CHAPTER 7

GLOVEBOX FILTRATION

7.1 Introduction

Gloveboxes are enclosures that enable operators in various industries (e.g., nuclear, biological, pharmaceutical, microelectronics) to use their hands to manipulate hazardous materials through gloves without exposure to themselves or subsequent unfiltered release of the material to the environment. In the nuclear industry, gloveboxes provide primary confinement for radioactive material handling and process protection and are used to handle a diverse range of chemical, oxygen-sensitive, pyrophoric, hazardous, and nuclear materials. [Note: There are many other factors, (e.g., seismic, shielding, etc.,) that could impact glovebox filtration design and operation. Secondary confinement may be provided by the room or building where the gloveboxes are located.]

Ventilation is the heart of the glovebox system. Nuclear materials requiring handling inside a glovebox usually present little or no penetrating radiation hazard, but emit radioactive particles that could be dangerous if inhaled. Gloveboxes prevent operators from inhaling radioactive particles as they work with various nuclear materials and help provide a clean, controlled, safe working environment. For glovebox ventilation to be effective, however, proper design pressures and flow criteria must be maintained. Glovebox pressures range from mostly negative (for confinement) to positive pressure environments (for process protection). Failure to maintain correct operational pressures or to follow established operational procedures could render a glovebox both ineffective and unsafe.

This chapter discusses filtration of air or other gases associated with glovebox ventilation. The discussions in this chapter are not meant to be application-specific, but are intended to provide general information that may be useful in glovebox design and operations (i.e., specifics related to activities such as plutonium or beryllium operations will affect glovebox ventilation design).

7.1.1 Glovebox Descriptions

To understand the importance of glovebox filtration, a clear understanding of glovebox characteristics and functions is necessary.

A glovebox (**Figure 7.1**) is a windowed, airtight (sometimes gas-tight) enclosure that may be capable of positive or negative internal pressure. It is equipped with one or more flexible gloves for manipulation of materials and performance of operations inside the enclosure from the outside, uncontaminated environment.

Figure 7.2 defines and lists characteristics of gloveboxes, with a focus on their use in the nuclear industry. Originally, many gloveboxes were vendor-designed, so the designs were proprietary. As a result, many older boxes have unique ventilation designs. Today, professional societies such as the American Glovebox Society (AGS) have documentation such as AGS-G001, *Guidelines for Gloveboxes*,[1] which was written by Government employees and vendors who work with, manufacture, and design gloveboxes. This document contains useful information on subjects ranging from the need for a glovebox to related quality assurance acceptance programs.

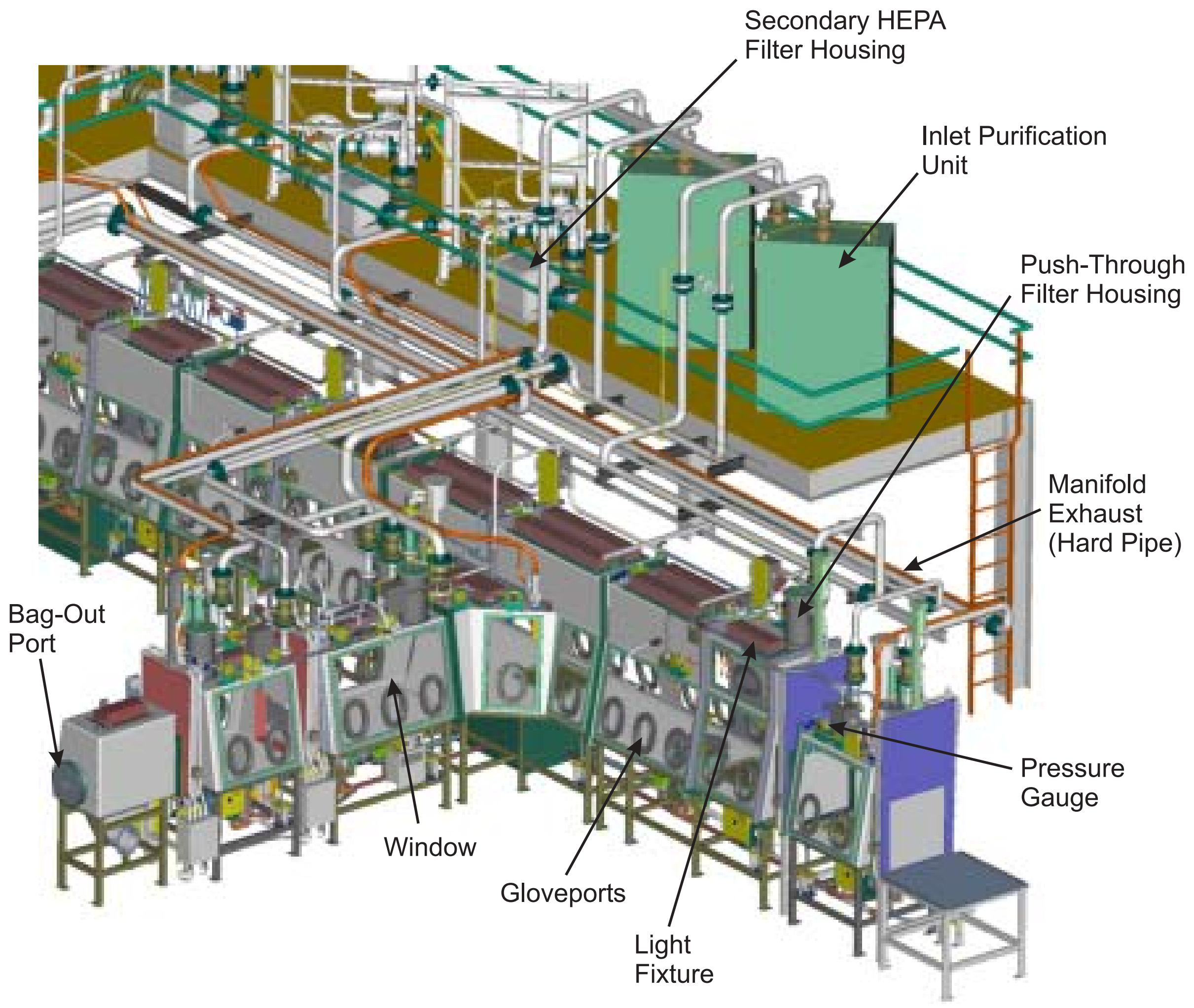
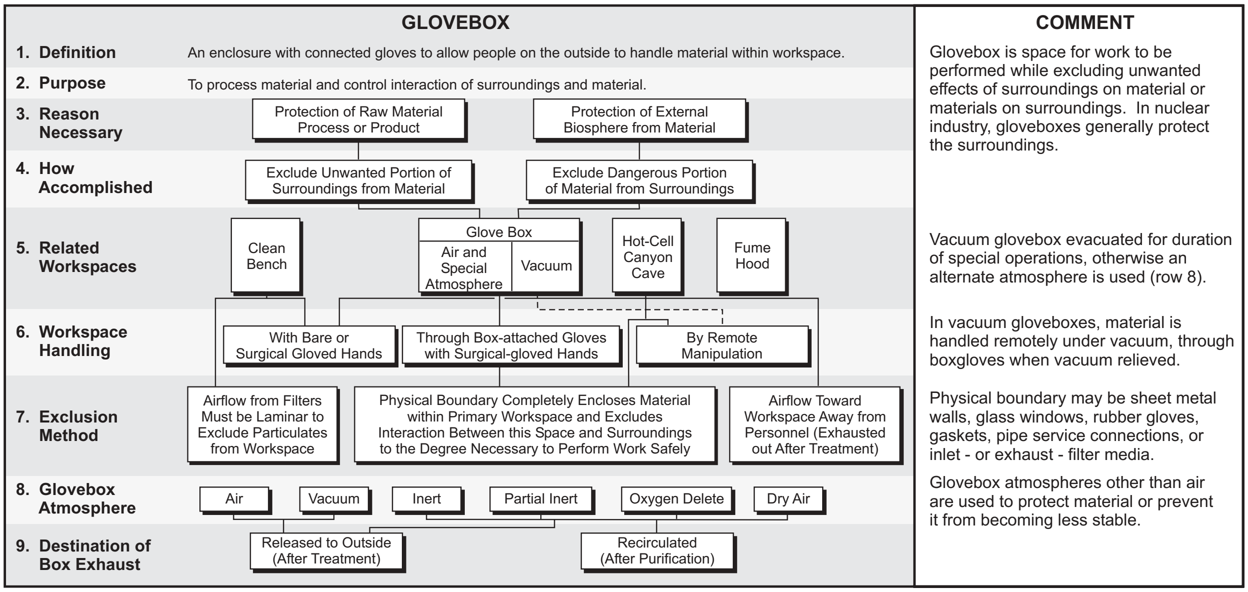


Figure 7.1 – Typical Glovebox Showing Major Features

There are still manufacturers who produce “research-type” gloveboxes in the United States today. These boxes can be used by some U.S. Department of Energy (DOE) facilities, but it is not advisable to use them for nuclear activities, as most are not equipped with a method for safely changing the high-efficiency particulate air (HEPA) filters and may not meet the provisions of this chapter. [Note: The HEPA filters used on some of these gloveboxes do not meet the recommendations provided in Chapter 2 or American Society of Mechanical Engineers (ASME) AG-1.][2]

Ongoing development of gloveboxes for use by the nuclear industry has resulted in many changes through the years. Gloveboxes have evolved from the somewhat standard sizes to larger custom systems containing all of the process-related equipment. The larger gloveboxes cited in this Handbook have some unique characteristics. Some are as large as 150 feet long, 4 feet deep, and 15 feet tall. See **Figure 7.3** for a portion of the type of glovebox. Note the numerous gloveports which allow access to all points in the box. Their ventilation design includes side-access filter housings (see Chapter 4) instead of the designs described later in this chapter. Other design philosophies place drive motors, equipment, and electrical devices externally, thereby reducing maintenance, heat loading, size, and disposal costs. Seals are used to pass drives and electrical controls through the glovebox pressure boundary. In some cases, the design philosophy has been



An enclosure with connected gloves to allow people on the outside to handle material within workspace.

To process material and control interaction of surroundings and material.

Glovebox is space for work to be performed while excluding unwanted effects of surroundings on material or materials on surroundings. In nuclear industry, gloveboxes generally protect the surroundings.

Vacuum glovebox evacuated for duration of special operations, otherwise an alternate atmosphere is used (row 8).

In vacuum gloveboxes, material is handled remotely under vacuum, through boxgloves when vacuum relieved.

Physical boundary may be sheet metal walls, glass windows, rubber gloves, gaskets, pipe service connections, or inlet - or exhaust - filter media.

Glovebox atmospheres other than air are used to protect material or prevent it from becoming less stable.

Figure 7.2 – Characteristics of Gloveboxes

to size the glovebox for a specific process to minimize volume and service requirements. In all cases, ergonomics and confinement are critical to the performance of daily operations and routine maintenance.

Gloveboxes generally have several common characteristics. They are often no deeper than 26 inches (as far as most arms can reach—it is desirable to be able to reach most areas of a glovebox). If deeper space is needed, a dual side-access design may be selected. These contain one or more safety glass, laminated-glass, or polymer viewing windows located on at least one side. Gloveports (window-mounted or in the stainless steel shell) are usually available in multiples of two at various locations in the glovebox walls. Interior workspace is reserved for primary operating purposes on the box floor between the gloveports and within reach of a gloved hand. Remote handling capabilities, other than tool extensions for the gloved hand, are usually not provided.

Gloveboxes are normally kept at a negative pressure of 0.3 to 0.5 inches water gauge (in.wg) relative to their surroundings. The maximum safe operating differential pressure between the interior and exterior of the box is usually less than 4 in.wg; greater differential pressure may damage or rupture a glove or window, causing subsequent loss of confinement. Operators experience fatigue when pressures inside a glovebox are greater than 0.5 in.wg, and performance of intricate tasks becomes tedious. Material and HEPA filter transfers between glovebox interiors and exteriors are commonly made through a bagging port which, although time-consuming and user-dependent, is still the safest practical way of maintaining confinement. New versions of this technology use a banding system. Other material transfers use rapid transfer ports (RTPs), which allow simple docking from glovebox to glovebox. This is a reliable method of maintaining confinement as long as the seals are maintained and undamaged. [Note: Transfers of powders can egress past the seals if exposed. Such powders should be contained in a secondary container and the seals protected during operations.] Gloveboxes with RTPs are still equipped with bagging ports for filter changes and waste disposal.

HEPA filter installations must adapt to limitations while still providing reliable service. Hybrid glovebox-shielded cells, vacuum gloveboxes, room-high gloveboxes, glovebox "trains," etc., are often encountered, and all require reliable filter installations.

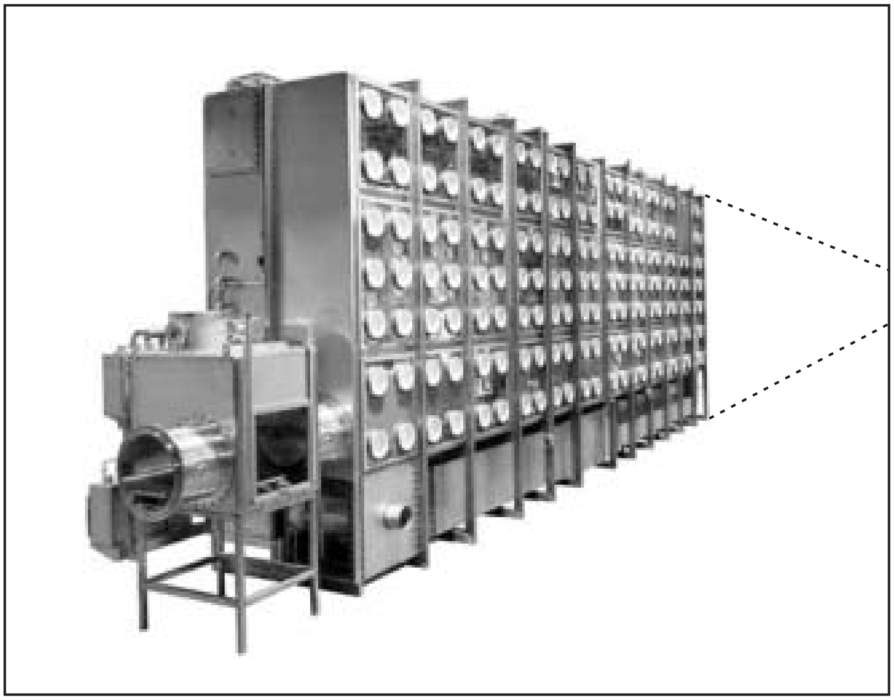


Figure 7.3 – Glovebox with Multiple Gloveports to Facilitate Access

Special atmospheres such as inert gas and dry air are often used in gloveboxes for fire suppression and for oxygen-sensitive and/or moisture-sensitive materials and processes. Gas purification systems are commonly used in conjunction with inert environments to maintain environmental control. These units purify and dry the environment to prevent consumption of large volumes of inert gas and desiccant. It is important to protect these devices from contamination because they constantly recirculate the volumes of the gloveboxes they serve.

7.1.2 Importance of Glovebox Ventilation and Filtration

Operations conducted in gloveboxes often provide the elements for unstable conditions (e.g., fire and pressurization). A properly designed and operated glovebox ventilation system minimizes these instabilities as well as the possibility of an accidental release of airborne radioactive material. Room air is a safe glovebox environment for many applications. On the other hand, operations with pyrophoric materials such as plutonium or the presence of reactive gases such as hydrogen may require a special environment (e.g., low oxygen, inert gas, and moisture control).

For air-atmosphere boxes, ventilation at relatively low flow rates provides sufficient dilution of the limited combustible volatiles found in well-operated gloveboxes. The correct airflow volume, along with the proper location of supply and exhaust filters, minimizes the likelihood of fire while providing sufficient dilution to prevent the buildup of explosive gases. Good glovebox ventilation dictates that HEPA filters are operated at their designed airflow [cubic feet per minute (cfm)]. It is important that HEPA filters are tested and certified at the manufacturers' rated airflow. As airflow increases, efficiency decreases.

Normal air changes through a glovebox remove some of the heat generated by equipment inside the box and help maintain reasonable working temperatures for the operator. However, this convective cooling may be insufficient to remove all of the process heat generated in the box, and auxiliary cooling or higher airflow volume may be required. Most glovebox ventilation systems include some form of pressure relief and adequate pressure control to maintain proper pressure differentials between the glovebox and its surroundings. If a glove should tear or accidentally come off, there should be an assured, sufficient ingress of air through the gloveport to prevent egress of contamination until the port is closed. This safety feature is inherent if the glovebox ventilation is designed and operated properly. Pyrophoric operations, however, should have appropriate safeguards to prevent air intake from starting a severe reaction.

Proper instrumentation should be provided to warn of inlet/exhaust filter blockage and loss of pressure/confinement. Pressure gauge/transducer line filters should be used to protect this instrumentation.

HEPA filters have been used on gloveboxes to contain radioactive materials since the early days of the nuclear industry. History has shown that, as a rule, they have been adequate; however, submicron-sized particles of some materials can pass through HEPA filters. In such cases, it is critical to have knowledge of the material properties. Technology should be used to help determine the type of filters and efficiencies that can be used for a proper filtration system.

In summary, the glovebox ventilation and filtration system must be capable of reliable performance to assure glovebox operators that they may safely operate the box without fear of exposure to airborne contamination to themselves, other facility personnel, and the environment.

7.2 Design of Glovebox Ventilation Systems

The principals of glovebox confinement are basic. Airflow of 125 ± 25 feet per minute (fpm) through a breached (8-inch diameter) gloveport will maintain confinement. This is an inherent (defined as "real time, at the moment of failure") safety feature that should be incorporated into the glovebox system. Most nuclear, biological, and pharmaceutical facilities in the United States are designed to provide this capability (within a range of 10 percent). It is important to understand how this is achieved.

A glovebox is basically a closed volume. When the blower unit draws air (negative side) from the box, the box is under negative pressure. The filters help regulate this pressure. Filters are essentially controlled leaks that allow airflow through them while trapping the particulates they are designed to filter out. The inlet filter establishes the actual glovebox working pressure, while the exhaust filter system establishes the inherent safety feature. It is therefore critical for the exhaust filter to be properly engineered into the system to perform its inherent duty. When a gloveport breach occurs, by design the inlet filter is bypassed and the breached gloveport becomes the inlet.

The air change rate is an important consideration for all gloveboxes. As glovebox volume increases, airflow should increase. Nonetheless, the inherent safety feature of 125 ± 25 fpm through a gloveport must be maintained. For normal operations, flow rate is based on the dilution of evolved combustible or corrosive gases and heat dissipation, as well as prior experience. The exhaust capability must be sufficient to provide safety under postulated abnormal conditions, including the gloveport breach. In certain other applications, the exhaust capability must be sufficient to provide safe access for planned activities.

Operating personnel, industrial hygienists, and radiation specialists can assist the designer in establishing realistic requirements, particularly when an existing system is being replaced or revised. The types and quantities of materials to be used inside the box and their toxicity and state (wet slurry, dry powder, etc.) must be considered when establishing the air exchange rate and velocity. When exposed radioactive material is handled inside a glovebox, the box becomes the primary confinement. When handling nuclear and pyrophoric materials, consideration should be given to whether pressure inside the glovebox should be positive or negative. A positive-pressured glovebox provides a motive force for airborne contamination to leak from the box into the secondary confinement (the room or facility). Negative pressure inside the box is essential to maintain glovebox confinement when working with radioactive material. It is not usually acceptable to design a normal operating condition that allows a primary confinement area to be positive to the secondary confinement area. However, in a unique or unusual application where an inert environment is used to control fire and explosion, the box may be slightly positive or even neutral, and the facility becomes the primary confinement. This suggests the need for a secondary confinement and also flags the need for personal protective equipment and appropriate procedures to protect the worker. The designer must design for failure (i.e., using the worse case scenario) to predict the consequences of a glovebox failure. The designer also must consider test and acceptance criteria.

7.2.1 Blowers

The blower is the motive force that provides the pressure and airflow requirements in a glovebox. Related principles are covered in Chapter 5. Glovebox blower requirements have different or additional requirements. Generally, the airflow is very low (approximately 35 cfm) for most applications. [Note: This is true for gloveboxes with volumes of less than 100 cubic feet (ft^3), and does not factor in heat or gas loading.] Blower selection must account not only for the breached gloveport scenario, but also for corrosive gases and filter loading.

The typical airflow for most gloveboxes is 35 cfm, assuming a standard 8-inch-diameter gloveport. A typical cartridge filter rated at 35 cfm will have an approximate 0.8-in.wg clean static pressure drop. When both inlet and exhaust filters are installed, the total pressure differential for the filter requirements is 1.6 inches water column (in.wc). [This does not factor in the ductwork and inlet configurations.] The filter loading factor for most facilities is sometimes greater than double the initial static pressure. In this situation, the blower must be able to perform within its blower curve at 1.6 to 3.2 in.wc and still produce 35 cfm. This is a higher pressure and lower flow than used for most fan and blower applications. A regenerative blower is often used in this application. These blowers operate similar to pumps in that the clearance between the blower wheel and blower housing is very small. If the blower is to service more than one glovebox, the blower should be sized to handle the additional requirements. Exhaust manifolds should use dedicated lines for each glovebox to prevent transfer of heat from one glovebox to another.

Regardless of the type of blower or manufacturer, the required airflow and pressure requirement must be attained for safe operation of a glovebox. Another criterion for blower selection and design is selection of a blower that does not exceed the pressure limits of the glovebox. Depending on their size, most stainless steel gloveboxes with 7-gauge walls are designed and tested at -4 in.wg. Exceeding this pressure may cause damage to the glovebox windows, seals, and shell. If the blower exceeds this limit, the glovebox should be equipped with a pressure relief device.

“Pressure recovery” is a term that evolved from quick insertion and removal of operators’ arms into and out of the gloves. Although the blower will deal with most of the volumetric changes caused by glove movement, loading the exhaust filter will prevent the blower from quick recovery. Exhaust filter and gloveport sizes also influence recovery. This is the reason for maintaining the inherent safety feature at the design phase of a glovebox project. If larger gloveports (greater than 8-inch-diameter) are selected, the need for additional airflow must be engineered. Site-specific filter housings and filters may not address the need for increased airflow.

Blower location depends on several variables in glovebox applications. If a scale or other vibration-sensitive device is used in the glovebox, the blower should be isolated from the glovebox shell with vibration isolators and a flexible inlet/exhaust connection. Although this works in most applications, some may require remote location of the blower away from the glovebox. Blower noise should be considered to prevent annoying the workers. Noise levels should be kept to less than 80 decibels A-weighted (dBA).

7.2.2 Filter Housings

It is imperative that the filter housing on a glovebox be designed to function correctly. It should incorporate designs for safety, ergonomics, and reliable operation. Filter change-out should be simple and should maintain a safe level of confinement. The design should prevent any form of contamination from reaching the downstream ductwork or secondary confinement (the facility). The design should satisfy the ergonomic requirements of filter changes and allow the operator to perform the operation safely (without exposure or injury). In most installations, the filter housings are located in areas of the glovebox that are awkward to reach. A top-mounted filter housing should be located as close to the front of the glovebox as possible and should be aligned with a gloveport. Although DOE-STD-1066, *Fire Protection Design Criteria,*[3] suggests locating the exhaust filter housing to a lower position in the glovebox for fire purposes, this may cause a loss of confinement in some applications. Process activities and materials could block the exhaust filter. Without the exhaust filter airflow, it would be difficult to maintain confinement. The filter housings on gloveboxes differ from most filter housings in that they are very small due to ergonomic limitations and low airflow requirements. Changing a glovebox filter is difficult because it must be performed through a gloveport with limited operator movement. Use of larger filters should be avoided because they are difficult to handle safely inside a glovebox without special tooling.

7.2.2.1 Types

The types of filter housings selected for use on gloveboxes have always been application-specific. See **Figure 7.4** for bag-in/bag-out port which allows for equipment removal. As many nuclear facilities function under different directives, filter housings have evolved to suit their respective applications. Early gloveboxes often had externally mounted HEPA filters. Because of the potential for spreading contamination during filter changes, this practice should be avoided.

Internal filter installations range in design, however, and all have a mechanism to restrain the filter (a HEPA filter) and a sealing mechanism. These mechanisms also vary; however, it is critical that the mechanism be free of sharp edges that can easily cut gloves. Cracks and crevices should be kept to a minimum since the location makes cleaning difficult. Filter housing construction typically requires clean, smooth finishes to allow cleanup of contaminated or potentially contaminated areas. Experience has shown that areas exposed to contamination can be impossible to clean. The rougher the surface of the housing, the more difficult it is to clean. Valves, located to the outside, are used to isolate the spent filters during filter changes. Most applications use a prefilter to protect the HEPA filter, as well as a fire screen when there is a potential for fire. Although diverse, the many prefilter and fire screen designs should meet the requirements imposed in DOE-STD-1066.[3]

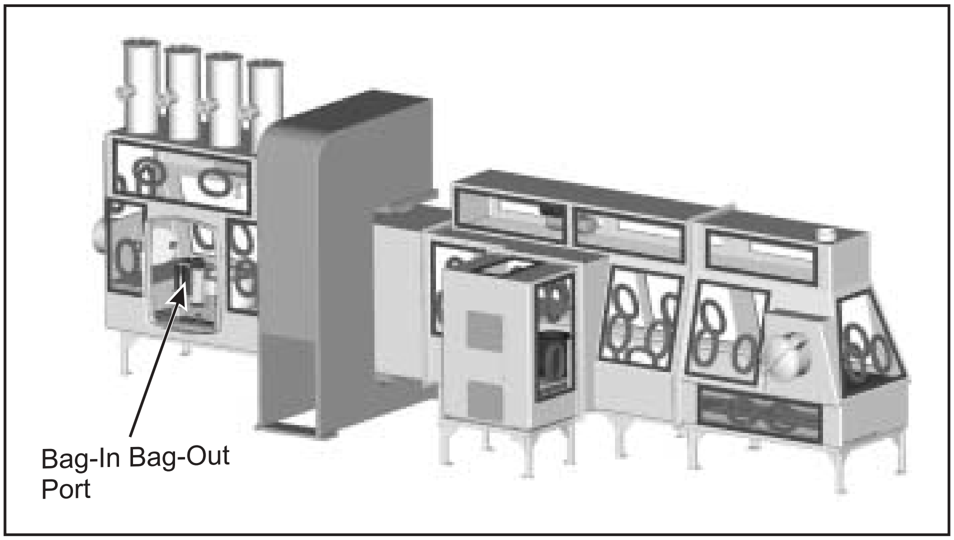


Figure 7.4 Bag-In/Bag-Out Port for Equipment Removal

The last basic requirement is a means and method to remove the contaminated filter from the glovebox. The most common method is the bag-in/bag-out method. Push-through filter housings differ in that they hold the standby filter in the filter housing. (See **Figure 7.5** for push-through filter housing). The filter is a cartridge type with chevron seals located at the inlet and the exhaust of the round cartridge filter. One of its advantages is that it is designed to maintain confinement during a filter change. A new filter displaces the spent filter as it is pushed through. The old filter and spacer are displaced to the inside of the glovebox. The

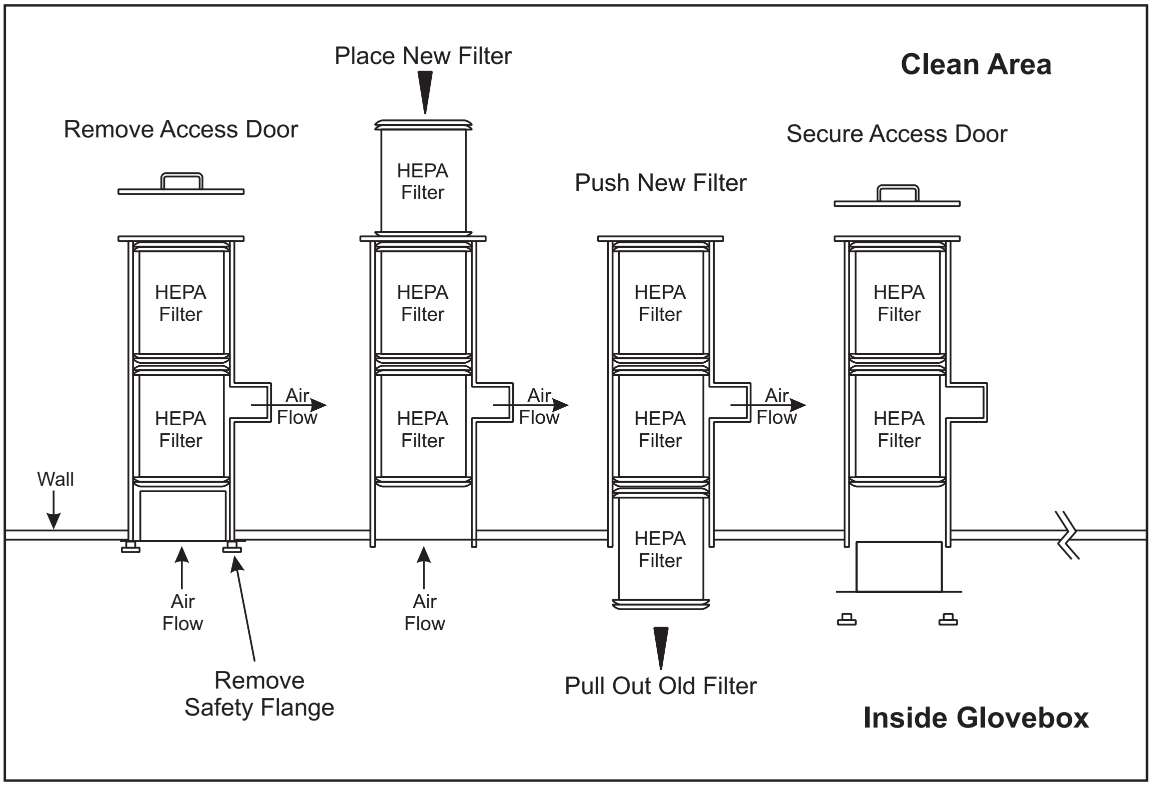


Figure 7.5 – Push-through Filter Housing

inner pipe "tube" of the housing is honed to obtain a smooth, round surface. The chevron seal, which is larger than the internal diameter of the tube, creates the seal. Although this system has been used with great success, seal quality and tube finish are critical to its proper operation. This filter housing design is vulnerable, however, when it is used for applications involving light, easily airborne materials. Such materials, if surface-deposited on the inside tube, can bypass the seals during a filter change because the seal can "roll over" the material. Another potential drawback of this design is its orientation. It should be installed in a vertical position for proper sealing. A horizontal installation will enable the seals to "take a set" and eventually bypass the filter. This filter housing has been used at nuclear facilities in the United States for many years with good reliability; however, its limitations should be noted.

Cartridge filters can be used for glovebox operations for both radioactive and nonradioactive applications. These filters incorporate the filter housing and filter as a single unit and are supplied from the manufacturer with options for pipe nipple connections on both the inlet and exhaust or on one end only. Test ports should be specified when ordering, as these filters range in size and airflows. Prefilters should be installed inside the glovebox for filters not already equipped with prefilters. A valve should be located on the outside of the glovebox filter housing.

Radioactive Applications

In some radioactive applications, the cartridge filter should be located on the inside of the glovebox for safe filter changing. The isolation valve is located on the outside of the glovebox filter housing.

Bag-in/bag-out side-access filter housings are used in some glovebox applications. They are available in sizes from 35 cfm on up and in rectangular or round configurations, as discussed in Chapter 4. For radioactive applications, it is desirable to mount the housing as close to the glovebox as practical. Long ducting or plenum runs are not desirable due to their lack of access for cleaning. Mounting the filter housing directly to the glovebox reduces the potentially contaminated surface area.

Redundant filter housings (**Figure 7.6**) are used when working with materials that, if released through the exhaust system, would be detrimental with respect to both safety and associated cleanup costs. All nuclear facilities use a secondary exhaust before discharging to the outside air; this method is a known as a "belt and suspenders" approach. In some older facilities, manifold systems were not designed for safe, clean decontamination. If contamination migrates into these systems' ducting, cleanup is both costly and time-consuming. As a result, use of a redundant filter should be considered. The design of a redundant system requires the use of an in-place-tested primary and secondary HEPA exhaust filter installation. Figure 7.6 shows two redundant filter housings—one filter changed from inside the glovebox (primary); the other (secondary) is shown as a bag-in/bag-out type changed from the outside.

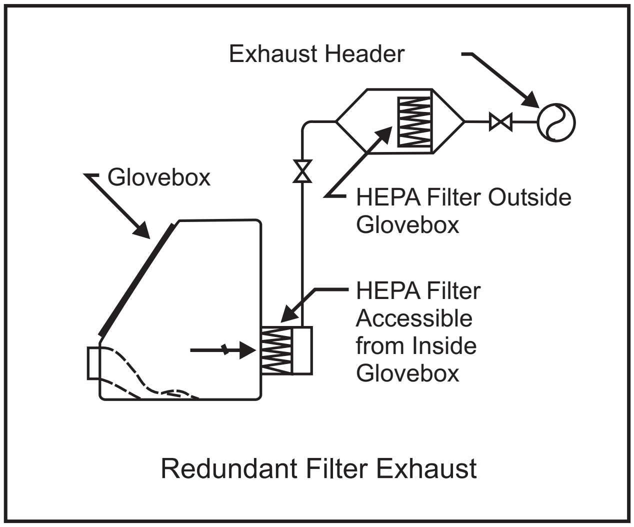


Figure 7.6 – Redundant Filter Housings

7.2.2.2 Materials

It is important to understand the construction materials used on the filters and filter housings for gloveboxes, particularly chemical processing gloveboxes. It should be clearly understood which chemicals and gases will be introduced into the airstream of the glovebox and where they will be processed if processing is required. If a bag-in/bag-out port is used, the bag material is subject to the same exposure to chemicals and gases as the rest of the ventilation. If the process performed in the glovebox changes or other materials are introduced into the glovebox system, the compatibility of the materials must be re-evaluated. Simply put, the materials, ducting, blower unit, etc., must be compatible with the chemicals and gases exposed to the exhaust airstream.

Filters are available in many different materials for different purposes. Wood, several different stainless steel and aluminum materials, etc., are commonly selected for different applications. Recently developed technologies such as stainless steel, ceramic, and Teflon® filter media have outstanding resistance to chemicals, heat, and gases. However, these recent developments have not gained wide acceptance in nuclear applications.

7.2.2.3 In-Place Test Ports

The size of a glovebox filter housing is relatively small compared to most filter housing installations. As with any HEPA filter installation, test ports should be placed on the filter housing to validate the installation. The criteria for testing gloveboxes focus on the proper location to inject the challenge aerosol, upstream, and downstream samples. The test ports should be designed to be sealed after each use and to be as cleanable as possible. This is usually a 3/8- to 1/2-inch half-coupling/nipple with the appropriate plug/cap. The weld and finish of a test port should emphasize clean smooth surfaces, especially from the inner diameter of the port to the filter housing. Cracks and crevices in this area are next to impossible to clean via access through gloveports.

7.2.2.4 Bag-in/Bag-out Ports

Bagging ports are used on gloveboxes for multiple purposes such as transferring materials and equipment and removing the waste generated during operations. Significantly, they are also used to transfer new or spent filters while maintaining confinement. It is important to size the bagging port to accomplish this purpose, and it is desirable to use a cylindrical bagging port because this design is much more “operator friendly.” A typical bagging port should have two outer-raised ribs around the outer circumference to prevent the bag from being easily pulled off during operations. The ribs are normally raised approximately 1/4- to 3/8-inches above the outer circumference and 1 to 1.5 inch apart. A safety-restraining strap should be used to prevent the bag from being easily pulled off. It should be installed whenever the bagging port is being used, and should be removed only when performing the bag-in/bag-out (new bag installation) procedure. The strap is secured between the two ribs. A cinching strap may be used to prevent the bag from being sucked into the glovebox due to negative pressure. It is installed when the bagging port is not being used. An internal access door may be used to isolate pressure surges and to act as a secondary confinement for the bag. The door should have a seal to prevent egress of contamination from the glovebox. An external cover may also be used to protect the bag and keep it out of the way of other operations. A “bagging kit” should be supplied with a bagging port. It should contain the components, tools, and procedures to perform the operation. These items are covered in Section 7.4.

7.2.2.5 Sealing Mechanisms

There are multiple sealing methods for filter housings and filters used on gloveboxes. These can be application-specific or site-specific and either gasket- or fluid-sealed. The designer should consider chemical, gas, radioactivity, and heat as deciding factors in determining which sealing mechanism to employ. In some applications, the filter housing is welded and incorporated into the glovebox. In others, the filter housing is a bolted, gasketed installation. The bolted design is more versatile by design; however, a potential crack at the gasket interface may make decontamination difficult. It should be noted that a push-through filter housing should be bolted due to the housing manufacturing process. Filter seals vary by application. HEPA filters can be supplied with many different gaskets and fluid sealing systems.

7.2.2.6 Blower Connections

If a dedicated blower is to be installed on a glovebox, several installation considerations should be addressed, including vibration, exhaust connection configuration, and blower discharge configuration. It is generally accepted practice to use a flexible connection in most ventilation applications; however, DOE-STD-1066[3] outlines the need for fire protection and the requirements associated with such installation. Vibration from the blower will transmit to the filter housing and subsequently to the glovebox. If a flexible connection is used to isolate vibration from the blower, there is a potential for heat damage to the connector. Noncombustible materials should be selected for this application. Blower designs vary. Selection of the exhaust and inlet connection should prevent severe effects on blower capacity. Obstructions at the immediate inlet and outlet will grossly affect blower capacity. Elbows and tees at the inlet will also affect capacity and should be avoided.

7.2.3 Dilution of Evolved Gases

A high air exchange rate is often required to dilute fumes generated in an air-ventilated glovebox. When evolved gases, vapors, and particles are not flammable, toxic, or corrosive, flow rates sufficient to maintain a negative pressure (with differentials from 0.3 to 0.5 in.wg in the box) may be employed. However, when fumes or vapors are hazardous, a higher ventilation rate is necessary. The maximum generation rate of hazardous substances must be determined to establish the minimum airflow rates needed for dilution. The following equations can be used to determine minimum safe airflow rates.[4]

$$Q = \frac{R(10^6)(S)}{L}, \tag{7.1}$$

where:

Q = required dilution flow rate, cfm

R = contaminant generation rate, cfm

S = safety factor (4 to 10 is suggested, depending on volatility, flash-point temperature, degree of mixing, and risk)

L = limit value of contaminant, volume parts per million (vpm) [use threshold limit value (TLV) for toxic vapors and lower explosive limit (LEL), 4 converted to vpm, for combustible vapors].

If the contaminant vapor is evaporated from a liquid, the contaminant generation rate, *R*, can be determined using the rate of liquid evaporated where:

$$R = \frac{W}{M}\ (359)\ \frac{t + 460}{492} \tag{7.2}$$

W = liquid evaporation rate, pound of solvent per minute

M = molecular weight of contaminant

t = air temperature, degrees Fahrenheit

Equation (7.2) above assumes that a pound mole of gas will occupy 359 ft^3 at 32 degrees Fahrenheit and standard pressure. The dilution flow rate, *Q*, in Equation (7.1) assumes that the dilution air is free of the contaminant under consideration; otherwise, the background concentration of the contaminant in the dilution air (in vpm) must be subtracted from the limit value, *L*, in the denominator.

Concentration gradients can easily be formed during rapid vaporization if the hazardous gas is much lighter or heavier than air and there is poor mixing. Safety factors above 7 should be used in such cases. For example, 1 pound of acetone evaporated in a box in 1 hour requires a dilution rate of 5.1 cfm multiplied by the safety factor, *S*, to ensure dilution below the lower explosive limit.[5] Since acetone evaporates rapidly and has a flash point of 0 degrees Fahrenheit and an LEL of 2.2 percent, a safety factor of 10 should be used. In operation, minimal amounts of a solvent like acetone should be permitted in the glovebox at any one time. It should be assumed that the entire contents could be spilled, thus creating an event. Consideration should also include feed-throughs where flammable liquids and gases are pumped or released into the glovebox environment. The feed lines should be constructed of materials that are resistant to the gas or liquid. It is preferable for these lines to be hard-piped to the glovebox, although this is not always practical. An isolation valve should be provided to shut off the feed system in an emergency. It is preferable to use an automated failsafe feature, with appropriate sensors, if the equipment located inside the glovebox is not explosion proof. This is also preferable when the equipment is not monitored for long periods.

7.2.4 Heat Dissipation

It is important to understand the importance of heat removal as it applies to ergonomics. Operators access the inside of the glovebox using gloves that are often awkward to use and gloveports that limit their operations. When higher than normal heat conditions exist in a glovebox, it leads to higher fatigue levels. This limits the operations that can be performed in the glovebox environment. For worker comfort, sufficient air should be exchanged through the box to limit the inside temperature to no more than 15 degrees Fahrenheit above room temperature. When the calculated airflow rate for cooling exceeds the exhaust cfm, consideration should be given to higher airflow (larger filters or more filters), supplementary cooling, better insulation of heat sources, cooling coils, or chill blocks for hot materials. In the design phase of a glovebox project, the designer should be aware of the heat load presented by the equipment that must be located in the glovebox. It is desirable, when practical, to determine whether items like electric motors can be placed to the outside of the glovebox. This can reduce the heat load inside the glovebox significantly, as well as simplify maintenance and serviceability and reduce disposal costs. Operations to be performed in a glovebox should be determined ahead of time. Airflow velocities can affect the operation of sensitive equipment and cause materials like powders to become airborne. [Note: Negative pressure also can cause equipment problems.] There are practical limits to the amount of cooling that can be accomplished by airflow, since high airflow rates can create strong air currents if not properly diffused. Where possible, operators should be protected from objectionable sources of radiant heat by surrounding the heat source with reflective shields or conductive jackets. Exhaust airstreams may be routed through such shields to permit the maximum pickup of convected heat before leaving the box.

When the heat load to the glovebox has been determined, the required cooling airflow rate to dilute the hot gases is calculated using the following equation.

$$Q = \frac{H}{C(t_2 - t_1)}, \tag{7.3}$$

where:

Q = airflow, cfm

H = sensible heat change (by conversion), British thermal units (BTU)/hour (1W – 3.41 BTU/hour)

t_1 = temperature of entering air, degrees Fahrenheit

t_2 = desired average temperature inside box, degrees Fahrenheit

C = conversion factor for sensible heat change, BTU/(cfm x hr)(degrees Fahrenheit)

Both the density and specific heat of air at room conditions depend on the humidity ratio of the air. The density also depends on the temperature. In a room at 75 degrees Fahrenheit and 50 percent relative humidity (RH), the air density is 0.073 pounds per cubic foot (lb/ft^3) and the specific heat is 0.24 BTU per pound. Therefore, C is 1.1 BTU/ (cfm)(hr)(degrees Fahrenheit) and Equation (7.3) becomes:

$$Q = \frac{H}{1.1\,(t_2 - t_1)}. \tag{7.4}$$

Long-term operation of high-heat-producing equipment can damage filters when exhaust air temperatures approach the temperature limit of the filters for continuous exposure to heat (see Chapter 3, Tables 3.5 and 3.6).

7.2.5 Empirical Flow Rates

It is important to design the ventilation system to provide a safe, ergonomically practical, and reliable unit. Experience has shown that filter pressure drops will vary, ductwork loss will be greater, and blower performance may be slightly different in actual working conditions (other variables also are discussed in this chapter). If the glovebox ventilation system does not perform as designed, it should not be used or commissioned until it meets the minimum safety requirements of this document and other referenced documents.

Troubleshooting an installation should include the inspection of the ductwork and installation of the blower (including wiring); the prefilter, inlet, exhaust HEPA filters; and the manifold (if equipped). Common problems with new installations include debris lodging in the ducting, blower housing, and filter housing and finding the blower motor wiring reversed. Long flexible connections will also affect performance since a bend can dramatically choke off airflow.

7.2.6 Exhaust Requirements

The maximum airflow rate from the glovebox determines the required capacity of the filters and the size of the equipment for the entire downstream portion of the ventilation system. The airflow resistance of the exhaust-air path must be sufficiently low so that pumping of gloves (pressure recovery) by operators in the box will not result in positive pressurization**.** In small low-flow boxes such as those with inert atmosphere, pressure surges due to glove pumping may be a serious problem. Fast insertion of the gloves can cause the glovebox to reach a zero or positive pressure. Although this is typical for most applications, another method called “passive recirculation” can be used to retain the inherent safety feature and larger filters for air cleaning functions. [Note: This method should not be used with pyrophoric materials because the inert environment will be lost during a glove breach.] Typically, the glovebox is fitted with an inlet and exhaust filter in a room air application. Another filter “emergency discharge” is added and fitted between the blower discharge and the inlet air filter. The blower installation connects the exhaust filter housing to the negative side of the blower, and the inlet filter installation connects to the positive side. When the installation is complete, the emergency discharge filter is in a standby condition. The ventilation unit basically recirculates the inert gas. If a breach or leak occurs, the emergency discharge filter becomes naturally activated. The path of least resistance during a breach discharges exhaust air through the emergency standby filter, since the inlet is now the gloveport. This filter should also be sized for the gloveport “inherent safety feature.” The filter should be rated for twice the cfm or half the pressure drop of the inlet filter. If the two filters, inlet and emergency standby, have the same airflow and pressure drop, the airflow will be directed to both instead of the emergency standby filter. If air is to be exhausted from the emergency standby filter, a bleed vent is necessary to prevent removing the inert gas and imposing additional negative pressure. When the glovebox ventilation unit is activated, there should be no flow through the emergency standby filter. If the secondary exhaust system is directly connected without a bleed vent, the glovebox pressure will become extremely negative. The vent allows room air to be removed until the emergency standby filter requires exhaust.

The maximum rate of exhaust flow from a room-air-ventilated glovebox is usually based on the required inlet flow when a glove is ruptured or inadvertently removed. The air velocity into the open port should be 125 ± 25 fpm. Good contamination control is more easily achieved in a glovebox with low air leakage. Gloveboxes should have a leakage of less than 0.02 to 0.5 percent box volume per hour, depending on the application requirements. In some applications, such as inert environments, a helium leak test is performed to ensure the integrity of the glovebox. The method, technique, and criteria for testing are given in AGS-G001, Section 9.11.4.[1]

7.2.7 Vacuum- and Pressure-Surge Relief

In some applications, gloveboxes must be protected against physical damage resulting from excessive pressure or vacuum. The exhaust and inlet supply system must be able to handle slowly manifested pressure or vacuum disturbances. Each glovebox containing service connections or internal equipment whose malfunction might cause a pressure surge should be equipped for prompt surge relief. This also applies to fire suppression systems, as outlined in DOE-STD-1066.[3] The response time and pressure-flow characteristics of the surge-relief device will depend on the flow and pressure characteristics of the pressure source, the free volume, and the relative strength of the gloves and glovebox. The relative strength is defined as the lowest pressure differential that will cause rupture of the glovebox pressure boundary at its weakest point. Depending on the design of the box, the weakest point will usually be a window or a glove. The surge-relief device can be a liquid-filled U-tube, as shown in **Figure 7.7**. The surge-relief flow capability should exceed the flow from the largest possible source of pressurization at the design relief pressure. The HEPA-filtered surge-relief line should not be connected to a glovebox exhaust manifold because this line will be subjected to the same pressure as the normal glovebox exhaust connection. A liquid storage reservoir is provided to handle the blown seal fluid. The filter and ductwork should be sized in accordance with the required cfm and pressure drop based on the pressure surge. The filter should be protected from impingement of the seal fluid. If room air cannot be tolerated in the glovebox, as is the case in some inert-atmosphere applications, a different vacuum surge-relief system must be used. A U-tube can be devised to restore its seal after relieving the surge, but such a system must include a feature to alert the operator that a pressure surge has occurred so that he can make the necessary safety checks. An inlet filter may provide surge relief if no backflow device or other restriction is provided. The filter face area would have to be about four times the area of an unfiltered port to achieve an equal venting effect.[3] [Note: Explosive venting is not covered in this Handbook.]

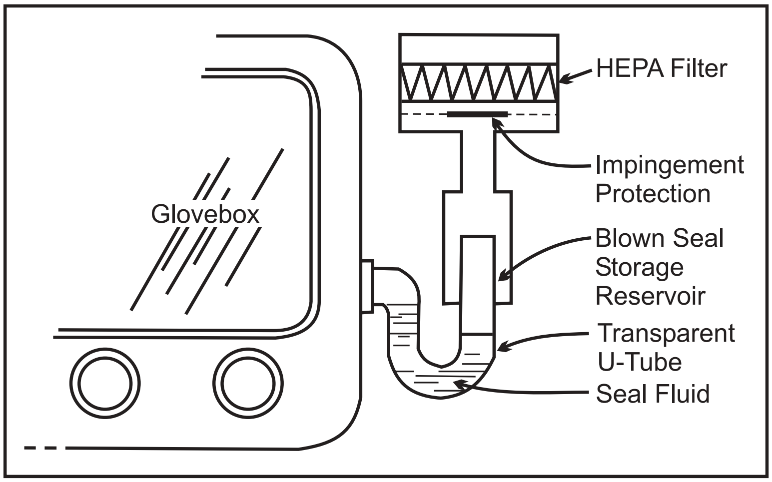


Figure 7.7 – Glovebox Vacuum-Pressure Surge Relief Device

7.2.8 Glovebox Exhaust Manifold

A glovebox exhaust manifold is used when multiple gloveboxes will share a common ventilation system. This method reduces the amount of exhaust ventilation components for dedicated exhaust systems. The glovebox exhaust manifold includes all of the glovebox exhaust system downstream from the point where the exhaust from two or more gloveboxes joins and the airflow is combined. Sections 7.2, 7.3, and 7.4 discuss details of the exhaust system and illustrate working examples.

The glovebox exhaust manifold draws air or exhaust gas from each connected glovebox at a controlled pressure and airflow (interdependently), houses secondary treatment facilities, and transmits the air for further treatment or exhausts it to the outside atmosphere. Primary exhaust treatment should be applied inside or as close to the glovebox as possible and, in all cases, before connection of the exhaust line to the exhaust manifold. It is critical to protect the manifold from contamination due to the difficulty of cleaning and decontamination. In some systems, a portion or most of the cleaned or treated exhaust gas may be recirculated back to the gloveboxes.

[Note: The manifold system should be sized and controlled to accept a range of flow whose high extreme is the sum of: (1) the maximum normal flow from each box (Sections 7.2.1, 7.2.2, and 7.2.3), (2) the largest maximum flow under removed glove conditions from one of each of five connected boxes (Sections 7.2 and 7.2.6), and (3) an allowance for system growth. The low extreme is the sum of the minimum flows from each box. An allowance for system growth should be provided at not less than 20 percent of (1) plus (2) above for a new system. If this allowance exceeds 50 percent of (1) plus (2), other provisions such as installing an equivalent dummy flow should be considered.]

7.2.9 Exhaust Cleanup Requirements

Providing As Low as Reasonably Achievable (ALARA) exposure to radioactive material is the guiding principle for determining the design of a glovebox ventilation unit. Protecting the exhaust downstream of the primary HEPA filter is paramount for nuclear installations. Experience has shown that exhaust systems are not only difficult to decontaminate, but have led to unnecessary operator exposures. It is also true that, after filter breakthrough, nuclear particles can migrate to all the gloveboxes in the chain. As discussed earlier in this chapter, a filter installation is only as good as the entire ventilation system.

When corrosive gases or vapors are in the exhaust airstream, all of the filters in a series will be exposed. The impression that the life expectancy of a group of HEPA filters arranged in series is dependent upon the number of filters in the series may be false when chemical or heat degradation occurs. Under these conditions, when the first stage fails, there is a potential for others to fail from the same cause. Corrosive gases and mists from vats, scrubbers, and similar equipment must be neutralized and removed before they reach the HEPA filters.

Installation requiring redundant HEPA filters must have provisions for in-place testing. The requirements are provided in ASME AG-1, Section TA[2] and ASME N510, *Testing of Nuclear Air Cleaning Systems;* [5] and if chemical detection systems are required due to possible filter installation damage, the monitoring system should be HEPA-filtered to prevent damage to the instrument. Many manufacturers supply testable filters of this type. These should be specified with upstream and downstream test ports. The filter flow should be consistent with the monitoring instrument airflow.

7.3 Glovebox Filter Installations

For the most part, the glovebox filter systems discussed in this section are first-stage (primary) HEPA filters, although redundant filters located upstream from the exhaust manifold (if equipped) connection are also discussed.

Filters must be able to perform properly whether they are clean or dirty. A maximum dirty-filter resistance of three times the clean-filter resistance for HEPA filters and two times the clean-filter resistance for prefilters is generally used for design purposes. **Figure 7.8** gives the approximate airflow and pressure-drop relationships for clean open-faced HEPA filters. **Figure 7.9** shows common locations for HEPA filters near or inside gloveboxes. Type 2C shows the installation of inlet and exhaust filters inside the glovebox.

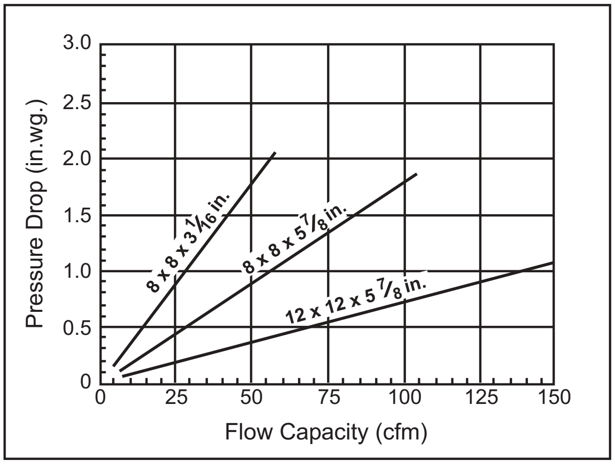
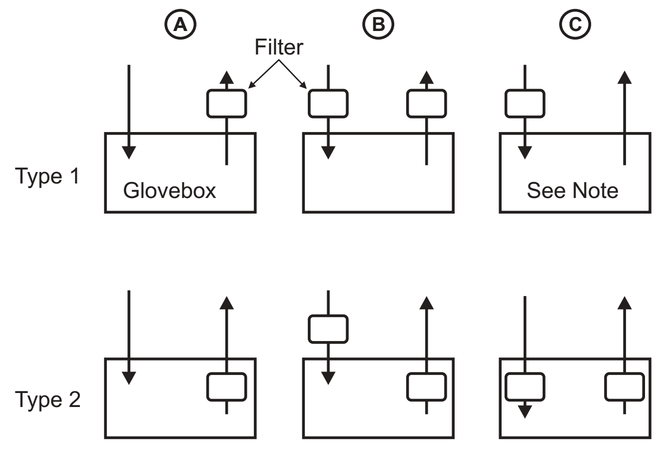


Figure 7.8 – Flow vs. Pressure Drop Relationship for Small, Clean, Open-face HEPA Filters

7.3.1 HEPA FILTERS

A detailed discussion of filter performance and construction materials is given in Chapter 3, Section 3.3. Operational experience with a particular system is the most reliable basis for filter selection for a particular service. For new and untried systems, the initial choice should be limited to the traditional site-specific, open-faced pleat, and should be constructed to the requirements of Section 3.2. These filters should also meet the requirements of ASME AG-1.[2] If exhaust streams are kept chemically neutral, as they



Note: Type 1C is not suited for containment of radioactive materials within the glovebox but is applicable where the intent is to exclude air borne particles from the glovebox space.

Figure 7.9 – Possible Arrangements of Filters Near or Inside Gloveboxes

should be for reliable exhaust system operation, HEPA filters of standard construction usually provide the most economical service.

A single-HEPA-filtered exhaust path is defined as a glovebox that does not involve highly toxic aerosols or potent, toxic, or radioactive materials, i.e., materials that do not pose a hazard to the operator during a filter change-out. A multiple-filtered exhaust path is defined as a glovebox requiring more than one line of defense from particle penetration. This occurs when the exhaust ductwork or manifold must be protected or the Most Penetrating Particle Size (MPPS) is well below the efficiency particle mean of the filters.

When continuous airflow is essential, two exhaust connections should be provided to avoid interruption of exhaust flow during a filter change and to provide standby protection in the event of system upset. The purpose of multiple exhaust connections is to allow an emergency connection to be made. **Figure 7.10** illustrates single- and multiple-filtered exhaust connections for a glovebox.

Multiple-filtered exhaust connections should be used when interconnected gloveboxes or a large enclosure with several compartmented work areas are needed. Compartmenting doors between work areas or between single boxes in an interconnected line must not isolate a work area with only one filtered exhaust connection. The multiple exhaust points required to handle total airflow in a line of interconnected boxes must be sized for maximum flow and valved individually for flow control. DOE-STD-1066[3] discourages the use of long lines of interconnected gloveboxes for fire control. Where they are necessary, fire doors between the gloveboxes should be provided. This would necessitate proper alarming and resolution of pinch-point concerns.

The glovebox designer should understand the limitations imposed by ergonomics. There is an art to designing the glovebox, ventilation service, and internal equipment operation and service. Some facilities build mockups of the glovebox concept to determine whether the operations can be done in a practical manner. It is critical to prove the practicality in some operator-intensive, hands-on operations and long-term production activities. Tasks performed within the confines of a glovebox should factor in the weight of the objects handled and the location of the operation(s) to be performed within. It is better to demonstrate the activities at the design phase than to wait for the glovebox to be built. Failure to do this can be very costly to repair and can seriously compromise operator safety.

The fatigue factor is high when working in a glovebox. The working pressure, heat, glove sleeves, gloveport location, and operations where the arms are outstretched all add to fatigue. Intricate or sensitive work significantly adds to fatigue because the operator cannot feel through the gloves. If visibility is poor or nonexistent, operations will be very difficult, if not impossible, to perform. Some operations with older gloveboxes used mirrors to perform some operations. [Note: This was done out of necessity due to poor design or a compromise with some other activity.] In glovebox terms, “extended reach” is used to describe an occasional operation where something is pulled forward to a working position or a simple operation such as turning a switch off or on (e.g., lowering or pulling out a spent filter for disposal). Extended reach should be avoided in repetitive or routine operations.

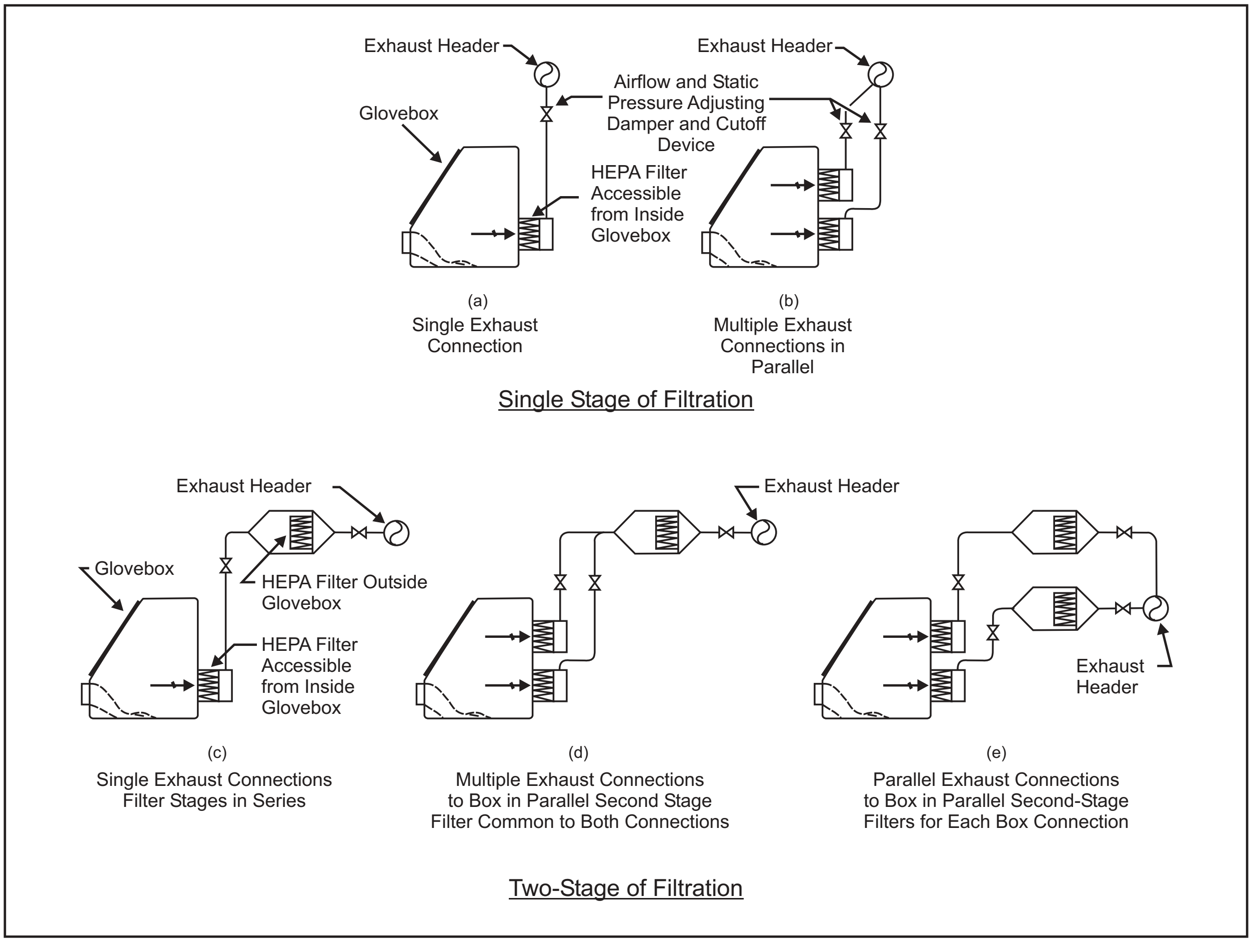


Figure 7.10 – Suggested Arrangements for Single- and Parallel-Filtered Exhaust Connections for Gloveboxes

7.3.2 HEPA Filter Selection Criteria

HEPA filters are available in many configurations for many applications. For most applications, glovebox HEPA filters are customized to meet industry needs. Not all the different filter housings described earlier are intended for nuclear service. These filter housings use different-sized filters with different types of seals. Filter selection should be based on airflow requirements and efficiency requirements. Airflows for protecting workers, venting fumes, and cooling are discussed in this section. The efficiency of HEPA filters is discussed in Chapter 3.

Another variable to application is efficiency. Selecting a more efficient filter for an application may be necessary to prevent particle bypass through a standard HEPA filter. The higher-efficiency filters are called Very Large-Scale Integrated (VLSI) filters. There are materials in use that have a greater amount of small particles below the MPPS for HEPA filters. These materials may pass through the HEPA filer unimpeded and migrate into the ductwork. Redundant filters can sometimes be used for these applications; however, this assumes that the area between the filters can be cleaned. [Note: VLSI filters are not approved for nuclear use and are referenced for nonnuclear applications).

Several of the characteristics listed below should be considered when selecting filters for use at nuclear sites.

- Uses a standard-size HEPA filter located in the back- or end-wall of the glovebox.
- Maximizes inside box space by partially recessing the filter in the wall.
- Provides adequate space to transfer the HEPA filter out of the glovebox (see **Table 7.1**).
- Has a simple clamping method with no removable pieces and is operable with a gloved hand by a simple, clean clamping mechanism.
- Has a retainer that serves as a face shield for the filter and permits attachment of a steel-cased prefilter by a flexible magnetic strip (accessible from the front); the filter remains in position after being unclamped because of the folded lip at the top.

Table 7.1 – Glovebox Bag-Out Port Sizes for Transfer of Standard Open-faced HEPA Filters

Filter Size	***Required Port Size (inches)***	
	Round (diameter)	***Rectangular***
8 × 8 × 2 1/16	9 3/4	8 ½ × 4 1/2
8 × 8 × 5 7/8	10 3/4	8 ½ × 6 1/2
12 × 12 × 5 7/8	14	12 ½ × 6 1/2
24 × 24 × 5 7/8	26	25 × 6 1/2
24 × 24 × 11 1/12	27 3/4	25 × 12

7.3.3 Prefilter Selection

Prefilters are used to extend the life of the more expensive HEPA filters located at the inlet and exhaust filter housings. These filters are disposable and should be routinely changed when they are loaded and affect the ventilation system. This can be determined by noting the sensitivity of glove movement and pressure recovery. In easily airborne powder applications where a significant amount of dust is airborne in a glovebox, removing the prefilter may be the only means to restore safety (negative pressure) to the glovebox during a powder mishap. Prefilters for gloveboxes come in a range of sizes and configurations. Some facilities use simple cut, in-place pads, and some use HEPA filters (not tested) to perform the prefilter function. This has been application-, site-specific-, and retrofit-driven. For some applications where air entering the glovebox is HEPA-filtered and there is little or no dust loading in the glovebox, an exhaust prefilter may not be needed. A prefilter should be considered on the inlet HEPA filter on the glovebox unless the glovebox resides in a cleanroom. Prefilters are manufactured from a fiberglass media similar to the HEPA filters. As a result, they are susceptible to the same chemicals, fumes, and heat damage. Some prefilters are manufactured with a beverage board (coated cardboard) frame, which should be avoided if fire is a concern.

Prefilters are typical of the type referenced in Chapter 3, Section 3.4, as Class I panel filters. The main advantage of these prefilters is cost, quick installation, and removal. There also is a distinctive ergonomic advantage. These filters are pushed into a channeled frame instead of tucked into and around a frame—a difficult operation when the exhaust filter is ceiling-mounted. Use of a separate removable frame is preferable in these applications. [Note: The ability to perform this operation should be based on either a mockup or an existing glovebox installation.]

Prefilter holding devices should be manufactured from the same material as the glovebox or a material that is resistant to the chemicals and fumes that will be present in the airstream. Retaining fasteners, when used, should be made of dissimilar materials that do not gall. It is better to dispose of a 302 stainless steel wing nut than to replace a 304-L stainless steel stud welded on a glovebox. The frame should be designed to minimize air bypass around the prefilter, yet allow enough clearance between the HEPA filter and prefilter to prevent media contact. An independent holding frame should be incorporated in the design to prevent disturbing another filter installation.

7.3.4 Inlet HEPA Filters

Work performed in gloveboxes frequently requires supply air that is free of airborne contaminants. Inlet HEPA filters help maintain clean conditions inside and, when chosen properly, also serve three other useful functions: (1) extending the service life of the exhaust filter by protecting them from atmospheric dirt loading, (2) preventing the spread of contamination from the glovebox to the room in the event of a glovebox pressure reversal, and (3) providing overpressure relief.

The design of the inlet filter installation is relatively simple for air-ventilated nonrecirculating gloveboxes. Since no duct connections are required, open-faced filters may be used with an installation and clamping method that leaves one face completely exposed. Typical methods of installation are shown in **Figures 7.11 and 7.12**. Because they are less likely to be contaminated, inlet air filters are easier to replace than exhaust filters; therefore, they provide fewer problems and less risk during changes. Whether mounted to the glovebox internally or externally (external mounting is preferred), the same high-quality mounting, clamping, and sealing are required.

The open face of the filter must be protected from physical damage and fire. Plugging of the inlet filter by smoke is a secondary concern, however, since one recommendation for glovebox fire suppression is to reduce normal airflow. Locating the inlet connection (or an attached inlet duct) high in the box tends to reduce the amount of air drawn into the box during a fire because of the chimney effect.

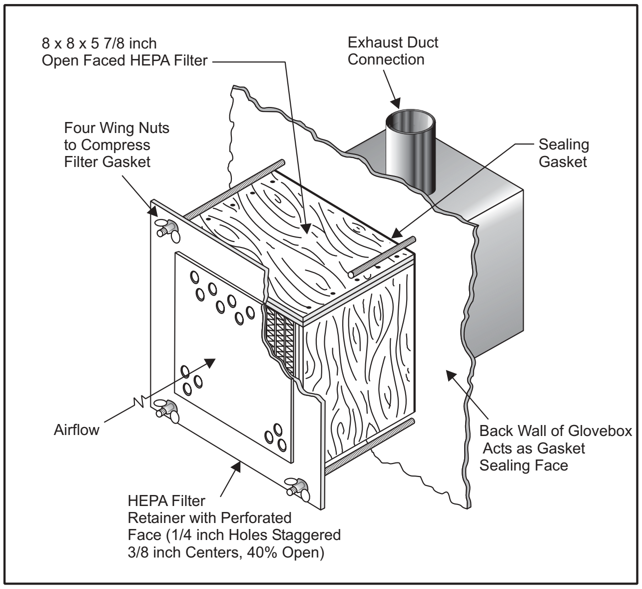


Figure 7.11 – Open-Face Filter Installation Method (a)

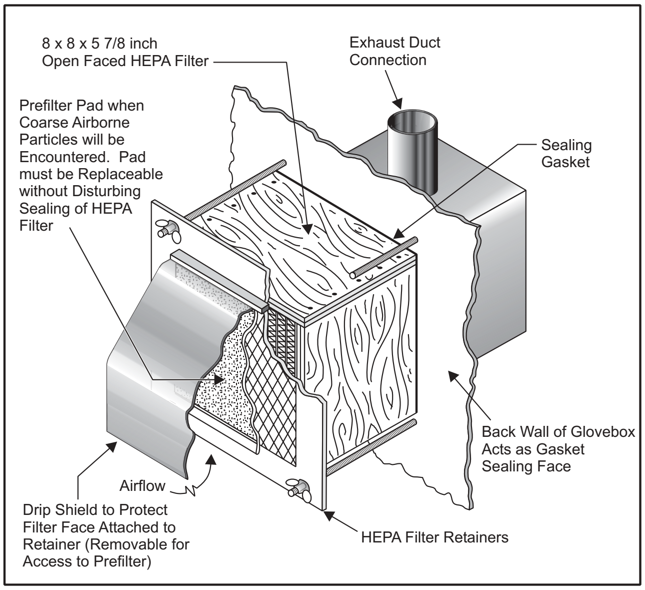


Figure 7.12 – Open-Face Filter Installation Method (b)

7.3.5 HEPA Filter Selection

The number of types and sizes of HEPA filters used at an installation should be minimized for logistical and operating economy. All HEPA filters should be constructed of fire-resistant materials. HEPA filter sizes used in glovebox systems vary, with square 8- × 8- × 3 1/16-inch; 8- × 8- × 5 7/8-inch; and 12- × 12- × 5 7/8-inch sizes and nominal airflow capacities of 25, 50, and 125 cfm, respectively. Glovebox filters should be operated at their design airflow. Wood-cased fire-resistant HEPA filters are less expensive and should be considered wherever the operating environment (temperature, humidity, etc.) permits. Most applications use 304 and 304-L stainless steel due to the robust nature of the casing and the chemical, fire, and humidity requirements. The "cartridge," as noted in Figure 7.5, comes in a round configuration with an 8-inch diameter.

Disadvantages of Enclosed and Open-Faced HEPA Filters. Disadvantages of both enclosed and open-faced HEPA filters include:

- Capacities are insufficient for large amounts of dust.
- Chemical fumes such as caustic or hydrofluoric acid mist can destroy filter medium separators and adhesives.
- Sharp corners and edges of metal casings can damage protective bagging.
- In dry atmospheres (less than 2 percent RH) the plywood of wood-cased HEPA filters may shrink and delaminate, eventually causing failure of the filter. Extremely low moisture levels may cause a shrinkage problem for particleboard casings as well. This could be an acute problem in inert atmospheres where very low moisture levels [less than 50 parts per million (ppm)] have to be maintained. In such systems, steel-cased filters should be used.

Open-faced HEPA filters have the following additional deficits:

- They are vulnerable to damage during handling and storage.
- They lack a handle or gripping area for easy withdrawal from an enclosure.
- It is difficult to replace damaged face gaskets.

Enclosed HEPA filters also have additional deficits:

[Note: They are not recommended for nuclear applications stated in Chapter 3.]

- They lack Underwriters Laboratories (UL) certification.
- Reeding (induced vibration of separators caused by air motion) at high flow rates is worse than in open-faced filters because the entering air impinges on a smaller area of the filter pack.
- Their weight is greater than that of open-faced filters.
- They cost substantially more than open-faced filters.
- They have greater space requirements.
- There is an air leakage problem with steel cases, especially in inert-atmosphere and high-pressure applications.
- There are no visible means of detecting damage to the medium.

7.3.6 Prefilters

As in larger systems, prefilters may be used in both the inlet and exhaust airstreams to extend the life of the HEPA filters used in glovebox filtration systems. Prefilters are inexpensive items, and the decision to use them requires the designer to evaluate the advantage of longer HEPA filter life against frequent glovebox system problems associated with limited space. Prefilters attached directly to the face of the HEPA filter provide no fire protection for that HEPA filter. Glovebox prefilter service often requires filters to be subjected to periods of high temperature, moisture, dust, and corrosive agents that shorten their effective life and mounting.

Experience with prefilters in glovebox ventilation systems has shown that the use of metal media is impractical. Without viscous coatings, the filtering efficiency of metal-media prefilters is poor, and these filters are often almost impossible to clean and decontaminate. Adhesives and oil coatings that improve particle retention reduce in-box cleanness and fire resistance. Experience clearly indicates that using conventional types of prefilters that require cleaning or decontamination or both before reuse also is impractical. Throwaway filters with simple installation methods are preferred. After use, the units are discarded as contaminated waste unless collected materials must be reclaimed. Glass-fiber-media prefilters are preferred because they offer good serviceability, low costs, and only a small amount of combustible content.

Inlet airstreams with HEPA filters should be fitted with prefilters when using atmospheric air. However, there may be no need for a prefilter when: (1) the room air has been cleaned of the bulk of its airborne dust by building supply-air systems, (2) local room activities do not generate dust and lint that can be drawn into the box, and (3) airflow through the HEPA filter is less than 75 percent of its rated capacity.

A common method of prefiltering in older gloveboxes is to clip a thin (1/8- to 1/4-inch) fiberglass pad to both the inlet and exhaust HEPA filters, as shown in **Figure 7.13**. Neither plastic foam nor organic fiber should be used because both are flammable. The pad is cut to fit the face of the HEPA filter and is clipped to the filter retainer. This method of attachment permits easy removal of the prefilter pad without disturbing the seal of the HEPA filter. Normal usage generally requires frequent replacement of the prefilter pads, which do not have much dirt-holding capacity and can quickly become plugged by house dust and lint. Convenient methods of attaching the prefilter pads are essential to simplify the operations performed inside the glovebox. Frequent replacement of prefilter pads provides the following benefits:

- Air resistance (pressure drop) does not change rapidly, which allows airflow to remain more constant without frequent manipulation of airflow dampers.

- Accumulation of combustible dust in the exhaust path is lessened, thereby providing better fire protection for the HEPA filter downstream if the prefilter is not applied directly to the face of the HEPA filter.

- The exhaust path can pass a greater airflow when relieving an emergency condition.

Thin fiberglass pads (1/4-inch thick or less) can provide average atmospheric dust collection efficiency of up to 20 percent with low airflow resistance. Thin, clean fiberglass pads used at air velocities of 35 fpm will create an initial pressure drop in the range of 0.03 to 0.15 in.wg. For applications where long-term continuous processes hamper regular maintenance of in-box filters, the designer must include the following provisions:

- Greater suction pressure (well below the limit that would subject glove or box integrity to unsafe differential levels) controlled by the damper to allow longer use of prefilters;

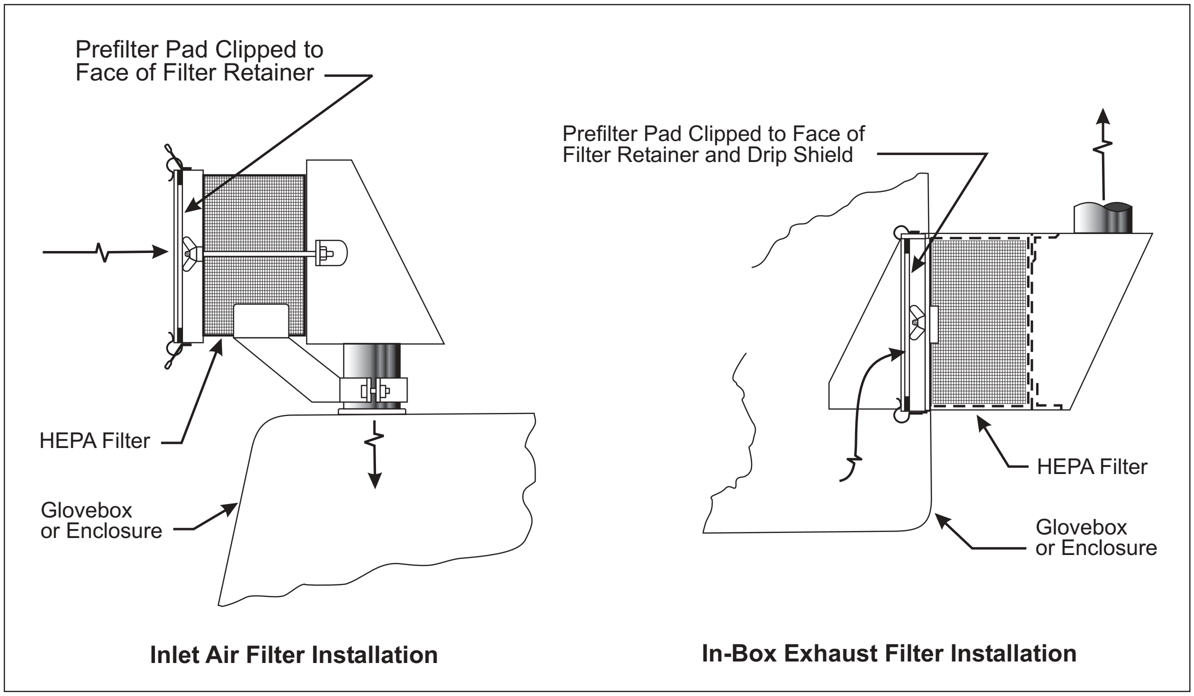


Figure 7.13 – Typical Installation of Prefilter Pads on Face of HEPA Filters

- Larger prefilters; and

- Selection of a prefilter with less initial resistance to permit longer use, even with lowered collection efficiency.

7.3.7 Roughing Filters

In some installations, it is desirable to recover material from the filters for either reprocessing or waste minimization. Roughing filters may be used for this purpose. The filter medium is typically less efficient than that of the HEPA filter. Construction materials may be suitable for the recovery process (Category 3 - combustion, acid dissolution, etc.), but must not present a hazard to the downstream prefilter and HEPA filters. Fire screens, etc., must be used to prevent roughing filters from impacting downstream prefilters or HEPA filters.

7.4 Filter Replacement

Safe replacement of a contaminated glovebox filter must be planned in the design phase to facilitate proper execution. The filter change method and other maintenance functions, if not site-specific, should be determined and planned. The designer should prepare a written preliminary filter change procedure along with the design documents. If the design is questionable due to an extreme custom nature, the glovebox should be mocked up so that an operational demonstration can be performed. [Note: In the past, special tools were used to perform filter and maintenance operations out of necessity and should be avoided, if possible.] In applications where controlled inert atmospheres are present, filter changes should be planned for times when other routine or special maintenance operations are taking place inside the box to reduce interruptions to operations and loss of inert gas, and to minimize the time required to reintroduce the inert gas into the box spaces.

The operational team directly involved in a filter change-out must wear appropriate respiratory protection, as specified by site-specific requirements. Filters installed inside the glovebox must be accessible via the gloves on the glovebox. When total contaminant activity is high, additional protective measures may be necessary to reduce worker exposure. One of the safest and most common methods for preventing the spread of contamination while maintaining confinement is bagging the filters in and out of the glovebox. The plastic bagging materials used are discussed in Chapter 6, Section 6.2.3. When inert-atmosphere or oxygen-free environments are used inside the glovebox, additional provisions may be required to prevent air leakage into the box.

Replacement of a HEPA filter inside an air-ventilated box involves many steps that must be performed sequentially. Standard Operating Procedures must be written, and the filter change team must be trained to perform the operations in a safe, controlled manner. Close coordination between maintenance and operating personnel is necessary to establish a mutually satisfactory date and time for the filter change, to identify the boxes and systems involved, to procure the necessary materials, and to schedule personnel. The health and safety requirements of the industrial hygienist, health physicist, and safety engineer must be established. One of these specialists should be designated the health and safety supervisor and should be available to monitor the operation and assist as necessary.

When the necessary materials and tools are ready and all personnel have been instructed in their specific duties, final permission must be secured from the responsible operator to alter the airflow and replace the filters. The flow path of the exhaust system should be thoroughly understood, and persons responsible for related exhaust systems that will be affected should be forewarned. For instance, if two glovebox exhaust systems manifold to the same blower, final filters, and stack, the removal of one system from service for a filter change will affect the system flow and pressure characteristics of the other system. Safety clothing and respiratory protection should be worn as directed by the health and safety supervisor. The following steps are suggested for changing a filter and placing a box back in service:

1. Cease all glovebox operations and contain unsafe materials in suitable containers.

2. Cut off gas flow to the glovebox affected, and adjust flow through the remaining branches to restore a safe negative pressure and flow rate in each.

3. Bag a clean replacement filter (and prefilter if used) in a small, clear plastic bag with sufficient tape to hold the spent filter and prefilter with all of the hand tools required, as shown in steps A, B, and C of **Figure 7.14**. It is recommended that the hand tools needed for filter changing be introduced the first time the filters are changed, and then left in the glovebox for subsequent use if space and environment permit. Decontamination is often more costly than tool replacement.

4. Using the glovebox gloves, remove the dirty filter and prefilter from their mounting frame.

5. Insert the dirty filter and prefilter into an empty plastic bag along with any residual materials, slowly expel excess air, and seal with tape.

6. Inspect the gasket sealing face or fluid seal knife-edge of the mounting frame and clean if necessary. Place the replacement filter in position and secure the clamping devices. Place the new prefilter in position and secure.

7. Remove the dirty filters and all debris from the glovebox and place the removed items in a container for contaminated waste disposal.

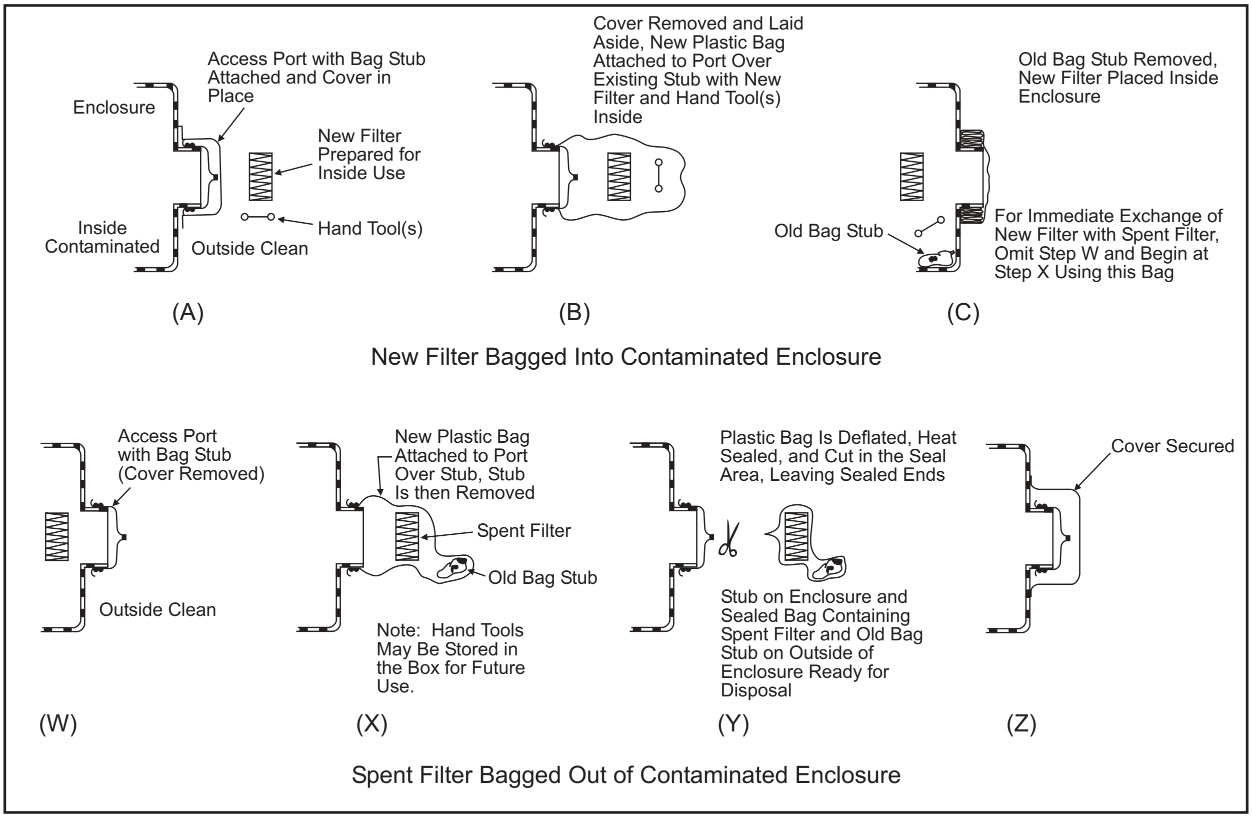


Figure 7.14 – Filter Changing Process

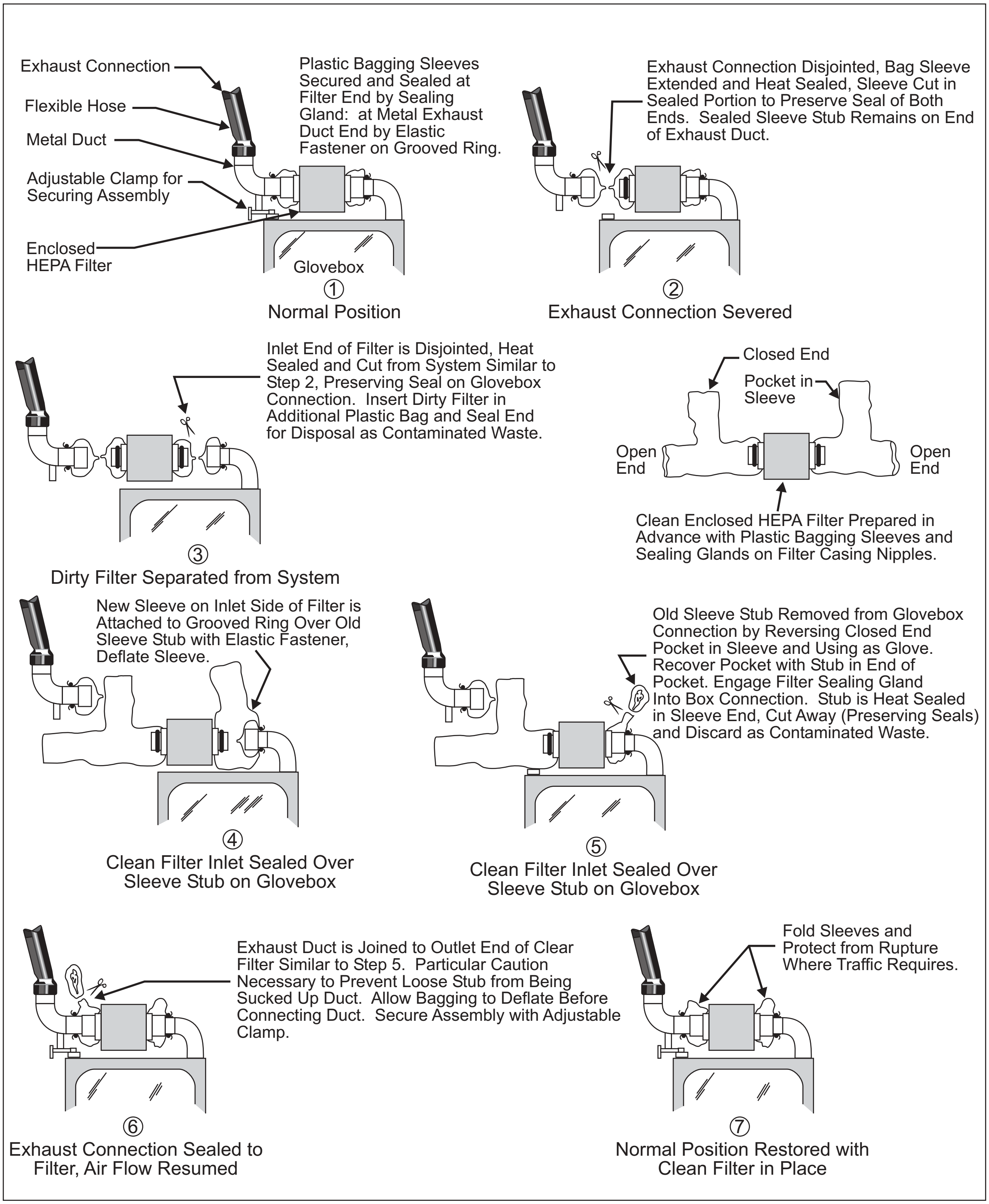
8. Restore airflow through the glovebox and adjust the flow and negative pressure throughout the system.

9. Before glovebox operations are resumed, test the newly installed HEPA filter with challenge agent, using the permanent test connections on the housing. If the test result is not satisfactory, stop the flow and inspect the filter for damage. If no damage is apparent, reposition the filter, restore the flow, and retest the filter. If the second filter challenge is unsatisfactory, the filter should be replaced and steps 3 through 9 should be repeated. Continued leakage suggests a mounting frame failure, filter damage, or a faulty test, and each possibility should be examined in detail until the fault is discovered and corrected.

10. Decontaminate the area.

11. After successful filter replacement, notify the responsible operator.

Filters located external to a glovebox (used in some older glovebox installations) require convenient access for changing, and it is usually necessary to interrupt airflow during the change. Since they are located outside the glovebox, highly contaminated filters must be bagged during the change. Different bagging techniques provide different degrees of protection. The technique shown in **Figure 7.15** is an old method of filter change, and is not recommended in new installations. This method seals both ends of the air ducts, and no flow can occur downstream while the filter is removed. When uninterrupted airflow through a box is required, this method of filter change necessitates the use of multiple exhaust connections on the box. An out-of-box filter in the process of being removed from a system by the procedure, illustrated in Figure 7.15 Step 3, is shown in **Figure 7.16**. [Note: This type of installation should not be used on future nuclear installations due to the potential for contamination release and cleanup. Further, note that flexible hose connections as shown in Figure 7.15 should never be used for new nuclear applications.]



Plastic Bagging Sleeves Secured and Sealed at Filter End by Sealing Gland: at Metal Exhaust Duct End by Elastic Fastener on Grooved Ring.

① Normal Position

Exhaust Connection Disjointed, Bag Sleeve Extended and Heat Sealed, Sleeve Cut in Sealed Portion to Preserve Seal of Both Ends. Sealed Sleeve Stub Remains on End of Exhaust Duct.

② Exhaust Connection Severed

Inlet End of Filter is Disjointed, Heat Sealed and Cut from System Similar to Step 2, Preserving Seal on Glovebox Connection. Insert Dirty Filter in Additional Plastic Bag and Seal End for Disposal as Contaminated Waste.

③ Dirty Filter Separated from System

Clean Enclosed HEPA Filter Prepared in Advance with Plastic Bagging Sleeves and Sealing Glands on Filter Casing Nipples.

New Sleeve on Inlet Side of Filter is Attached to Grooved Ring Over Old Sleeve Stub with Elastic Fastener, Deflate Sleeve.

④ Clean Filter Inlet Sealed Over Sleeve Stub on Glovebox

Old Sleeve Stub Removed from Glovebox Connection by Reversing Closed End Pocket in Sleeve and Using as Glove. Recover Pocket with Stub in End of Pocket. Engage Filter Sealing Gland Into Box Connection. Stub is Heat Sealed in Sleeve End, Cut Away (Preserving Seals) and Discard as Contaminated Waste.

⑤ Clean Filter Inlet Sealed Over Sleeve Stub on Glovebox

Exhaust Duct is Joined to Outlet End of Clear Filter Similar to Step 5. Particular Caution Necessary to Prevent Loose Stub from Being Sucked Up Duct. Allow Bagging to Deflate Before Connecting Duct. Secure Assembly with Adjustable Clamp.

⑥ Exhaust Connection Sealed to Filter, Air Flow Resumed

Fold Sleeves and Protect from Rupture Where Traffic Requires.

⑦ Normal Position Restored with Clean Filter in Place

Figure 7.15 – An Older Method of Filter Change [Note: Not recommended for new installations, a bag-in/bag-out filter housing is recommended for new installations.]

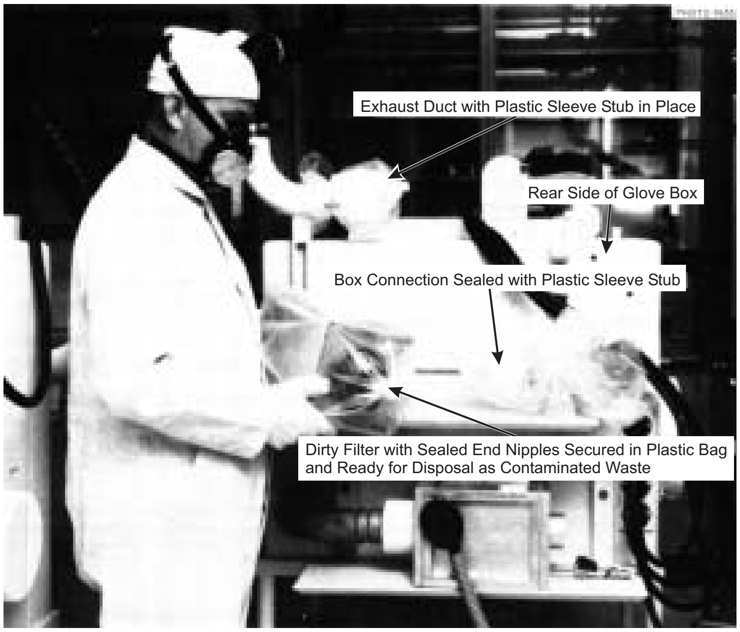


Figure 7.16 – Removal of an Out-of-box Filter

For other methods where bagging does not block the airflow path (e.g., using the housings represented by Figure 7.15), but merely encapsulates the filter being removed or replaced, there is a dependence on the damper in the duct to prevent blow-by (leakage) during a filter change. In other methods, isolation dampers or valves are used to isolate the filter during a filter change. The filter housing is still adjusted to the glovebox to remain slightly negative in pressure. The technique of bagging filters from housings (Figure 7.15) offers protection only for local personnel and the service area where the filter mounting device is located. The side of the system downstream of the filter is protected not by bagging, but by leak-proof dampers and flawless handling of the dirty filter. Because any dislodged particles will be swept downstream when airflow is restored, downstream HEPA filters should be provided to intercept these particles.

7.5 Glovebox Safety

The history of glovebox safety in the United States began with the use of very unsophisticated gloveboxes of simple design for simple operations. These were "sandblasting-style" gloveboxes with and without filters. Some early gloveboxes were actually manufactured from plywood. Glovebox use evolved from the need for safe working environments and reduced operator exposure. This evolution led to more complex gloveboxes and more complex problems. Most lessons learned were the result of accidental experiences. Simply put, many variables existed due to lack of experience with glovebox use. Through all of these experiences, much was learned about ergonomics, operator safety, the importance of training, and fire and explosion protection. Ergonomic problems related to handling material, performing service functions, and transfers were discovered early and are still a critical requirement in glovebox design. Operator safety has improved as a result of better glovebox designs with less operator intervention. Training has become a critical path from design through commissioning, operation, and decommissioning. Fire prevention is important enough that a chapter in DOE -STD-1066, *Fire Protection Design Criteria*,[3] was written specifically for gloveboxes.

7.5.1 Protection Against Fire and Explosion

The current guidance regarding fire and explosion is given in DOE-STD-1066[3] and DOE O 420.1, *Facility Safety*[6] which outlines the requirements for glovebox applications needing fire suppression (see Chapter 10 for more discussion of fire protection).

Fire Protection. Applications employing fire protection are guided by the following principles:

- Use nonflammable materials as much as possible in construction. Gloves and windows are the most susceptible to fire due to their construction materials. Laminated or tempered safety glass is the material of choice regarding fire. [Note: For applications where explosion, overpressure, or moving or rotating machinery are a concern, impact-resistant, fire-retardant polycarbonate should be used to protect the worker.] Some material hazards may also dictate the use of high-impact material due to the hazards to operating and maintenance personnel from a cracked or broken window. Some applications resolve this problem by placing a layer of glass inside the glovebox.

- Strictly adhere to acceptable housekeeping practices. Spontaneous combustion of certain materials can occur in a glovebox as well as in the secondary work area.
- Avoid the use of flammable materials within the box wherever possible and limit the amount of flammable material to the calculated air change (see Section 7.2) when no suitable nonhazardous substance can be substituted. Use containers for flammable substances that are approved for the planned operation.
- Maintain a current in-box material inventory. Gloveboxes should be used as designed. They are inappropriate for long-term storage, especially for chemicals.
- For inoperative gloveboxes, establish a safer, glovebox configuration and periodically check to ensure the gloveboxes are in a safe condition. Precautions include isolating boxes by closing fire stops, checking through-flow, checking port covers, disconnecting electrical equipment, and removing corrosives.
- Design the box with downdraft ventilation (high air inlet, low outlet) if possible to inhibit combustion while still purging the box. Generation of light flammable gases by the process may dictate exhausting from the top.
- Provide a protective atmosphere (see Section 7.5.2). This measure is listed last because those preceding it are applicable to all gloveboxes, whereas inerting is used only when there is too much risk involved in operating without a protective atmosphere. Assessing the degree of risk involved in an operation is often a subjective evaluation.

7.5.1.1 Detection

A glovebox fire detection system is recommended when there is a high risk of fire determined by a Fire Hazard Analysis (FHA). If flammable solvents, coolants, packaging materials, etc., must be present during operation, especially in unattended boxes, a heat detector should be installed on the glovebox. Fire detectors should be consistent with DOE-STD-1066.[3] Fire detectors are required in plutonium gloveboxes due to the pyrophoric nature of the material.

7.5.1.2 Suppression

Since a fire within a glovebox may be of paper, chemical, electrical, or pyrophoric metal origin, there is no single suppression method that is best for all gloveboxes. This is discussed thoroughly in detail in DOE-STD-1066.[3] However, when designing a glovebox, the designer should be aware of the materials, material quantities, process, and interfacing equipment that will be involved in the installation. At this point, the FHA should determine the proper suppression system for the installation. The fire suppression system must not cause a breach of the glovebox confinement that can spread contamination and increase the personnel exposure hazard to an unacceptable level.

There is no assurance that filters will remain functional during and following exposure to fire, smoke, or burning debris. Variable destructive effects on prefilters and HEPA filters include the temperature reached during a fire, the quantity and density of the smoke released, and the duration of the fire.

7.5.2 Inert Environments

Inerting a glovebox environment is done when working with materials that are pyrophoric, oxygen-sensitive, or moisture-sensitive, or when a process must be protected. Inert gases such as helium, argon, and nitrogen are metered into a gas-tight glovebox to displace the "air" volume. The characteristics of the gas (lighter than air, heavier than air) are applied using proper sampling sensors to obtain a true inerted glovebox. In pyrophoric and high-fire-potential applications, oxygen sensors are used to verify real-time concentrations. Inline filters should be installed to protect the oxygen monitor, or any monitor, from contamination. Monitors and sensors are available for many different types of gases and fumes. These should be selected when fire, explosion, and any associated risk to the process would result in danger to personnel and/or the facility. This should be determined by the facility risk and fire assessment groups. In most of these instances, the facility fire department should be directly connected to any alarms related to the event.

Gas-tight systems require quality construction of all components including gloveboxes, filters, and associated ducts. Any air ingress associated with the filter mounting or connecting duct will adversely affect the quality of the inert atmosphere that can be maintained in the glovebox and thus the cost of inert gas purification. Penetrations used to pass electrical input/output signals and power into the glovebox should be hermetically sealed for this purpose.

In fire protection applications, the preventive step of inerting is safer, though more expensive, than extinguishing a fire if it does occur. However, oxygen must be reduced below 1 percent before it fails to support the burning of some pyrophoric metal.[1] The use of dry air (RH less than 20 percent) reduces the hazard of pyrophoric metal fires, but does not eliminate it. Moisture in the presence of heated pyrophoric or reactive metals (e.g., finely divided plutonium) increases the possibility of explosion by generating hydrogen. The suitability and cost of an inert gas for the process are significant factors when selecting this type of fire control. The gas flow rate in most inert gas boxes is generally low. The flow must be consistent with required box-atmosphere purity levels, the scrubber, or the inert gas purification system that supports it. The inert gas may be purged on a once-through basis or recirculated through a purification unit. Purification, scrubbers, etc., should be protected with HEPA filters. Some of these systems are equipped with filters; however, it should be noted how the filter is safely changed while maintaining a level of confinement. Gloveboxes usually have filters installed for this purpose, the designer should assess the potential for equipment contamination and cleanup.

7.5.3 Control and Instrumentation

Glovebox instrumentation may range from simple indicators and alarms to sophisticated control systems. The type of control or instrument used will depend on the characteristics to be monitored, the relative hazards, and the method and time available to correct an upset condition. Operational characteristics to be measured and alarmed should always include the differential pressure between box and surroundings, the filter resistance, the gas flow rate through the box, and the box atmospheric temperature. An alarm should be available for any activity that could lead to degradation of or loss of confinement; fire; or any other safety concerns. In addition to instruments and sensors on the box, it may be necessary to indicate and provide for readouts and/or alarms at a central panel for oxygen content, liquid level, neutron flux, gamma flux, fire, and explosive gas mixture inside the box.

When a monitored characteristic requires annunciation for safety when the level of a monitored parameter passes some predetermined point, the alarm may be local. For example, an alarm may alert the operator to an upset condition (e.g., when the glovebox pressure differential becomes less negative than its design relative to the surroundings) or it may signal an annunciator panel in an adjoining "cold" area (e.g., by the entry door to the glovebox room, in a control room, or both). Standard operating procedures and sufficient information on the current contents of each box should be available to assist evaluation of the hazard area when an alarm sounds and to aid in planning corrective action.

Minimum instrumentation for a glovebox ventilation system should include devices to indicate the differential pressure between the box and its surroundings, exhaust filter resistance, total exhaust flow rate, and exhaust air temperature. **Figure 7.17** shows the arrangement of indicating devices in a glovebox ventilation system. The items shown above the double-dashed line indicate the types of instruments commonly used to supplement the minimum instrumentation necessary to improve safety for a particular operation or circumstance. For example, when box operators are not in full-time attendance for a continuous process, a sensor can be provided to monitor abnormal pressure, temperature, or almost any other critical process parameter and to actuate a remote alarm where an attendant is stationed. **Figure 7.18** shows an example of a local mounting for a differential pressure gauge (commonly referred to as a differential pressure gauge) on top of a glovebox. The instrument should be mounted near eye level, and the indicating face should be located so that the operator has a clear view while manipulating the gloves. The gauge display should make operating conditions easily discernible to the operator (e.g., a differential pressure gauge with a range of 1 in.wc with "0" at the top). Sensing lines should be short and should be sloped directly back to the glovebox so that moisture will not pocket in the tube. Inline HEPA filters either should be located inside or as close to the glovebox as possible to prevent contamination migration into the gauge lines and gauge. Tubing should be at least 3/16 inch-diameter to allow the instrument to respond quickly to rapid changes in pressure. Use of a three-way vent valve at the gauge permits easy calibration (zeroing) without disconnecting the sensing tube. Calibration of glovebox differential pressure gauges should be done routinely.

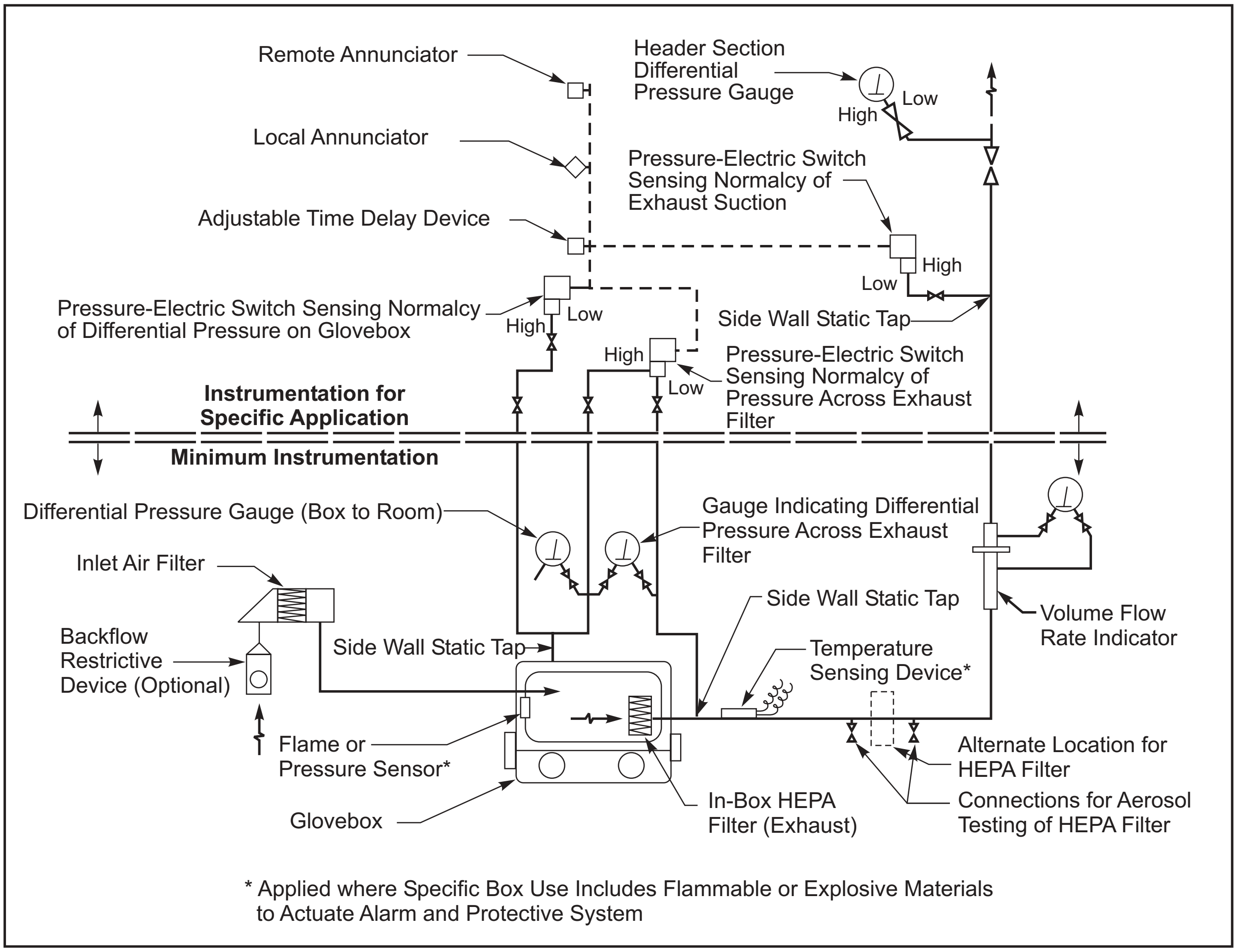


Figure 7.17 – Arrangement of Indicating Devices in Glovebox Ventilation System

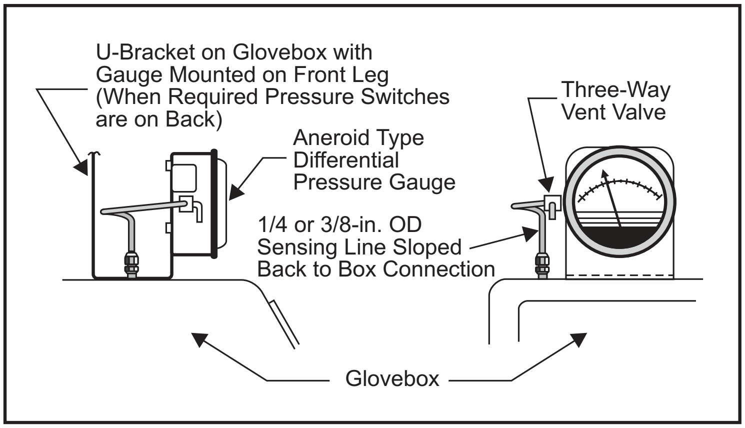


Figure 7.18 – Typical Local Mounting for Differential Pressure Gauge

Selection of a differential pressure gauge, differential pressure gauge with switch, or transducer should be determined by the application. One advantage of using a gauge is simplicity. A line is connected across the upstream and downstream plenums of a filter where the pressure drop can be measured. Most gauges and transducers install in this manner. A differential pressure gauge with switch has the addition of an alarm function. A transducer allows multiple readouts and greater accuracy, and can be used to automate the exhaust system. It is more costly, however, because it must have a power supply, readout, and transducer. The requirement for a gauge should be based on the actual system pressure. Exhaust filter pressure drops, for example, can vary up to 3 in.wg. If the inlet filter housing valve is closed, the device will see the full negative capacity of the blower. The gauge or transducer must have a proof pressure greater than the maximum system pressure (negative or positive) so that it will not be damaged by excessive pressure.

Devices that measure pressure have a problem with “drift.” This occurs on most devices because of continual pressure on the device. As a result, they must be recalibrated on a routine schedule. Liquid-filled devices (manometers) are not recommended for glovebox pressure indicators; however, they have been used to check the calibration of an existing device. Inlet filters on air-ventilated gloveboxes generally do not require differential pressure gauges. The pressure drop across the inlet filter is approximately the same as the box pressure.

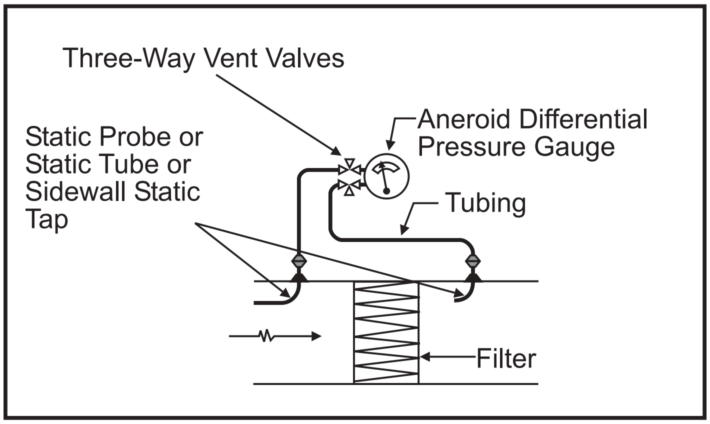


Figure 7.19 – Indicating Pressure Drop through a Filter

A differential pressure gauge should be provided for each exhaust HEPA filter stage to indicate filter resistance. Pressure-sensing connections can be provided to permit the use of portable instruments. Suitable alarms or controls that can function on small pressure differentials (equal to 0.25 in.wg) are difficult to keep calibrated and are often expensive. **Figure 7.19** shows a method for indicating pressure drop through a filter. Chapter 5, Section 5.6, gives some further information on differential pressure instrumentation.

Instruments used to measure airflow rates from gloveboxes include an orifice plate, venturi meter, flow nozzle, and calibrated Pitot tube. The important point is to use a simple, trouble-free device that gives reliable readings within an accuracy of ±15 percent. When free moisture is absent, a Pitot tube is the least expensive and most adaptable device for the small volume flow rates associated with glovebox ventilation. Velocity pressure measurements (corrected for Pitot-tube single centerline location) for airflows and duct sizes common in glovebox applications are given in **Figure 7.20**. The corrections shown are for air at 60 degrees Fahrenheit and 14.7 pounds per square inch absolute (psia), and neglect the Pitot-tube coefficient. Pitot tubes are available with coefficients of 1.00, but there is an advantage in using the more common commercial Pitot tube with a coefficient of 0.825 at low flow velocities. The equation for measuring velocity with a Pitot tube is shown below.

$$V = K\,(2gh)^{1/2}, \qquad (7.5)$$

where:

V = fluid velocity, ft/sec

K = coefficient of the pitot tube

g = acceleration of gravity, 37.17 ft/sec^2

h = velocity pressure (ft) of the air-gas stream

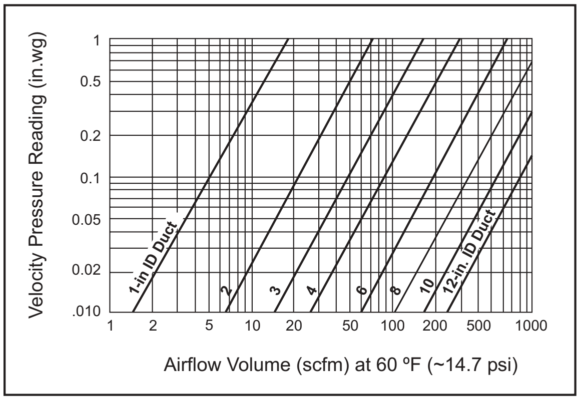


Figure 7.20 – Velocity Measurements

The following equation is used for air at standard conditions:

$$V = 4005\,K\,(hw)^{1/2} \qquad (7.6)$$

where:

V = fluid velocity, fpm

hw = velocity pressure, in.wg.

A Pitot tube with a coefficient of 0.825 has a velocity pressure reading that is 1.47 times the velocity pressure reading of the Pitot tube with a coefficient of 1.00 for the same fluid velocity. This pressure differential allows the low velocities often encountered in glovebox ventilation to be measured more easily.

Figure 7.21 shows the arrangement of a round orifice in a straight section of metal duct. Either method (Pitot tube or orifice) can be used to read the flow volume directly on a properly calibrated gauge. For a thin, sharp-edge, round, concentric orifice with the properties given in **Figure 7.22**, the flow rate can be determined with sufficient accuracy for glovebox applications by the following equation:

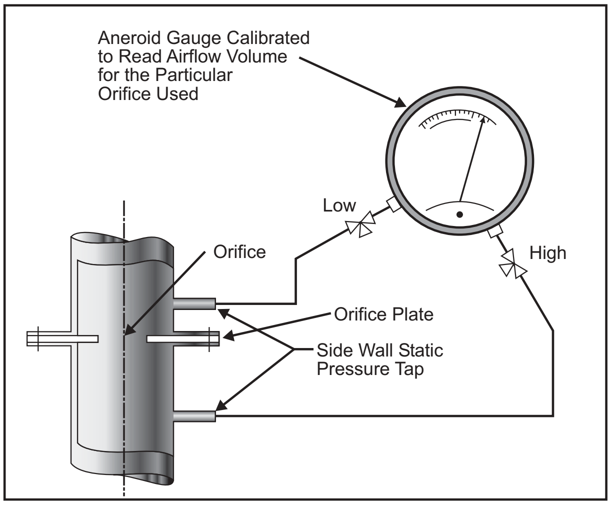


Figure 7.21 – Orifice Meter Method of Measuring Volume Flow Rate in Small Ducts

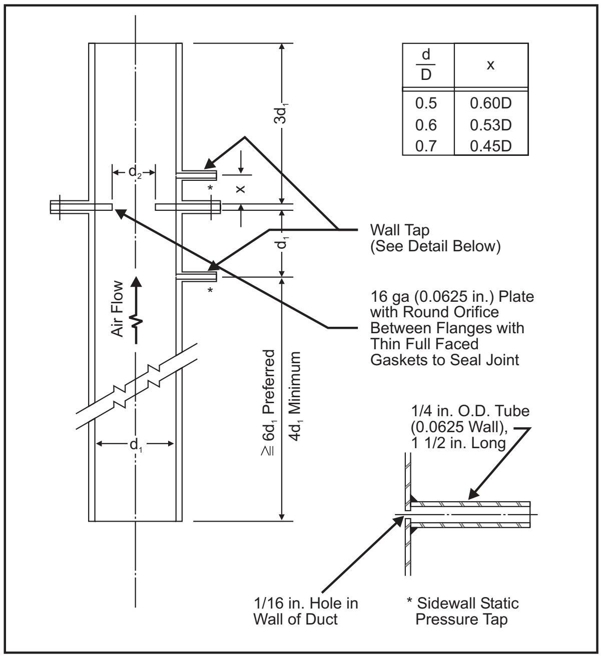


Figure 7.22 – Arrangement of Sharp-Edge Concentric Orifice in Small Duct

$$Q = 14\, d^2 h^{1/2} \tag{7.7}$$

where:

Q = airflow, cfm

d = orifice diameter, inch

h = pressure drop across orifice, in.wg

Assumptions inherent in the constant 14 used in equation (7.7) include: (1) air at standard temperature and pressure, (2) flow coefficient for orifice = 0.65, and (3) ratio of orifice diameter to smooth-duct diameter, D, $0.2 = d/D = 0.7$. The practical use of this formula can be shown by the following example.

Determine the orifice size necessary for a 20-cfm airflow rate that would give a reading near the center of scale on a 0- to 0.50-inch-range gauge.

$$\begin{gathered} Q = 20\ cfm \\ h=\frac{0.50}{2}=0.25\ in.wg \\ d=\frac{Q}{14h^{1/2}}=\frac{20}{14(0.25)^{1/2}} \\ d = 1.79\ in. \end{gathered} \tag{7.8}$$

For 3-inch schedule 10 stainless steel pipe (3.260-inch-diameter), the d/D ratio is $1.79/3.26 = 0.55$, which is within the acceptable range.

A shortcoming of the thin-plate orifice is loss of head of the air flowing through the device. **Table 7.2** gives the loss of head of concentric orifices for various d/D ratios.

Table 7.2 – Loss of Head for Various d/D Ratios

d/D ratio	***Fraction of Velocity Head Not Regained***
0.2	0.95
0.3	0.89
0.4	0.83
0.5	0.74
0.7	0.53

In the example above, 0.70 × 0.20 = 0.14 in.wg is the pressure loss when 20 cfm flows through the orifice of $d/D = 0.55$.

Immediately after installation and while filters are still clean, the measured pressure drop across the HEPA filter can be used to check airflow to a high degree of accuracy by proportioning the measured pressure drop to that stamped on the filter case at the time of predelivery testing. The pressure drop across the filter is no longer a dependable indication of gas flow rate after the filter has accumulated dust. After a filter has been in service for a period of time, it is necessary to measure both the pressure drop across the filter and the airflow through it to evaluate the filter's status and relationship to the whole ventilation system.

Written procedures for periodically testing each alarm, control, and emergency system serving the glovebox and its ventilation system are essential.

7.5.4 Challenge Aerosol Testing of Glovebox Filters

Testable HEPA filter installations must be tested immediately after installation and then again periodically to ensure that air cleanup capability and confinement integrity remain intact. The principles of challenge aerosol testing of HEPA filters are given in Chapter 8. The HEPA filters used in glovebox systems are often inconvenient to test because the challenge aerosol must be injected into the inlet duct or glovebox. The challenge aerosol cannot be fed into the inlet of the box to test the exhaust-side filters if high-efficiency filters are used in the inlet. Methods A and B (**Figure 7.23**) require the challenge aerosol to be drawn into the glovebox by the suction of the exhaust system. However, the challenge aerosol should not be injected into gloveboxes housing apparatus with open or exposed optical lenses or with highly polished surfaces, delicate balances, crystalline structures, sensitive conductors, or similar equipment or products. In such cases, the filter should be installed in the duct downstream of the glovebox so that the injected challenge aerosol will not back up into the glovebox proper. Method C (**Figure 7.24**) may then be used for challenge aerosol testing of the exhaust HEPA filter.

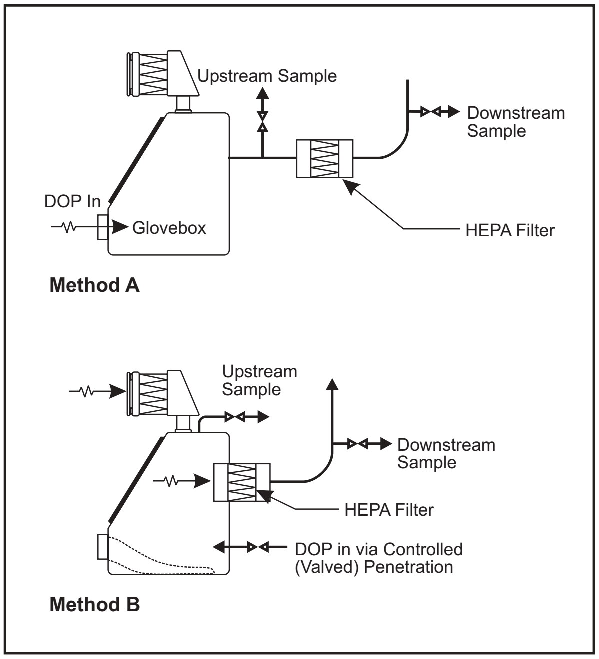


Figure 7.23 – Methods of Injecting Test Aerosol and Extracting Samples (Method A and B)

Where new or replacement exhaust filters are required to be tested before restarting the ventilation system, Method D (Figure 7.24) may be used. Note that in this method the exhaust path from the glovebox is closed and the challenge aerosol-air mixture for filter testing is drawn from a separate valved path. The side path is closed and sealed after testing is completed.

Methods A and B (Figure 7.23) require injection of the challenge aerosol-air mixtures into the glovebox via some convenient opening. A gloveport can be used if confinement is not critical during testing. Otherwise, a connection can be prepared (**Figure 7.25**), or an alternate method can be devised. Methods C and D (Figure 7.24) do not require the introduction of a challenge aerosol into the glovebox. The challenge aerosol inlet connection must be sized to pass the challenge aerosol or challenge aerosol-air mixture. The connection for concentrated challenge aerosol in Method C must admit 2 to 5 cfm, while the connection in Method D must accommodate the total challenge aerosol-air mixture used for the test.

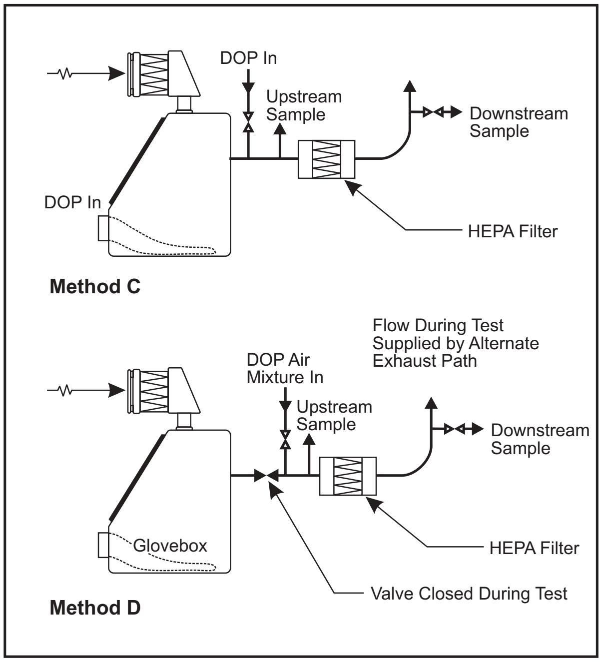


Figure 7.24 – Methods of Injecting Test Aerosol and Extracting Samples (Methods C and D)

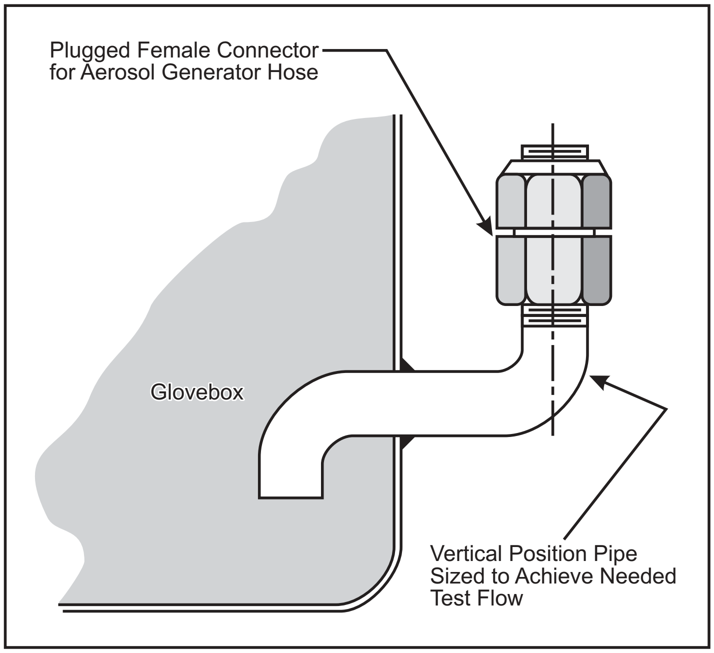


Figure 7.25 – Connection for Introducing Test Aerosol into Glovebox

7.5.5 Glovebox Shielding

Some gloveboxes may require gamma, beta, and neutron shielding because of the nuclides used and the amounts of material involved. Boxes handling kilogram quantities of plutonium can be shielded by providing lead-impregnated gloves, glovebox shielding (water or any other similar mass), lead glass over the windows, and lead-hinged plugs or covers over the ports. The operating, shielding, removal, and replacement requirements of the glovebox HEPA filter must also be considered when glovebox shielding is required. The thickness of the shielding affects the design of the filter housing used on this type of glovebox. The designer should account for this by extending the service fittings (pressure measurement) and any other glovebox pass-through used in the design. This practice is also mandated for bagging ports used to remove the primary HEPA filters and the cover doors. Ergonomic operations inside shielded gloveboxes should be given careful consideration because lead-lined gloves and dimensional differences make manipulations very difficult.

7.5.6 Seismic Design Considerations

By their very nature, gloveboxes are typically top heavy. This presents some unique challenges when designing the supports and holddowns for the systems during a postulated seismic event. Several facilities have had to redesign their support systems after the facility was operating. This led to many obstructions and interferences which could have been avoided at an earlier design stage. For seismic considerations in DOE facilities, see Chapter 9.

7.5.7 Criticality Considerations

When criticality is a potential concern for glovebox design, care must be taken in providing for the appropriate geometry control and water use restrictions. Drains, in particular, must be designed with great care. The buildup of fissile material on the HEPA filters must also be considered.

7.6 References

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