recommended by the coating manufacturer) between coats.

Quality assurance for nuclear grade coatings is discussed in ASTM AG-1, Section AA[1] and ASTM D3843[19], *Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities*. Other standards applicable to painting of nuclear facilities include ASTM D3911,[20] *Standard Test Method for Evaluating Coatings Used in Light Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions* and ASTM D3912-95,[21] *Standard Test Method for Chemical Resistance of Coatings Used in Light Water Nuclear Power Plants.*

Because the difficulty in applying nuclear grade coatings to carbon steel surfaces often results in unsatisfactory performance of the coatings in service, designers should seriously consider use of stainless steel for mounting frames and housings in corrosive environments or where frequent decontamination is required. While there are some special handling and fabrication rules associated in working with stainless steel, (particularly the highly polished surface finishes that must be protected from scratches during fabrication) the overall costs of painted carbon steel versus stainless are similar.

4.4 Man Entry Housing

4.4.1 General

Steel man-entry housings may be shop built or field fabricated. The trend is increasingly toward shop-built steel housings. Stainless steel is the most common material of construction; however, carbon steel also may be used. Aluminum and galvanized steel are not suitable.

4.4.2 Structural

The mounting frame is a statically indeterminate lattice that generally consists of a set of full-length members spanning the height or width of the bank (whichever is shorter), connected by cross members that are slightly shorter than the width of individual filter (adsorber) units. For design purposes, the frame may be considered as an array of simply supported, uniformly loaded beams. Experience has shown that, to obtain adequate frame rigidity, these beams (frame members) should deflect no more than 0.1 percent of their length under a loading equivalent to 1.5 times the maximum dirty filter pressure drop across the bank. This loading is determined from the following equation.

$$W = 0.036(1.5)\Delta pS \qquad (4.1)$$

Where

0.036 = conversion factor, inches water gauge (in.wg) to pounds per square inch (psi)
W = uniform beam loading, lb/in.
Δ p = pressure drop across bank, in.wg.
S = center to center spacing of filters on bank, inches

Assuming a center-to-center spacing of 26 inches for 24- x 24-inches filters, equation (4.1) reduces to:

$$W = 1.404\Delta p \qquad (4.2)$$

The value determined from equation (4.2) can be used in standard beam equations[8] to determine the minimum moment of inertia required. Knowing the minimum moment of inertia required for the member, the size and shape can be selected directly from the tables of structural shape properties given in the American Institute of Steel Construction (AISC) *Manual of Steel Construction*.[8] It can also be determined by calculating the moment of inertia of a built-up or cold-formed section. For ASTM A36 steel, the standard beam equation reduces to the following equations. [4]

Major frame members, $$I = \frac{\Delta pL^3}{1.59x10^6} \qquad (4.3)$$

Cross members, $$I = \frac{\Delta p}{149} \qquad (4.4)$$

Where

I = minimum moment of inertia[4] required, inches
Δp = maximum dirty – filter pressure drop across bank, in.wg.
L = length of member, inches (cross members assumed to be 22 inches long)

In addition to flexural strength, the frame for an exhaust or air cleanup filter system should also be capable of withstanding a shock loading of at least 3 psi across the bank without exceeding the elastic limit of the frame material. In most cases, members calculated using equations (4.3) and (4.4) will meet this requirement; nevertheless, they should be checked. The section moduli (S values) given in Part I of the AISC *Manual of Steel Construction*[8] then should be compared with the minimum values obtained from the following equations.

Major frame members, $S = \frac{13L^2}{f_a}$ *(4.5)*

Cross $S = \frac{6290}{f_a}$ *(4.6)*

Where

S = section modulus, in.^{3}
F_a = maximum allowable fiber stress, psi
L = length of member, inches (cross members assumed to be 22 inches long)

For ASTM A36 steel, these equations reduce to

Major frame members, $S = 0.00361L^2$ *(4.7)*
Cross members, S = 0.175 *(4.8)*

For built-up and cold-formed members, the minimum *S* value calculated from these expressions is compared with the value for the member calculated from the formula.

$$S = \frac{I}{c} \tag{4.9}$$

Where

S = section modulus, in.^{3}
I = moment of inertia[8] of the section, inches
c = distance from neutral axis of member to extreme fiber, inches

If the *S* values obtained from the AISC manual or calculated by using equation (4.9) are greater than the values calculated from equations (4.5) through (4.8) (as applicable), the members selected are satisfactory.

Note: The above equations are for illustrational purposes only. The designer is responsible for verifying this information.

4.4.3 Structural Design

Structural design of housings for both Engineered Safeguard Feature (ESF) air cleaning units and non-ESF units must consider the service conditions the housing may experience during normal, abnormal, and accident plant conditions. The design requirements for determining housing plate thickness, stiffness, spacing, and size are presented in the ASME ASME AG-1, Section AA.[1]

Housing design should consider the following load criteria.

- Additional dynamic loads,
- Constraint of free end displacement loads,
- Dead weight,

- Design pressure differential,
- Design wind,
- External loads,
- Fluid momentum loads,
- Live load,
- Normal loads,
- Normal operating pressure differential,
- Seismic load, and
- System operational pressure transient.

Stress criteria limits are given in ASME AG-1, Section AA.[1] The maximum deflection for panels, flanges, and stiffeners for the load combination should be the lesser of the two values derived as shown below.[14]

4.4.3.1 Criterion 1

- Plate or sheet: 1/8 inch per foot of the maximum unsupported panel span in direction of airflow, but not more than 3/4 inch
- Stiffeners and flange connections: not to exceed 1/8 inch per foot of span, but not more than 3/4 inch
- Flange connection to dampers and fans: 1/360th of the span, but not to exceed 1/8 inch

4.4.3.2 Criterion 2

Deflections shall be limited to values that will not cause:

- Distortion of the airflow path cross-section, resulting in unacceptable increase in system pressure;
- Damage to safety-related items such as instrumentation or other safety-related equipment or accessories;
- Impingement of deflected elements on adjacent services such as equipment, pipe, cables, tubing, etc.;
- Loss of leaktightness (in excess of leakage limit);
- Buckling (refer to ASME AG-1, Section AA-4000)[1]; or
- Functional failure of components attached to ductwork (e.g., instrument lines, etc.).

4.4.4 Mounting Frame Configuration

The basic type of mounting frame construction is face-sealed (i.e., the filter seals to the outermost surfaces of the frame members by means of gaskets glued to the front surface or to the flange around the face of the filter unit) as shown in **Figure 4.11**. The face-sealed configuration is generally recommended for conventional-design HEPA filters and Type I adsorber cells.[22]

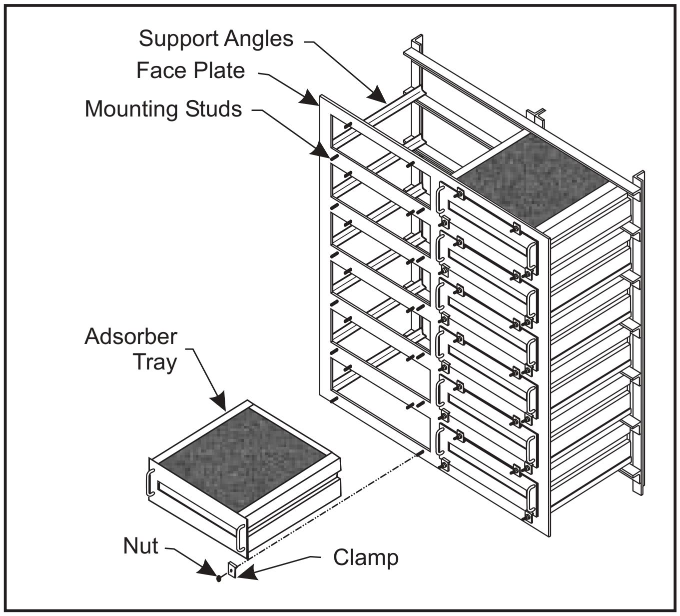


Figure 4.11 – Adsorber Gasket Seals Against Mounting Frame Face Plate

A minimum face width of 4 inches is recommended for major and cross members of face-sealed HEPA filter frames. This allows 1-inch-wide filter-seating surfaces to compensate for any misalignment of the filter during installation and a 2-inch space between filters, horizontally and vertically. It also provides adequate room for handling (personnel replacing contaminated filters will probably have to wear double gloves), using power tools or torque wrenches during filter change, and manipulating a test probe between units.

Face widths of frame members for installing Type I (pleated-bed) adsorber cells are the same as those for HEPA filters. Face widths of frame members for installing Type II (tray-type) adsorber cells may be narrower, since handles are provided on the front of the trays to facilitate installation. To provide interchangeability for cells of different manufacture, Institute of Environmental Sciences and Technology (IEST) CS-8[22] recommends the following mounting frame dimensions for the installation of Type II cells (see IEST CS-8[22] for standard cell dimensions):

- Openings: 6.37 by 24.188 inches (+0.063 inches, -0 inches),
- Space between openings: vertical, 2.5 inches minimum; horizontal, 2 inches minimum.

Figures 4.12 and 4.13 show a built-up all-welded Type II adsorber cell mounting frame made from rectangular structural tubing; note that a structure is required behind the frame openings to support the weight of the cells (approximately 100 pounds each). Because the length of Type II cells may be different for each manufacturer, the support structure should be deep enough to take a cell up to 32 inches long to permit interchangeability of cells of different manufacture.

Figure 4.12 – Adsorber Tray Mounting Frame ("X" Cross Units Are for Test Gas Injection)

Satisfactory mounting frames may be made from rolled structural shapes or rectangular structural tubing. **Figure 4.14** shows a HEPA filter frame made from 4- × 4-inch structural tubing that meets all structural requirements. Rolled structural shapes for building mounting frames are given in **Table 4.1**. Square structural tubing frames for HEPA filters should be made from rectangular tubing with a face width of at least 4 inches; structural tubing frames for Type II adsorber cells may have narrower face widths.

4.4.5 Frame Fabrication – Gasket-Type Filter and Adsorber

Filter mounting frames should be shop-fabricated if practicable because it is nearly impossible to avoid misalignment, warping, and distortion in field fabrication. Shop fabrication is less costly than field fabrication and permits better control over assembly, welding, and dimensional tolerances. Care must be taken to avoid twisting or bending the completed frame during handling, shipping, and field installation. For proper performance and maintenance of installed filters, dimensional and surface-finish tolerances must be tight and rigidly enforced. **Table 4.2** gives minimum tolerances for the installed frame. Welds on the filter-seating side of the frame must be ground flat, smooth, and flush.

Only welders qualified in accordance with the American Welding Society (AWS) D1.1, *Structural Welding Code-Steel* [10] or Section IX of the ASME *Boiler and Pressure Vessel Code* [23] should be permitted to make welds on HEPA filter and adsorber mounting frames. Both seal and strength welds should be visually inspected by a qualified inspector under a light level of at least 100 foot candles on the surface being inspected. In addition, liquid penetrant (ASTM E165)[24] or magnetic particle inspection (whichever is applicable for the base material being inspected) of the seal welds between frame members is recommended.

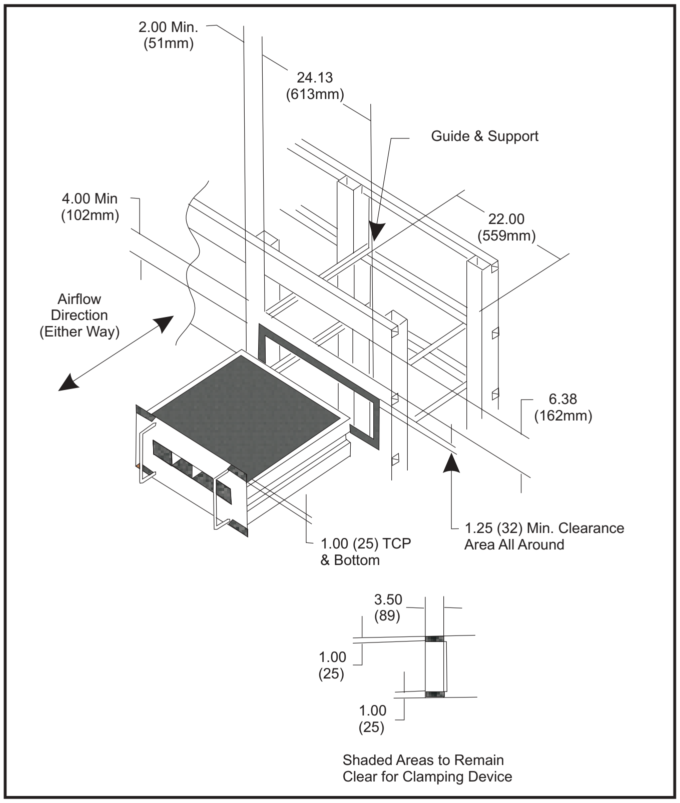


Figure 4.13 – Adsorber Mounting Frame with Carbon Trays

Figure 4.14 – Filter Mount

Table 4.1 – Minimum-Cost Structural Members for 24-by-24 HEPA Filter and Type I Adsorber Mounting Frames (maximum pressure drop to 12 in.wg)

Number of 1,000 cfm Units High	**Principal Member[a] I-beam**			**Cross Member Channel (span = 22 in.)**	
	Span[b]	**Size (in.)**	**lb./ft.**	**Size (in.)**	**lb./ft.**
2	4 ft. 8 in.	4 × 4 M	13	4 × 1¾	5.4
3	6 ft. 10 in.	4 × 4 M	13	4 × 1¾	5.4
4	9 ft. 0 in.	4 × 4 M	13	4 × 1¾	5.4
6	13 ft. 4 in.	6 × 4 B	16	4 × 1¾	5.4
8	17 ft. 8 in.	8 × 4 B	10	4 × 1¾	5.4
10	22 ft. 0 in.	10 × 4 5/8	25.4	4 × 1¾	5.4

[a] Principal members should span the shortest dimension of the bank.
[b] Span = [(number of filters) (26) = 4] inches
Note: This table is intended to provide information only. The designer is responsible for verifying this information.

Table 4.2 – Recommended Tolerances for HEPA Filter and Adsorber Mounting Frames

Alignment	Perpendicularity: maximum offset of adjoining members 1/64 inch/foot or 1/16 inch, which ever is greater. Planarity of adjoining members: 1/64 inch maximum offset at any point on the joint.
Flatness	Each filter surface shall be plane within 1/16 inch total allowance. Entire mounting fixture shall be plane within 1/2 inch total allowance in any 8-by 8-foot area.
Dimensions	Length and spacing of members shall be true within +0, -1/16 inch.
Surface-finish	Filter seating surfaces are 125 microinch (μin.) AA maximum, in accordance with USA Standard B46.1; pits, roll scratches, weld spatter, and other surface defects shall be ground smooth after welding, and ground areas shall merge smoothly with the surrounding base metal; waviness not exceeding 1/32 inch in 6 inch is permissible, as long as the overall flatness tolerance is not exceeded.

Note: This table is intended to provide information only. The designer is responsible for verifying this information.

4.4.6 Filter Clamping and Sealing

HEPA filters and adsorber cells must be carefully sealed to the mounting frame (**Figures 4.15 and 4.16**) to achieve the required low penetration leakage rates and to allow easy replacement. Except for the fluid-seal design described at the end of this section, sealants are not a satisfactory substitute for gaskets. Experience in clean rooms and contaminated exhaust and air cleanup applications has shown that flat, closed-cell, neoprene gaskets, ASTM D1056[25] grade 2C3, give the most satisfactory seal for high-efficiency filters, adsorbers, and demisters. There is no advantage in using shaped (molded) gaskets; not only are they more expensive, but research has shown that they are prone to leaks.[26, 27] Gaskets that are too soft (i.e., are less than grade 2C3) take an excessive compression set that may permit leakage when there is relaxation of the clamping bolts. Gaskets that are too hard (i.e., harder than grade 2C4) require such high clamping loads to effect proper scaling that the filter itself can be distorted or damaged.

As little as 20 percent gasket compression is needed to effect a reliable seal when the thickness of the gasket is uniform to within ±0.01 inches and the seating surface of the mounting frame is plane to within ±0.01 inches[16] However, these tolerances are much too restrictive for economical construction, and experience has shown that it is usually necessary to compress a 2C3 gasket at least 80 percent to effect a reliable seal over long periods. Eighty-percent compression requires a loading of approximately 20 pounds per square inch of gasket area, or a total clamping load of about 1,400 pounds for a 24- by 24-inch filter unit. The recommended procedure for installing filters under nonhazardous conditions is to initially torque the clamping bolts to produce 50 percent gasket compression and then retorque them 1 or 2 weeks later to a total compression of about 80 percent. In a radioactively contaminated filter system, replacement can be a hazard to personnel and to the filters and/or adsorbers installed in the system. Under such conditions, one entry is advised. One option is to manually compress the filter gasket to an estimated 50 to 80 percent. A spring-loaded hold-down (**Figure 4.17**) is another option used at some U.S. Department of Energy (DOE) sites. Torsion bar clamps designed to exert the proper clamping forces are a third option.

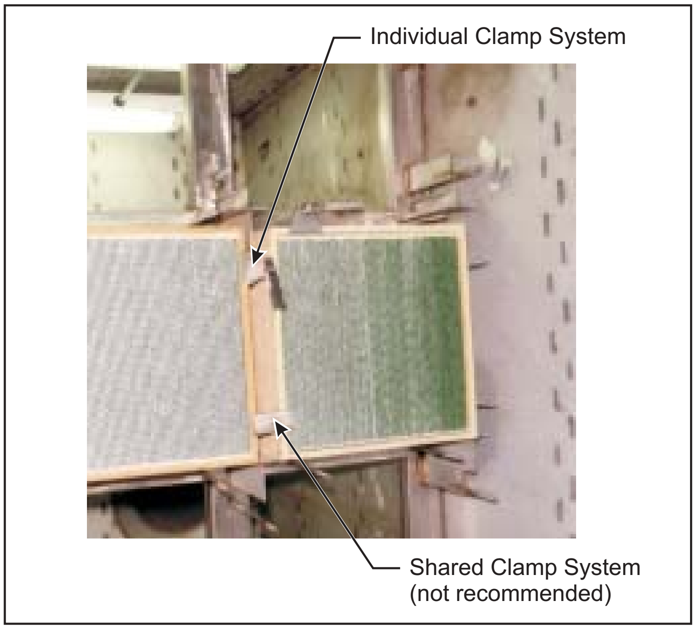


Figure 4.15 – HEPA Filter Mounting Frame (Showing Two Clamp Designs)

Gaskets that are too thin may not give a reliable seal using the recommended frame tolerances given in Table 4.2, whereas those that are too thick may be unstable and tend to roll or pull off the flange of the filter case as they are compressed, perhaps to the extent that sections may be extruded between the case and mounting frame and produce a serious air leak. Recommended gasket sizes are 1/4 to 3/8 inch thick by 3/4 inch wide and 1/4 to 3/8 inch thick by 5/8 inch wide. Gaskets must be glued to the filter element rather than to the mounting frame because they must be replaced with each filter change. A sealant such as silicone could be applied lightly to the filter gasket. Residue must be removed before installing new filters as the sealant may be contaminated, making disposal more difficult. Gaskets should have cut surfaces on both faces because the "natural skin" produced by molding sometimes tends to bridge discontinuities or defects in the seating surface, and because the silicone mold-release compounds used in the manufacture of sheet neoprene prevent proper adhesion of the gasket to the filter case.

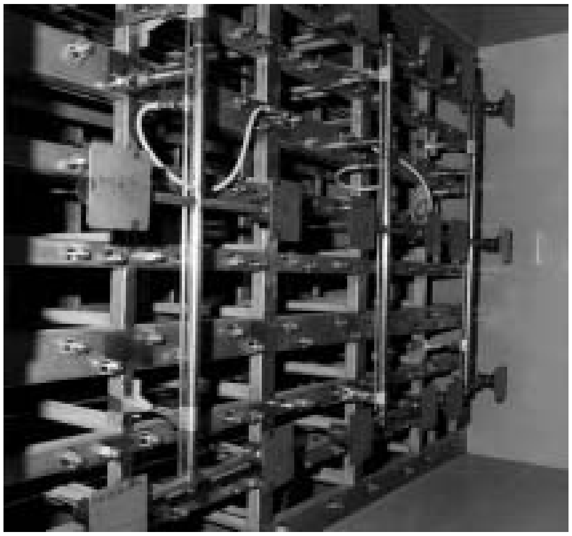


Figure 4.16 – Absorber Mounting Frame with Test Section Manifold

Filter units and adsorber cells must be clamped to the mounting frame with enough pressure to enable the gasket to maintain a reliable seal when subjected to vibration, thermal expansion, frame flexure, shock, overpressure, and widely varying conditions of temperature and humidity that can be expected in service. Clamping devices must function easily and reliably after long exposure to hostile environments. In addition, they must be capable of easy operation by personnel dressed in bulky protective clothing, gloves, and respirators (or full-face gas masks) while working in close quarters. Experience has shown that a simple nut-and-bolt system (Figure 4.17) gives satisfactory service under these conditions. Nut-and-bolt clamping, however, entails removal and handling of a large number of nuts, and this procedure can be a problem during a filter change in a highly radioactive system. However, clamping systems that provide the required torque and gasket compression without loose parts are highly recommended. Any system that achieves the desired clamping torque is acceptable. Examples of Type II adsorbent filter clamping systems are shown in **Figure 4.18**. Eccentric, cam-operated, over-center, or spring-loaded latches, and other quick-opening latches, such as the

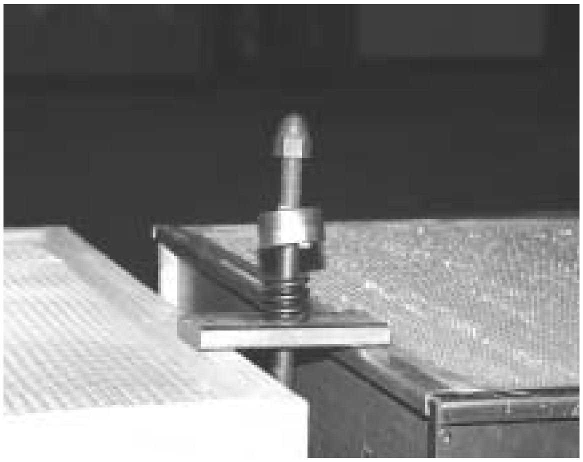


Figure 4.17 – Filter Hold-down-torque Spring Design

window latch design, are not recommended for clamping high-integrity components such as HEPA filters and adsorber cells.

Magnitude and uniformity are major requirements for filter and adsorber clamping systems. At least four, and preferably eight, pressure points are required for HEPA filters and demisters. Individual clamping of each filter unit is preferred. Shared clamping, in which holding clips (or bolts) bear on two or more adjacent filters or adsorber cells, has been widely used because it is less expensive than individual clamping and requires manipulation of fewer loose items within the confines of the housing during a filter change. However, shared clamping limits the ability to adjust or replace individual filters in the bank without upsetting the seals of adjacent units. In the improved system shown in Figure 4.18, no clip bears on more than two filter units, and the seals of only four surrounding filters are upset when replacing a filter unit. This common hold-down design is not recommended. The clamping systems shown in Figures 4.16 and 4.17 have the advantage that clips and nuts do not have to be removed to replace filters, since the clips can be rotated out of the way after the nuts have been loosened. A pressure distribution frame is shown in **Figure 4.19**. Although this type of clamping system has been used with good success in nuclear and nonnuclear applications, many inplace test personnel object to it because of the extensive leak-chasing often required before a satisfactory inplace test can be achieved. Leak-chasing also occurs in multi-filter common clamping when, on adjusting or replacing one filter, the seals of surrounding filters are disturbed, resulting in new leaks that have to be corrected. This process is time-consuming, costly, and, when conducted in a contaminated housing, can result in lengthy exposure of personnel.

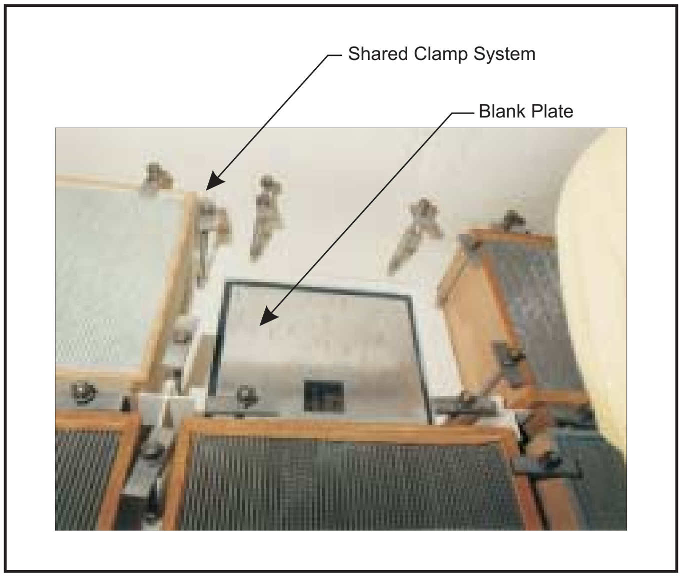


Figure 4.18 – HEPA Filters Mounting Frame with Blanking Plate Installed for Filter Change

Because of their weight, eight pressure points are desirable for clamping Type I (pleated-bed) adsorber cells. For clamping Type II (tray-type) cells, two pressure points on the top and two on the bottom edges of the front plate are needed for proper sealing, with individual clamping, as shown in Figure 4.15. Clamping on the short sides only is not adequate. As Figure 4.18 shows, captive nuts reduce the number of loose items that must be manipulated within the confines of the filter housing during filter or adsorber replacement, but they must be prevented from rotation when positioned for withdrawal of the filter.

The minimum bolt size recommended for individually clamped filters is 3/8-16-UNC, but 1/2-11-UNC or 5/8-11-UNC bolts are less prone to damage. For Type I adsorbers, 5/8-11-UNC bolts are necessary. The nuts and bolts of the clamping system must be made of dissimilar materials to prevent galling and seizing. Bolting materials and clips must be corrosion resistant. Stainless steel (300 series) bolts with brass nuts are frequently used. Springs, if used, should also be made from a PPH grade of stainless steel if they are to resist corrosion and relaxation over a period of service.

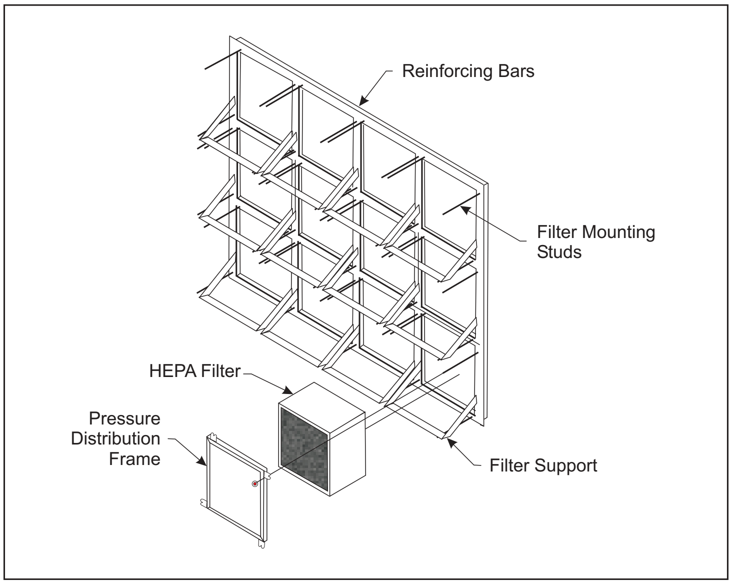


Figure 4.19 – HEPA Filter Mounting Using Pressure Distribution Frame Design Filter Hold Down

The design knife-edge type of framing and sealing (**Figure 4.20**),[28] employs a special cross-section-extruded- framing member which presents a knife-edge-sealing surface to the filter element. The filters have a channel filled with a nonflowing, nonvulcanizing, silicone polymer around the sealing edge that fits into the knife edge of the mounting frame to form a positive seal between filter and frame. Rigidity of the mounting frame is not a consideration, since frame flexure cannot affect the seal or the filter. The clamping pressure needs to be sufficient only to hold the filter unit in place. If the filters are installed on the downstream side of the frame, clamping must be sufficient to resist displacement of the filter under normal operating filter resistance and the pressures produced by shock loadings in the system.

4.4.7 Filter Support

A cradle or other support for the filter element as it is moved into position on the frame is a desirable feature from a maintenance standpoint. The cradle should not obscure any more of the filter-to-frame interface than necessary to avoid interference with inspection as the filter is installed. The support shown in Figure 4.19 is better because it obscures less of the gasket-frame interface. In some installations, filters have been supported on the bottom clamping bolts, a practice that risks damage to the threads of the clamping bolts and is not recommended.

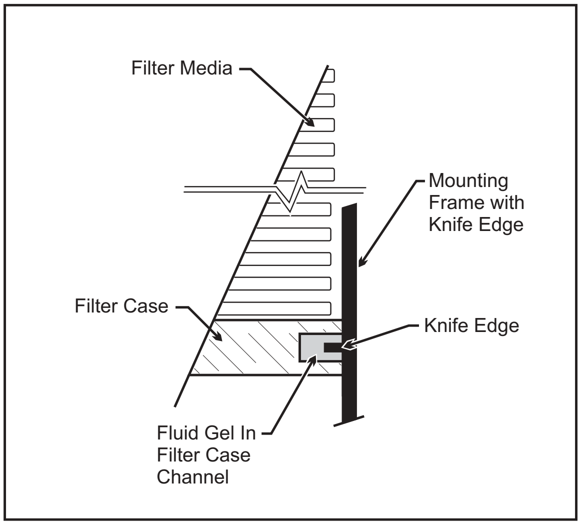


Figure 4.20 – Fluid Seal

4.4.8 Size and Arrangement of Filter and Adsorber Banks

The size (nominal airflow capacity) and orientation of filter banks (vertical or horizontal), the location of filters on the bank (upstream or downstream side), and the floor plan and height of the bank all affect the reliability, performance, maintainability, and testability of the air cleaning system. Savings gained by designing for minimum space and materials can be wiped out many times over by the higher operational, maintenance, and testing costs that will result from higher pressure drop and cramped working space in the filter housing.

4.4.9 Vertical Filter Banks

Vertical banks with horizontal airflow are preferred in contaminated exhaust systems because the filters are more favorably oriented with respect to ease of handling, mechanical strength of the filters, and collection of condensate. On the other hand, the pleats of Type I adsorber cells and the beds of Type II cells must be installed horizontally to avoid adsorbent settling in the cells. Before designing a horizontal filter bank with vertical airflow, filter/adsorber components should be validated for performance in this application/design. In addition, the design should include provisions for filter installation and removal.

4.4.10 Location of Filters on Mounting Frame

No clear-cut preference can be justified for mounting filters on either the upstream or the downstream side of the mounting frame. Both methods have been used successfully and the advantages and disadvantages of each are listed below.

4.4.10.1 Upstream Mounting of Filters

Advantages:

The filters are withdrawn into and handled within the contaminated side of the system during a filter change. No contaminated materials are brought into the clean side of the system, so there is more complete separation of the clean and dirty sides of the system.

Disadvantages:

- Personnel have to work within a potentially contaminated zone during a filter change.
- It is possible that contamination can be tracked or carried out of the contaminated zone by workmen, unless the filter change is carefully planned and executed.
- The filter clamping devices are located in the dirty side of the system where they are most exposed to corrosion and dirt.
- Contaminated material may accumulate on the horizontal surfaces of the filter case and may dislodge during removal.

4.4.10.2 Downstream Mounting of Filters

Advantages:

- Filters are withdrawn into and handled within the clean side of the system, thereby reducing the likelihood of tracking or carrying contamination into the building during a filter change.
- Filter clamping devices are located on the clean side of the system where they are less subject to corrosion.
- Leak-scanning of installed filters is more sensitive. If there are gasket or casing leaks, the driving force of air entering the filter forces the test aerosol through the leak, and they are readily detected. With upstream mounting, on the other hand, any test aerosol that goes through a leak in a gasket or filter case mixes with the air and test aerosol passing through the opening in the mounting frame, thus obscuring

the leaks. Although the existence of a leak may be disclosed by a test, the location of the leak cannot be easily determined by probing.

- Only the upstream face of the filter is contaminated during operation. The outer surfaces of the filter case and the downstream face of the filter pack are not usually contaminated.

Disadvantages:

- The contaminated filters must be withdrawn into the clean side of the system in a filter change. This disadvantage can be offset by "fixing" (locking down) the contaminated dust by spraying the upstream side of the filter pack with paint or acrylic spray or by taping cardboard over the upstream face of the filter. However, this procedure requires personnel to enter the contaminated chamber of the housing, and the possibility still exists of dislodging contaminated dust into the clean side of the system, either from the filter itself or from the edges of the frame opening (which is exposed to contaminated air during operation).

- Filters have been mounted on both sides of a mounting frame in some installations. This is not recommended. A cardinal rule in contaminated exhaust systems is that no credit is granted for untested and untestable filters. Such mounting precludes testing of both filters. Therefore, although double mounting may provide two sets of filters, the operator cannot take credit for two-stage filtration or series redundancy. This design has been shown to fail in a fire. The upstream filter blows out when plugged with smoke particles and impacts the filter downstream, causing it to blow out also.

4.4.11 Size of Banks

A nominal system capacity of 30,000 cfm has been recommended by DOE and the U.S. Nuclear Regulatory Commission (NRC) for any filter or adsorber bank. For larger systems, this limit requires the system to be segmented into two or more smaller subsystems, each contained in an individual housing and having an installed capacity of 30,000 cfm or less. The purpose of this requirement was to facilitate maintenance and inplace testing, to improve control in the event of a system upset, and to enhance the reliability of the total system. A 30,000-cfm bank was considered the largest that can be tested inplace conveniently. By breaking the system into two or more air cleaning units, testing and filter replacement can be conducted in one unit while the other unit remains online. NRC Regulatory Guide 1.52 recommends such redundancy for ESF air cleaning systems in reactors.[29] The designer may also choose to segment a system into units of substantially less than 30,000 cfm when redundancy is desired to achieve advantages of control, maintainability, and testability. The development of higher-flow aerosol generators and manifold inplace test systems has allowed larger filter banks than the recommended 30 filters. The use of 1,500-cfm filters allows higher-capacity systems without increasing the physical size of the bank. Inplace testing and maintenance is the determining factor.

4.4.12 Arrangement of Banks

Arrangement of filters on a mounting frame influences operating performance and maintenance. Where possible, banks should be laid out in an array of three filters high or nine Type II adsorber cells high. When floor space is at a premium, the bank may be arranged with one 3-high array above another, with a service gallery between, as shown in Figures 4.6 and 4.7. Thus, an 18,000-cfm bank might be arranged in an array 6-wide by 3-high or 3-wide by 6-high, with a service gallery between the third and fourth tiers. The arrangement of a 24,000-cfm bank in a 6-wide by 4-high array would be undesirable. A better arrangement is an array 8-wide by 3-high or, if floor space is at a premium, two 4-wide by 3-high arrays, one above the other, separated by a service gallery. In no case should filter changing require the use of temporary ladders or scaffolding. To require a workman dressed in bulky protective clothing (with sight obscured by a respirator or gas mask and sense of feel dulled by double gloves) to manipulate a ladder or scaffold within the confines of a filter house is an open invitation to personnel injury and filter damage (see Figure 8.9, which shows HEPA filters testing). Based on the 95th-percentile man, the maximum height at which a man can operate hand tools effectively is 78 inches, and the maximum load he can handle at a height of 5 feet or more is 40 pounds, which is the approximate weight of a clean HEPA filter. Therefore, provision for access to the higher tiers of filters is necessary. In fact, ASME AG-1, Subsection HA,[1] requires that a permanent platform be installed to access filters to access filters above 6 feet.

Filter banks should be rectangular. The use of odd-shaped banks to limit installed filter capacity to calculated system airflow requirements increases construction costs significantly. By filling out the rectangle, construction costs will be less. In addition, if all nine spaces are filled with filters, operating costs may also be reduced because the additional filters permit operation at a lower flow rate per unit resulting in longer filter life and reduced filter-change frequency, as discussed in Chapter 2. For the purposes of laying out adsorber banks, three Type II (tray) adsorbers will fit vertically into the space occupied by one 24- by 24-inch HEPA filter.

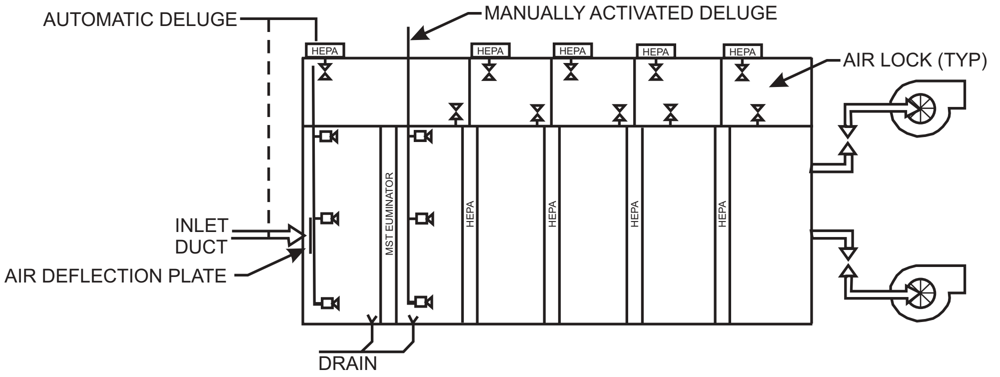
4.4.13 Floor Plan of Filter Banks

The plenum floor plan of a vertical filter bank varies with the application of the system. The location of filters and/or adsorbers is shown in **Figures 4.21 through 4.28**. Judicious configuration of banks can often reduce pressure losses in the system and bring about more uniform dust loading of filters, thereby equalizing the utilization of the filters installed in the banks.

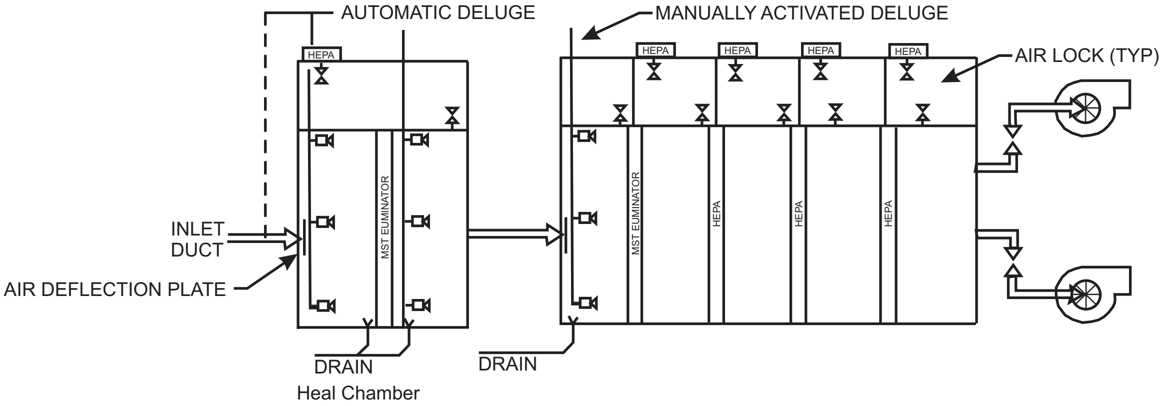
The procedures required for construction and operational maintenance must be considered early in the planning stages. Adequate clearances for access must be maintained at turning points and between the bank and the nearest obstruction. Passageways both between the banks and between the banks and the housing wall must be wide enough for welders to operate effectively and for workmen, dressed in bulky clothing, to get in to change filters (see **Figures 4.29 and 4.30**). Both welders and workmen will have to kneel or stoop to get to the bottom tier. A 95th-percentile man in a kneeling position requires a minimum clearance of 36 inches from the face of the filters to the nearest obstruction, excluding withdrawal space for the filter unit itself. A minimum clearance of 40 inches is therefore recommended between the face of one bank and the nearest obstruction.

4.4.14 Steel Housings

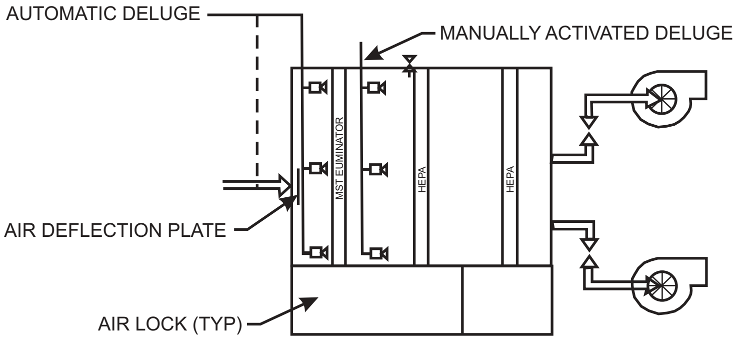
Design practices used for conventional air conditioning and ventilation system ductwork and equipment casings are not adequate for high-reliability, high-efficiency contaminated exhaust and air cleanup systems. Experience has shown that, under system upset and shutdown conditions, housing leaks can result in the escape of contamination to clean areas. Even with fans operating, reverse leakage of particles from the low-pressure side of a system (i.e., the interior of the housing or duct) to the high-pressure side (i.e., the occupied area of the building) can sometimes occur because of dynamic and aspiration effects. Out-leakage may also occur when the system is shut down. Filter housings for contaminated exhaust service must be able to withstand negative pressures without damage or permanent deformation at least up to fan cutoff, which may be equal to 20 in.wg. in many systems. A pressure differential of 2 in.wg. between the inside and outside of a housing produces a load of more than 1,000 pounds over every 10 square feet of the housing wall. If the filters are operated to economical pressure drops, the housing may have to withstand 10 or more times this load without appreciable deflection. Pulsation and vibration may aggravate the condition. In addition, the housing should be able to withstand design shock loads without damage.



One Stage Demister Plus Four Stages HEPA Filters



One Demister Stage Four Stages HEPA Filters



One Stage Demister Plus Two Stages HEPA Filters

Figure 4.21 – Typical Filter and Demister Layouts

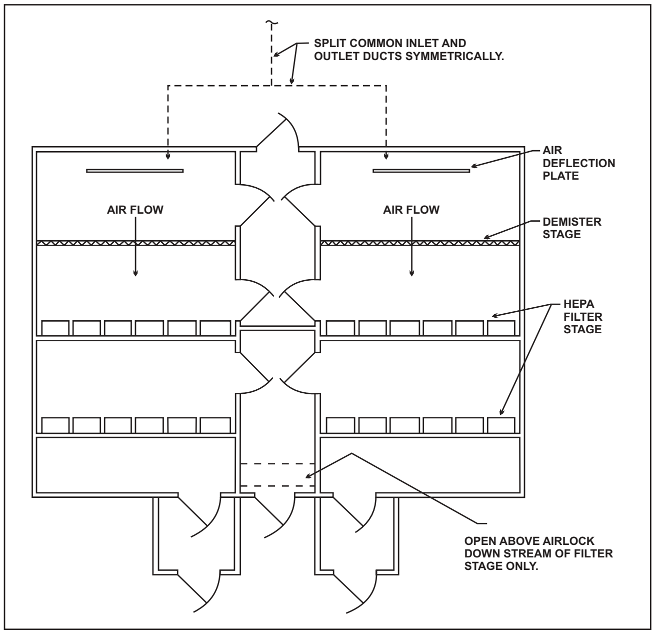


Figure 4.22 – Plan Section of "Double" Plenum

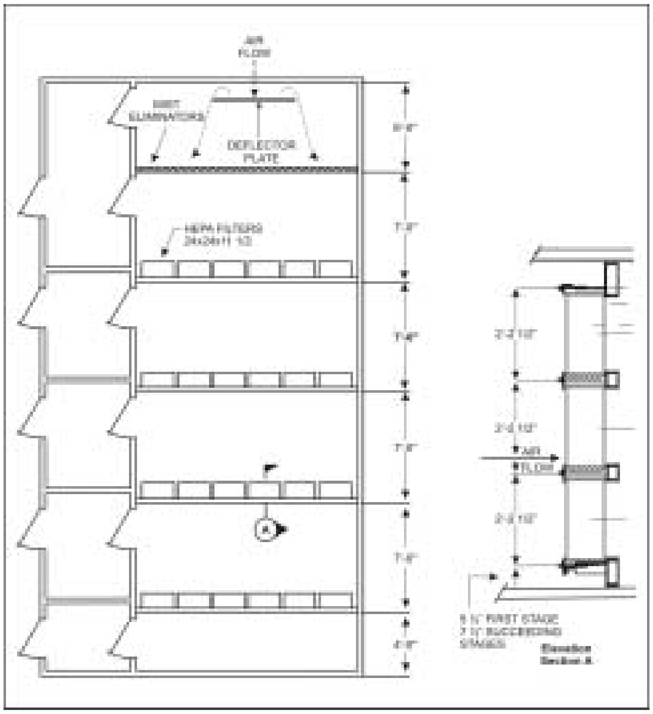


Figure 4.23 – Plan Section of "Single" Plenum

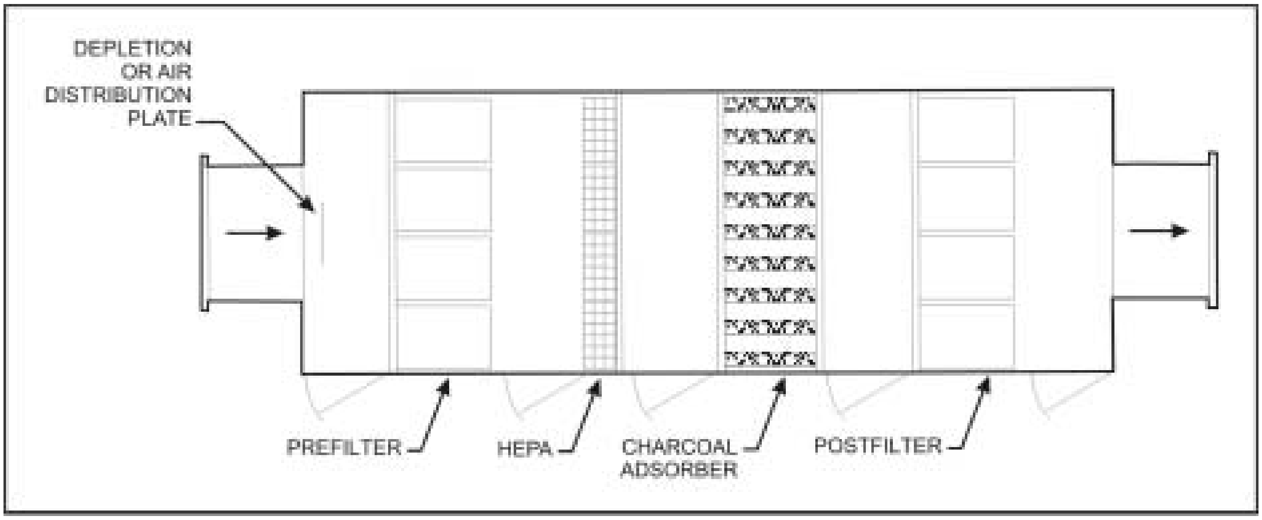


Figure 4.24 – Common Configurations Requiring Test Manifolds (Plan A)

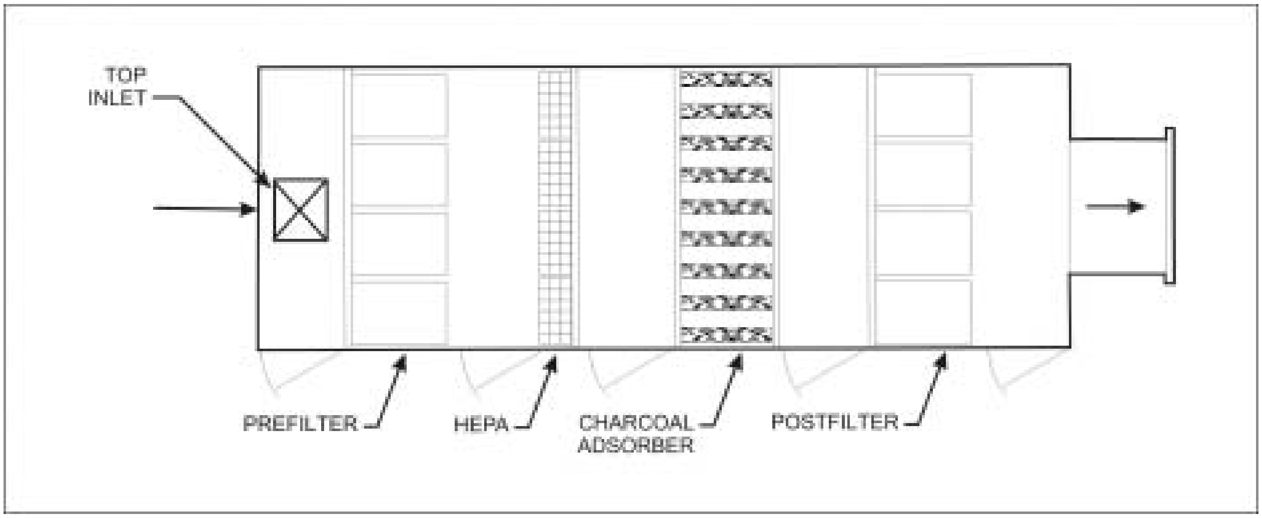


Figure 4.25 – Common Configurations Requiring Test Manifolds (Plan B)

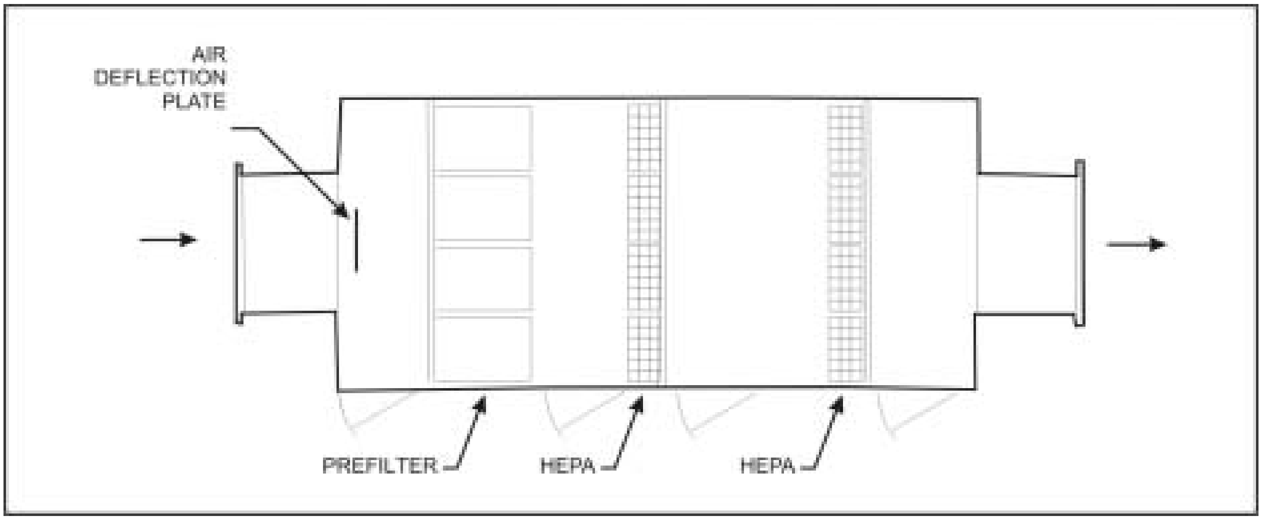


Figure 4.26 – Common Configurations Requiring Test Manifolds (Plan C)

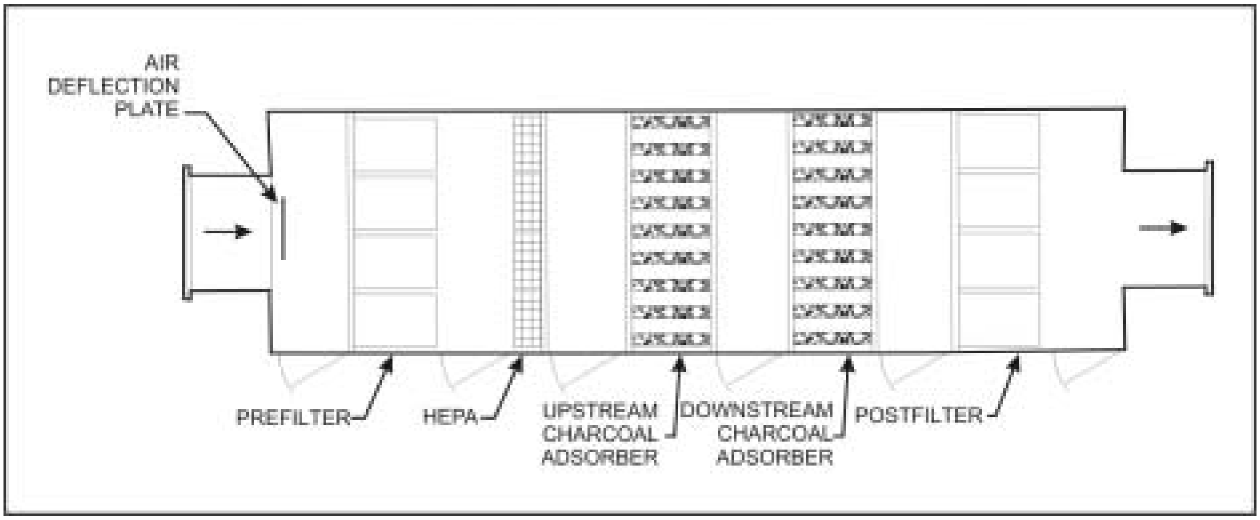


Figure 4.27 – Common Configurations Requiring Test Manifolds (Plan D)

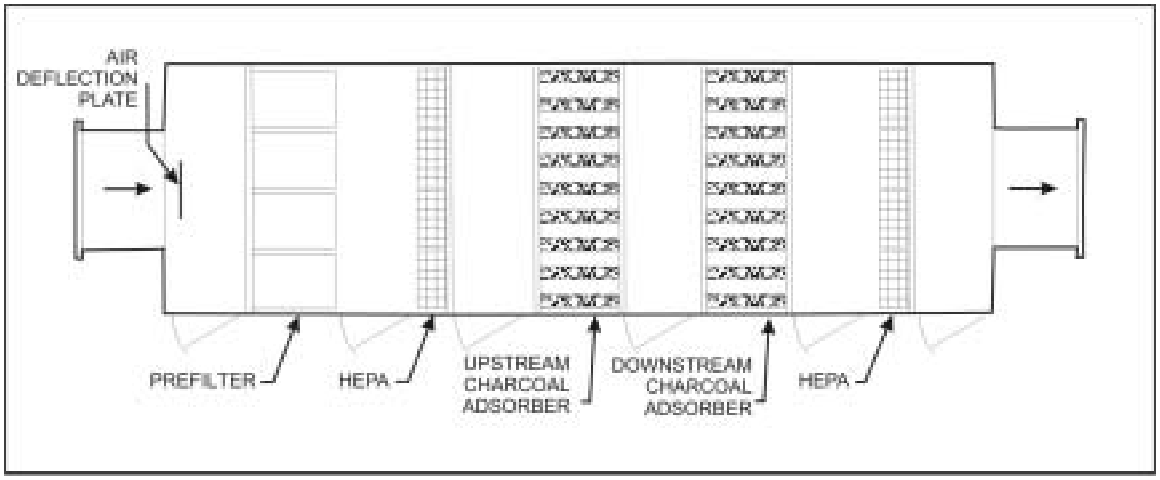


Figure 4.28 – Common Configurations

Figure 4.29 – HEPA Filter Mounted on Upstream Side of Mounting Frame Filter Replacement

Figure 4.30 – Blanking Plate Being Installed On Downstream Side of Mounting Frame

The references cited in Section 4.4.5 for the design, fabrication, and welding of mounting frames are also applicable to steel housings. Housings should be of all-welded construction, with bolted flange or welded inlet and outlet connections to the ducts and fans. **Table 4.3** gives minimum sheet metal thicknesses for sheet steel housings, and **Table 4.4** gives minimum moments of inertia for steel reinforcing members. Sheet metal thicknesses in Table 4.4 are based on a maximum deflection of 1/4 inch per linear foot at a pressure differential between the interior of the housing and atmosphere equivalent to 1.5 times the maximum pressure at fan cutoff. The moments of inertia for reinforcing members listed in Table 4.4 were selected to avoid exceeding the allowable stress of the steel. Members up to 20 inches long were considered to be uniformly loaded beams with fixed ends, whereas members longer than 20 inches were considered to be uniformly loaded beams with simply supported ends. The sheet-metal thicknesses in Table 4.3 are given in U.S. gauge numbers for sheet and fractional inches for plate.

Table 4.3 – Minimum Sheet-Metal Thicknesses[a] for Welded Steel[b] Filter Housings under Negative Pressure

Dimensions of Largest Unsupported Panel (in.)		**Thickness[c] (U.S. gauge for sheet, fractional in. for plate) for negative pressure (relative to outside)**					
Long Side[d]	**Short Side**	**4 in.wg.**	**8 in.wg.**	**12 in.wg.**	**20 in.wg.**	**1 psi**	**2 psi**
54 (2)	12	18	18	14	16	14	11
	24	18	14	11	12	8	1/4
	36	16	12	8	11	1/4	3/8
	48	14	12	6	8	1/4	3/8
80 (3)	12	18	16	14	16	14	11
	24	18	14	11	12	8	1/4
	36	16	12	6	11	1/4	3/8
	48	14	12	6	8	1/4	3/8
106 (4)	12	18	16	16	14	14	11
	24	18	14	12	11	8	1/4
	36	16	12	8	6	1/4	3/8
	48	16	10	6	1/4	3/8	

[a] Based on flat plate edges held but not fixed (*Roark's Formulas for Stress and Strain*),[30] and maximum deflection of 0.25 inch per foot between reinforcements.

[b] 30,000 to 38,000 psi yield strength.

[c] Metal thickness less than No. 18 U.S. gauge are not recommended because of welding problems.

[d] Length based on 2-inch spacing between 24- × 24-inch filter units; the numbers within parentheses denote number of filter units. The metal thicknesses are adequate for panel lengths within ±10 inches of the length shown.

Note: This table is intended to provide information only. The designer is responsible for verifying this information.

Housings installed inside a reactor confinement may experience a pressure lag during rapid pressurization of the confinement following a major accident. Unless the housings are equipped with pressure-relief dampers, this lag could result in a pressure differential between the housing and confinement substantial enough to collapse the housing.

Reinforcing members should be spaced to minimize vibration and audible drumming of the housing walls, which can be transmitted through the system. Reinforcements should be installed on the outside of the housing, when possible, to eliminate interior ledges and projections that collect dust and constitute hazards to personnel working in the housing (**Figure 4.31**). All sharp corners, welds, weld spatter, and projections inside the housing should be ground smooth. The housing design must minimize cracks and crevices that are difficult to clean and that may collect moisture that can cause corrosion.

Mastics and caulking compounds, including silicone-based, room-temperature vulcanizing (RTV) sealants, deteriorate in service and should not be used for sealing between panels and sections of a contaminated exhaust housing. Lock seams, rivets, and bolts used in conventional construction for joining panels do not produce leaktight joints. When bolted flange joints are used between the housing and ducts, 1.5- × 1.5- × 0.25-inch-angle flanges with ASTM D1056, grade 2C5 or 30-40 Shore-A durometer neoprene gaskets are minimum requirements.[25] A maximum bolt spacing of 4 inches is recommended for flanges.

Shop fabrication of housings is recommended over field fabrication because of the superior workmanship and control possible under shop conditions. These housings are built in sections and assembled in the field. Field joints for such housings should be seal welded, since mastic and gasket-sealed joints cannot be considered reliable for permanent installations.

Table 4.4 – Recommended Minimum Moments of Inertia for Selecting Reinforcing Members for Steel Filter Housings under Negative Pressure [a, b]

Reinforcement		Moment of inertia (in.^{4}) [c] for negative pressure (relative to outside)					
Length [d] (in.)	**Spacing (in.)**	**4 in.wg.**	**8 in.wg.**	**12 in.wg.**	**20 in.wg.**	**1 psi**	**2 psi**
54 (2)	12	0.04	0.04	0.04	0.04	0.04	0.08
	24	0.04	0.04	0.04	0.06	0.08	0.16
	36	0.04	0.04	0.05	0.09	0.12	0.24
	48	0.04	0.05	0.07	0.12	0.16	0.32
80 (3)	12	0.04	0.04	0.05	0.08	0.11	0.21
	24	0.04	0.06	0.09	0.16	0.21	0.43
	36	0.05	0.10	0.14	0.24	0.32	0.63
	48	0.06	0.13	0.19	0.32	0.42	0.86
106 (4)	12	0.04	0.09	0.13	0.22	0.30	0.60
	24	0.09	0.18	0.26	0.44	0.60	1.19
	36	0.13	0.27	0.39	0.66	0.90	1.79
	48	0.18	0.36	0.52	0.88	1.19	2.38
132 (5)	12	0.09	0.17	0.26	0.51	0.69	1.39
	24	0.18	0.34	0.52	1.02	1.39	2.78
	36	0.27	0.51	0.78	1.53	2.08	4.17
	48	0.36	0.68	1.04	2.04	2.76	5.55
158 (6)	12	0.15	0.29	0.44	0.73	1.0	2.0
	24	0.29	0.59	0.88	1.46	2.0	4.0
	36	0.44	0.87	1.32	2.19	3.0	6.0
	48	0.58	1.16	1.76	2.19	4.0	8.0

[a] Based on permissible deflection of 1/8 inch per foot.

[b] Uniformly loaded beam, 50 percent simply supported and 50 percent fixed end assumed.

[c] Structural angles can be chosen from the tables given in the AISC *Manual of Steel Construction*.[8]

[d] Length based on 2-inch spacing between 24- x 24-inch filter units; the numbers within parentheses denote number of filter units. The metal thicknesses are adequate for panel lengths within ±10 inches of the length shown.

Note: This table is intended to provide information only. The designer is responsible for verifying this information.

4.4.15 Masonry and Concrete Housings

Filter housings for low-gamma-activity systems and vaults for high- (or potentially high-) gamma-activity systems sometimes have been built as an integral part of the building structure utilizing the same concrete building walls for HEPA housing walls. This construction is not recommended.

4.4.16 Housing Floor

Steel housings should have steel floors welded continuously to the walls of the housing. In no case should the housing be installed on a wood floor or on a floor having less than a 3-hour fire rating. A steel curb, welded to the floor, is recommended to raise the filter-mounting frame off the floor. The section of flooring between two banks of components must be considered a separate floor to be drained independently. Floors should be free of obstructions or raised items that could be hazardous to workmen.

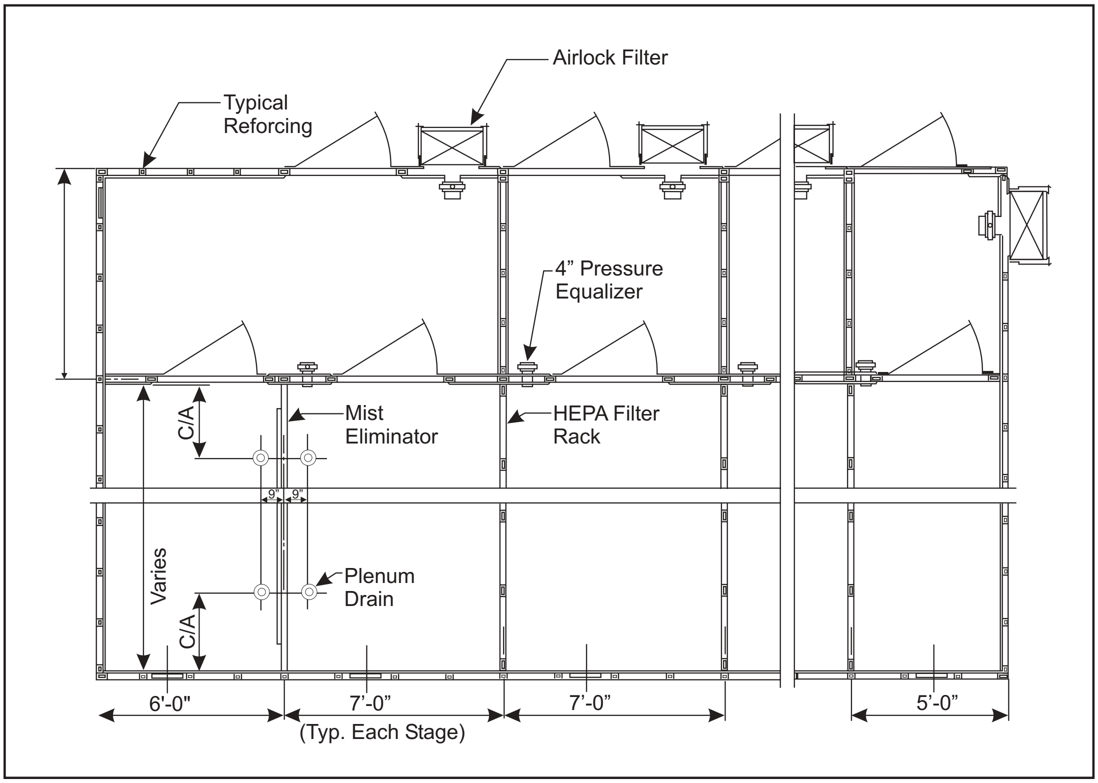


Figure 4.31 – Filter Plenum Floor Plan

4.4.17 Housing Doors

Easily opened doors are essential on large housings, and more than one door is generally needed. A door should be provided to each compartment (space between banks) where maintenance, testing, or inspection may take place. The use of bolted-on removable panels for access to filter compartments should be avoided for even the smallest filter housings when human entry is required. Sliding doors should never be used for filter housings, because they cannot be sealed and because they jam after any distortion of the housing.

Sturdy double-pin-hinged doors with rigid, close-fitting casings and positive latches, such as the marine bulkhead-type shown in **Figure 4.32**, should be provided on man-entry housings, particularly those for ESF and other high-hazard service. Doors and gaskets must be designed to maintain a hermetic seal under positive and negative pressures equal to at least the fan cut-off pressure. Doors of negative pressure systems must open outward and, since they may have to be opened against the negative pressure, a means for breaking the vacuum or for mechanically assisted opening is desirable. Doors should have heavy-duty hinges and positive-latching devices that are operable from inside and outside. Means for locking, preferably a padlock, should be provided to prevent unauthorized entry. Door stiffness is important because flexible doors can be sprung when opened against negative pressure or allowed to slam shut under load. An airlock at the entry to the housing will eliminate problems with opening doors against negative pressure and slamming, and, if large enough, will provide an intermediate work area for personnel during a filter change.

Housing doors of the type shown in **Figure 4.33** require a minimum of two latching dogs on each side. Lighter-construction doors require additional latches to achieve a satisfactory seal. Latching dogs should be operable from inside and outside the housing, and shafts must be fitted with O-rings, glands, or stuffing boxes to prevent leakage. Door hinges should be of the double-pin, loose-pin, or other type that will permit the full plane of the door to move perpendicular to the plane of the doorframe during the last fraction of an

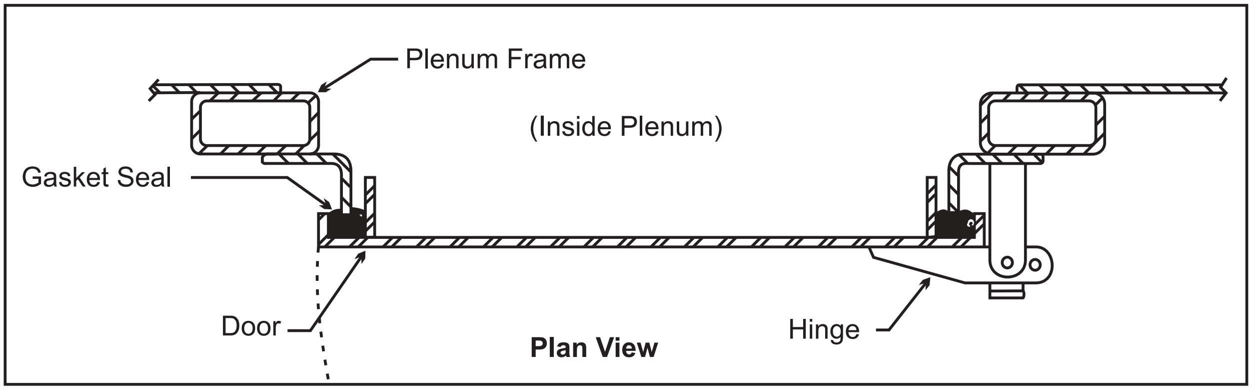


Figure 4.32 – Marine Bulkhead-Type Door

inch of closure. Single-pin hinges, which result in angular motion throughout the door closing arc, do not permit the door to seal properly and may cause the gasket to be rolled out of its groove after a period of use, thus resulting in the loss of housing leaktightness. If door gaskets are too hard they will be incompressible, and the door cannot be sealed properly even with lever-and-wedge latching dogs. If too soft, the gasket will rapidly take a compression set and lose its ability to seal. Solid neoprene or silicone rubber of about 30 to 40 Shore-A durometer is recommended.

A compromise may have to be made in sizing doors for man-entry housings. On the one hand, the door must be large enough for easy access to personnel dressed in bulky protective clothing, wearing gas masks or respirators, and perhaps carrying 24- × 24- × 11 1/2-inch filters weighing up to 40 pounds, or 26- × 6- × 30-inch adsorber cells weighing up to 130 pounds (dimensions of the door through which a 95th-percentile man can pass erect carrying such loads are shown in **Figures 4.34 through 4.38**). On the other hand, the larger the door, the more difficult it is to seal and the more likely that it or its frame can be damaged if allowed to slam under load. The door should be as large as possible for easy access, but in no event should it be any less than 26 inches wide × 48 inches high. A coaming (2-inch-high minimum to 6-inch-high maximum) should be provided at all doors to prevent the outflow of contaminated water should the housing become flooded.

Figure 4.33 – Filter Plenum Entry Door (No Airlock Type-Test Manifold with Valves Shown)

Figure 4.34 – Filter Plenum (Inside Looking at Entry Door)

Figure 4.35 – Filter Plenum (Looking from Outside through the Airlock into the Plenum)

Figure 4.36 – Filter Plenum (Looking from Outside into the Airlock at the Final Stage Upstream and Downstream Doors)

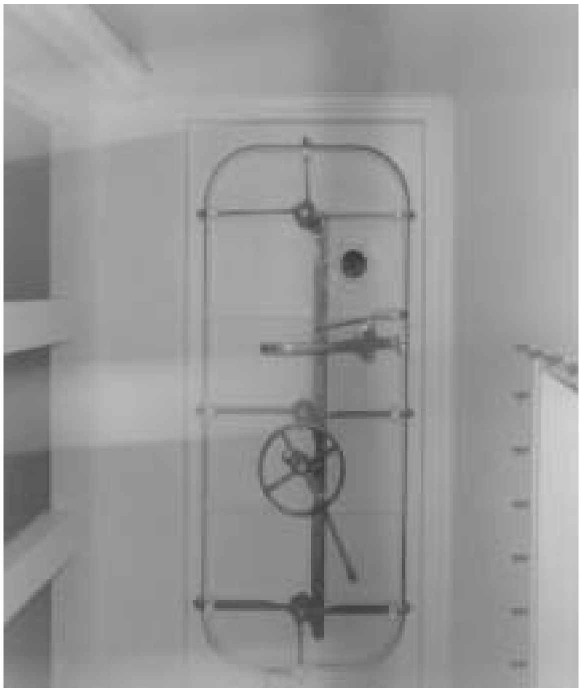


Figure 4.37 – Filter Plenum (Door-Wheel Style)

Figure 4.38 – Filter Plenum (Door Bar Style Showing Difficult Access)

4.4.18 Housing Drains

Floor drains are essential in contaminated-exhaust filter housings, particularly when sprinkler protection is provided. Even if moisture or condensation is not expected under normal conditions, occasional wash-down may be required for decontamination and water will be needed in the event of a fire. When the housing is above grade, the minimum provision for drainage is a Chicago half-coupling that is sealed with a bronze pipe plug using tetrafluorethylene (Teflon®) plastic "ribbon dope" so the plug can be easily removed when needed. [Note: Use of Teflon in radiation areas needs to be specifically considered for radiolytic decomposition on a case-by-case basis]. When the filter is at or below grade, drains should be piped to an underground contaminated waste system during initial construction, since later drainage system installation is likely to be costly. Drains from contaminated systems should be piped to the radioactive waste system. In cold climates, water seats, traps, and drain lines must be protected against freezing if they are above the frost line. In hot climates, water seats/seals may dry out. When fire sprinklers are installed in the filter house, the drains must be sized to carry away the maximum sprinkler flow without water backup in the housing.

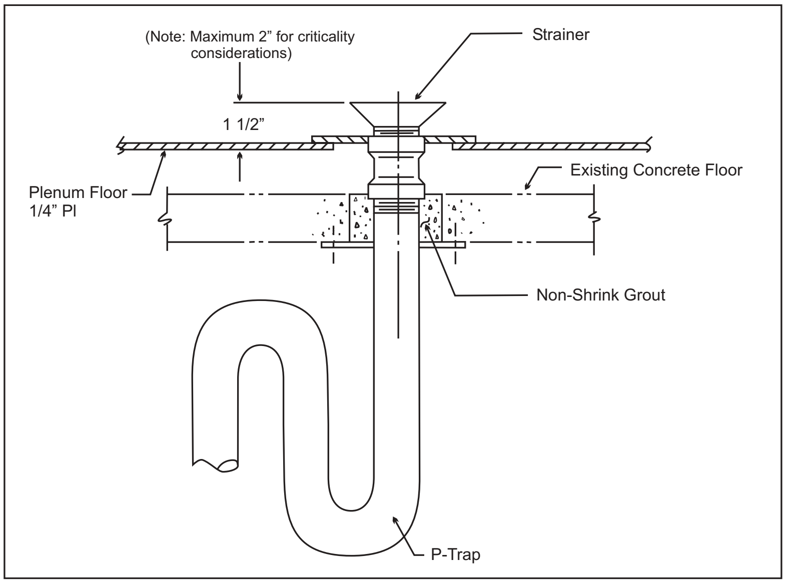


Figure 4.39 – Plenum Drain Detail

If a separate drain is needed for each chamber of the filter house, then each drain must have its own water/loop seal or trap (**Figure 4.39**). The raised drain (shown) takes into consideration criticality concerns while minimizing wastewater. The spaces between two banks of components in series are considered separate chambers. When piped to a common drain system, drain lines from the individual chambers of the housing must have a valve or be sealed, or otherwise protected to prevent bypassing of contaminated air around filters or adsorbers through the drain system. The drain system must be tested for leakage as part of the housing leak test, as well as part of system bypass testing of the HEPA and adsorbent filters.

Provision must be made for those seals or traps to ensure they are filled with water during the plant life (**Figure 4.40**). Water seals must be periodically checked to ensure they do not dry out. A manual or automatic fill system may be utilized to ensure water seals do not evaporate for systems that do not experience moisture conditions continuously. **Figure 4.41** shows alternate methods of drain connection. The design of housing drain systems is often overlooked until the time of filter housing installation or testing when it is usually very difficult and expensive to resolve.

Figure 4.40 – Filter Plenum Drain P-Trap Fill Tube

4.4.19 Demister/Moisture Separator Mounting Frame

The frame must be fabricated from corrosion-resistant, non-perforated steel sheet and must be formed and assembled in a manner that allows no bypassing of the separator pad (**Figures 4.42 through 4.46**). Drain holes must be provided in the bottom of the frame. The design must include provisions to ensure the pad is maintained in its operating position and does not settle, pack down, or pull away from the top or sides of the frame when installed. Seals must be provided as necessary to prevent bypass of entrained liquid droplets.

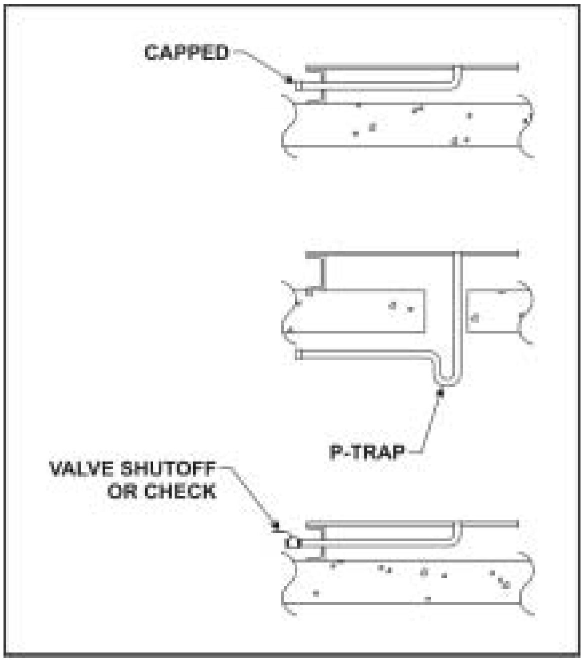


Figure 4.41 – Plenum Drain Designs

Figure 4.42 – Moisture Separator Mounting Frame

Figure 4.43 – Moisture Separator and Mounting Frame

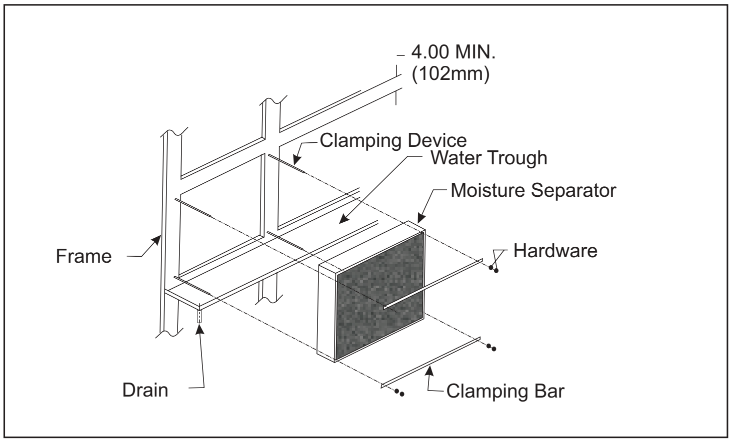


Figure 4.44 – Typical Moisture Separator and Mounting Frame

Figure 4.45 – Moisture Separators with Heat Sensor (Upstream Side)

Figure 4.46 – Moisture Separator (Downstream Side)

4.4.20 Other Housing Requirements

Figures 4.47 and 4.48 illustrate a number of features that are desirable in an air cleaning housing. The housing is all-welded construction. This housing consists of the moisture separator, prefilter, HEPA filter, carbon adsorber, and downstream HEPA filter. The housing is a 9,000-cfm capacity system and includes the following features.

- Shop fabrication,
- Wired-glass viewports on each side of the filter bank for visual inspection without entering the housing (**Figure 4.49**),
- Permanently installed lights in vapor-tight globes that are replaceable from outside of the housing,
- Wiring installed on the outside of the housing (penetrations for wiring are a common source of leakage),
- Shock-mounted instruments with a pressure-drop manometer across each bank of filters and inlet and outlet temperature indicators (**Figures 4.50 and 4.51**),
- A large marine bulkhead door that is operable from both inside and outside the housing (**Figure 4.52**),

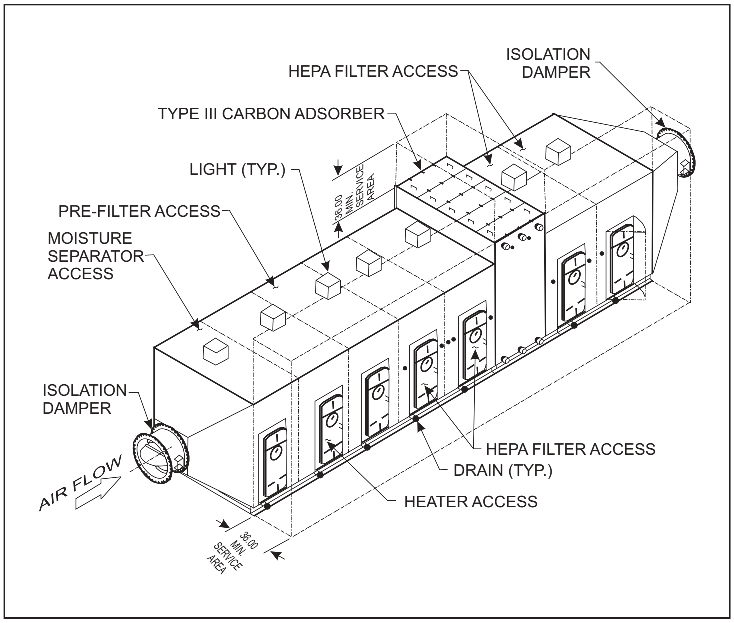


Figure 4.47 – Desirable Air Cleaning Housing Features

- Ample space (approximately 4 × 7 feet) inside the housing to allow personnel to work during a filter change,

- All reinforcements located on the outside of the housing,

- A housing opening on the aisle that can be controlled and that serves as a workspace during filter change-out,

- All-welded construction to eliminate leaks to occupied areas,

- All penetrations sealed by either continuous seal welding or adjustable compression-gland-type seals rated and qualified for the environmental conditions, and

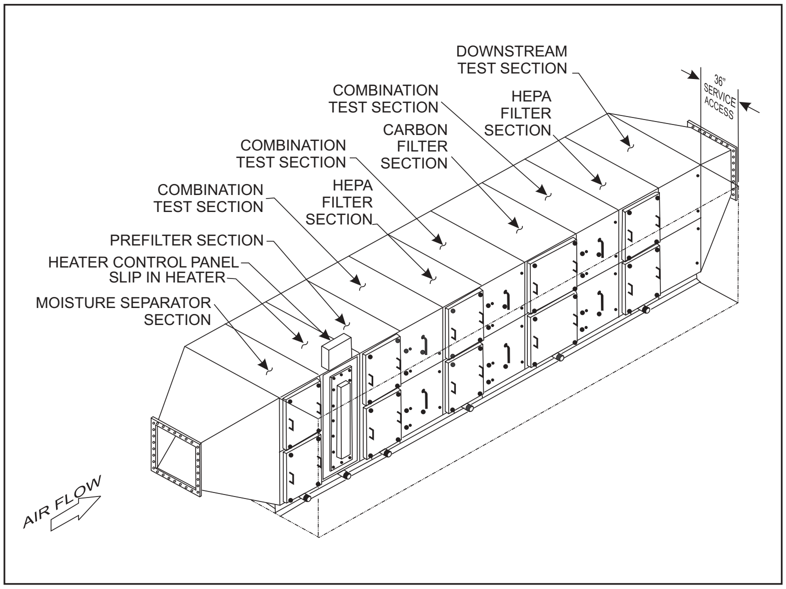


Figure 4.48 – Desirable Air Cleaning Housing Features

- Housing drains located in each compartment. Permanently installed test aerosol and Freon injection and sample ports are highly recommended.

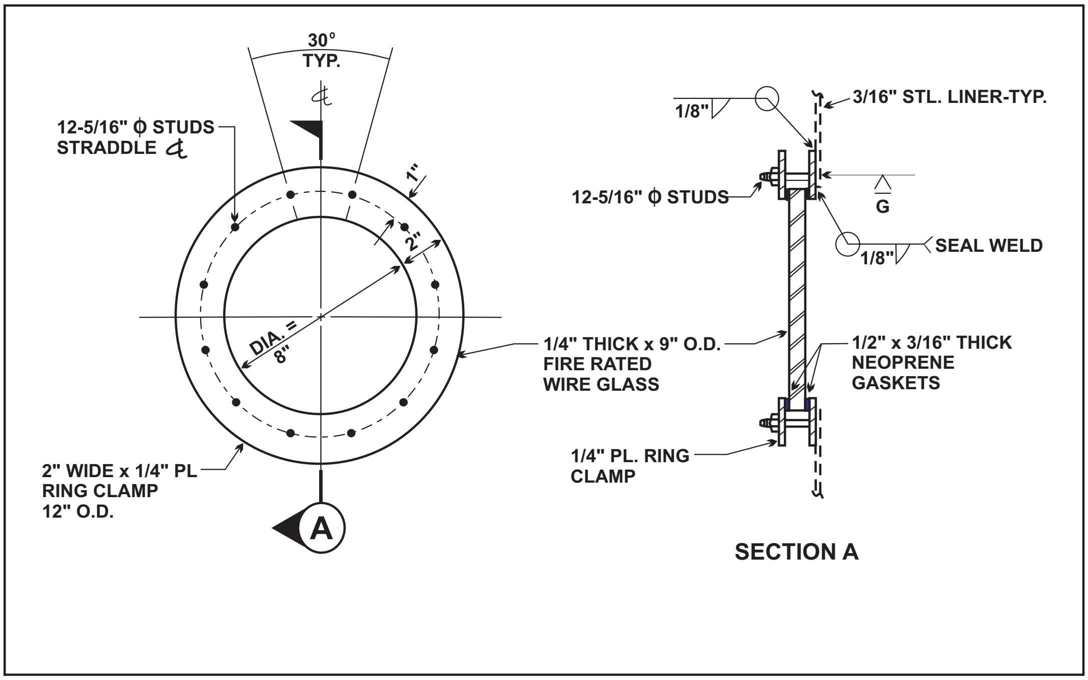


Figure 4.49 – Viewport

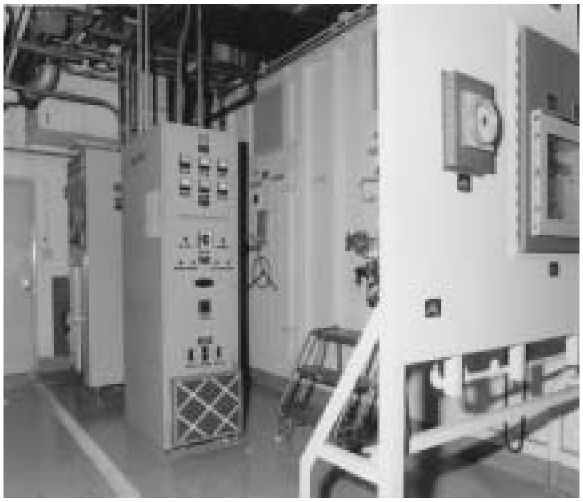


Figure 4.50 – Manual Control and Instrument Panel

Figure 4.51 – Air Monitor in Exhaust Duct from Plenum

4.5 Side-Access Housings

4.5.1 Guidance for Design of Side-Access Housings

The recommended capacity range for side-access housings is 2 filters (24 × 24 × 11 1/2 inches) per stage to 12 filters per stage (4 across × 3 high). Single filter units are also avaliable. Units may be stacked 3 high or higher if platforms are provided.

Housings may be provided with or without bag-in/bag-out features (**Figures 4.53 through 4.67**). Bag-in/bag-out side-access housings feature a ribbed bagging ring inside the side-access door. A specially designed polyvinyl chloride change-out bag is secured around the bagging ring after initial filter loading. All subsequent filter changes are accomplished through change-out bags. Contaminants are isolated to the inside of the bag to protect site personnel and permit safe handling and disposal of spent filters. A self-adjusting filter seal mechanism prevents filter bypass and maintains a positive seal during normal system operation. The housing can also be utilized without the use of change-out bags, which may be specified where future hazardous contaminants are unknown.

Figure 4.52 – Plenum Door (Wheel-Type Inside Plenum Access)

4.5.2 Recommended Design Features

4.5.2.1 Housing Material

The following is a list of recommended housing design features.

- Standard 14-gauge stainless steel.

4.5.2.2 Unit Construction

- All pressure boundary joints and seams seal welded,
- Surfaces free of burrs and sharp edges, and
- Reinforced to withstand up to 30 in.wg.

Figure 4.53 – Bag-In/Bag-Out Filter Housing

4.5.2.3 Access Panel

- Completely hand-removable,
- Handles retained in access panel after removal, and
- Protected panel gasket seal covers entire inner panel surface.

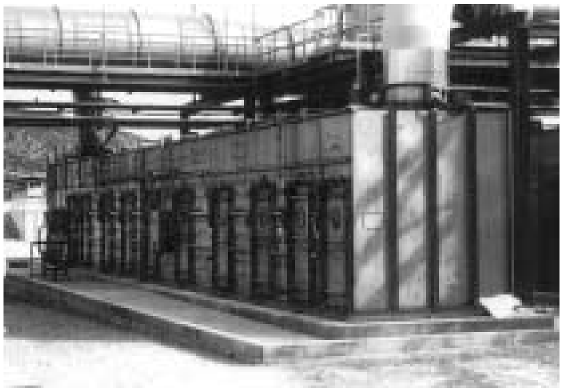


Figure 4.54 – Incinerator Exhaust Filter

4.5.2.4 Bagging Ring

- Two continuous ribs for optimum bag seal,
- Ring depth designed to contain bag during operations, and
- Smooth outer surface and hammed outer edge.

4.5.2.5 Filter Clamping Mechanism

- Spring-loaded pressure bars exert uniform clamping force on filed frame;
- Spring loading compensated for any loss of filter gasket memory;
- Positive displacement screw-drive clamping mechanism;
- Leaktight connection for clamping mechanism on outside of housing;
- Stainless steel clamping mechanism; and
- Over 1/2-inch travel to prevent filter binding.

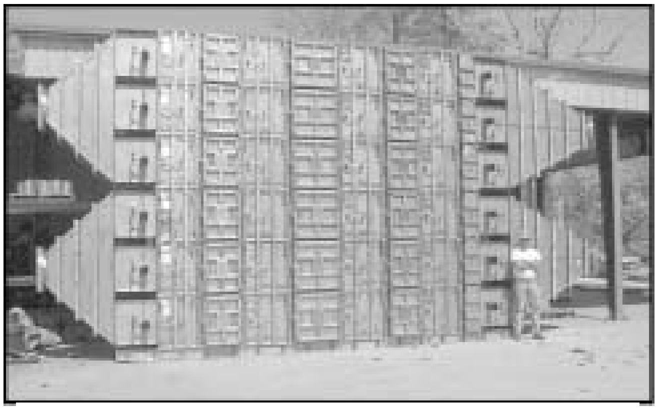


Figure 4.55 – Side Access Housing with Combination of Filter and Adsorber Sections

Figure 4.56 – Two Single Housings with Common Exhaust Fan (Dual Entry Shown)

Figure 4.57 – Side-Access Housing

Figure 4.58 – Side-Access Housing with Fan

Figure 4.59 – Side-Access Housing with Single Air Entry

Figure 4.60 – Side-Access Housing

Figure 4.61 – Side-Access Housing

Figure 4.62 – Side-Access Housing

Figure 4.64 – Side-Access Housing

Figure 4.66 – Side-Access Housing with Moisture Separator

Figure 4.63 – Side-Access Housing with Multiple Inlet Valves

Figure 4.65 – Side Access-Housing with Bag-In/Bag-Out Covers

Figure 4.67 – Side-Access Housing with Test Manifold

4.5.2.6 Filter-to-Housing Seal

- Standard full perimeter flat mounting frame mates to filter gasket; and
- Full seal weld around filter frame.

4.5.2.7 Filter Removal Rod

- Standard mechanical assist on all multiple wide housings; and
- Operated through bagging ring.

4.5.2.8 Pressure Taps

- Welded in housing, upstream and downstream of filter,
- 1/2-inch National Pipe Thread half-coupling with plug.

Seals and gaskets should be installed on panels, and a "knife-edge" gasket sealing surface should be provided. The gasket should be installed in as few pieces as possible to minimize the number of joints and designed to prevent leakage due to miss fitting butt joints. Side-access, bag-out access panels often use gaskets that accommodate the panel to the housing seals. Latches or bolts must be of sufficient quantity and strength to compress the gasket and ensure that the housing leakage criteria are met. Panels must allow access for testing and component inspection. The drawings for each type and size panel should be submitted to the owner for review before fabrication. Panel drawings should show the location and details concerning the hinges, latching lugs, and gaskets.

The number of normally open drains should be kept to a minimum. Drain lines must be valved, sealed, trapped, or otherwise protected to prevent an adverse condition where: (1) air bypass can occur around filtration components, and (2) cooling/heating coil capacity is negatively impacted.

Traps or loop seals, when used, should be designed for the maximum operating (static) pressure the housing may experience during system startup, normal operation system transients, or system shutdown. Provision should be made for manual or automatic fill systems to ensure the water loop seals do not evaporate. If manual filling is utilized, a periodic inspection or filling procedure should be implemented. Use of a sight glass should be considered to aid inspection. The same applies if a local sump is included in the design.

The drain system should be designed so that liquids do not back up into the housing. Hydraulic calculations should be prepared by the manufacturer to document this drain system feature to treat maximum coincident flow rate. Initial testing of the drain system should be performed by the owner onsite after installation to demonstrate operability. When shutoff valves or check valves are utilized, they should be initially tested for operability and leakage onsite, after installation, and periodically thereafter.

4.5.2.9 Basic Differences Between Nuclear Filtration Systems and Commercial/Industrial Filtration Systems

- The standard design pressure for nuclear systems is 10 to 15 in.wg. compared to 3 in.wg. or less for commercial/industrial systems. In addition, confinement systems can be built to higher pressures, such as 30 to 40 in.wg. without significant cost increases.

- Nuclear systems are designed, manufactured, and tested to a higher level of quality assurance, such as ASME NQA-1.[31] This includes certified welders, in-process inspections, and material traceability. Several factory tests are standard, such as filter fit, operability of filter locking mechanisms, flatness of filter sealing surfaces or alignment of knife edges and leak testing of each filter sealing surface and overall pressure boundary of each housing and/or system. Test reports are available to the customer for their files.

- Nuclear systems are designed and built with all-weld construction. All pressure-boundary welds are continuously welded. These systems are built for long life, and RTV sealants are not trusted over long periods of time.

- Over the last 2 decades, stainless steel has become a standard material of construction for confinement systems versus galvanized construction for commercial/industrial systems.

- Most nuclear systems incorporate the bag-in/bag-out feature which allows the user to protect their maintenance personnel and the surrounding environment during filter change-out. Some applications do not require the bag-in/bag-out feature, but still require all the other features of confinement.

- Nuclear filter housings incorporate filter locking mechanisms that are designed to achieve a filter-to-frame seal that will last throughout the life of the filter, not just when the filter gasket is new.

- Nuclear systems are designed so that each tier of filters has its own access door. This is absolutely necessary when the bag-in/bag-out feature is required, but it is a desirable feature even without the bag-in/bag-out feature.

- Nuclear systems offer optional inplace test sections.

- Nuclear systems offer optional separate access panels for prefilters, which allows the seal of the HEPA filters to be on the upstream side.

- Most nuclear filter housings have “filter removal rods” to assist in pulling the second or third filter to the change-out position.

- Nuclear systems now incorporate isolation dampers in many cases. These dampers are now readily available in both “bubble-tight” and “low-leakage” designs. These dampers are designed, manufactured, and tested in the same manner as the filter housings.

4.5.2.10 Advantages of Stainless Steel over Heavy Carbon Steel Construction

- Nuclear filtration systems are usually constructed of 14- and 11-gauge stainless steel reinforced externally. The cost of this design is very nearly the same as manufacturing from heavy steel plates and priming/painting for corrosion protection.

- Stainless steel offers much better corrosion protection during installation and use than painted steel.

- Decontamination and cleaning of systems is much easier with stainless steel.

- Modification of systems in the field is much easier with stainless steel. Changes, including welding, can be made without ruining the corrosion protection of the system.

- Stainless steel systems typically weigh less than carbon steel systems.

4.5.3 Side-Access Housings for Radial Flow Cylindrical HEPA Filters

Recently, radial flow cylindrical filters have been applied to DOE nuclear applications. Side-access housings for radial flow cylindrical filters have been designed for the installation of up to 12 plug-in, 2000-cfm filters, for a total of 24000 cfm. Larger installations are possible (**Figures 4.68 through 4.70**). Operational experience is still being gathered for these units.

Figure 4.68 – Side-Access Housing (Cylindrical Radial Flow HEPA Design)

HEPA filters must maintain: (1) their gasket integrity in both manual and remote handling situations; (2) a reliable seal after installation; and (3) correct orientation and fastening must be obtained. Radial flow cylindrical HEPA filter manufacturers maintain that the use of an internal seal offers the highest performance with the least force required. It is integral to the design and is extremely effective in negating alignment problems because it eliminates the remote handling restrictions of the square filters.

Manufacturers claim the following for radial flow cylindrical HEPA filters.

- Clamping is not required.
- The gasket is less likely to be damaged in normal handling.
- Positioning and orientation are not required.
- The filter is free of sharp edges and the sealing face integrity is reliable.
- The filter is normally used in-to-out so that the collected contaminant is on the inside.
- The outside surfaces are "clean," thereby easing handling.
- Radial flow filters permit higher airflow designs with lower pressure drops compared with conventional square section filtration systems.
- Plug-in filters are easy to install; they simply slide into the canister along guide rails and locate on a spigot at the rear of the canister. A ring is provided around the filter access to facilitate fitting of the change bag (**Figure 4.71**). An access cover is positioned over the filter. A locator fitted in the cover ensures correct positioning of the filter in the module.

Figure 4.69 – Side Access Housing Cylindrical Radial Flow HEPA Design

4.5.4 Inplace Leak Test

This is a test to determine if there is leakage through the filter frame/filter gasket surface or from damage to the HEPA filter. Inplace leak testing is performed at the user facility, not at the DOE FTF, because for this test, the HEPA filter must be installed in a filter housing. The FTF performs quality assurance efficiency testing on each individual filter prior to installation in a HEPA filter housing. HEPA filter housings must be supplied with test sections on the upstream and downstream sides of the filter bank. Each test section must be isolated from the other to permit individual leak testing of each HEPA filter and its supporting framework in parallel and/or in series in compliance with ASME AG-1.[1]

All leak testing must be conducted from a location outside the system using apparatus and devices that are supplied as an integral part of the test sections, including mixing devices and sample ports. The upstream and downstream test chambers contain 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. All mixing devices in the airstream must be designed to swing aside when testing has been completed.

The manufacturer must submit evidence that he has proof-tested his in-place test method according to the requirements of ASME AG-1[26] for systems containing two filters in series and two filters in parallel, with one leaking filter in each bank.

Figure 4.70 – Side-Access Housing (Cylindrical Radial Flow HEPA Design)

Figure 4. 71 – Radial Flow Filter Bag-Out

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