

Factors to Consider to Avoid Problems in High Efficiency Particulate Air Filter Applications - 11585

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ABSTRACT

HEPA filters are tested and inspected at the manufacturer and the Filter Test Facility to assure that they meet the requirements of nuclear codes, standards, and site specifications. Once the filter reaches the site many factors will determine if the filter operates as intended. This paper addresses some of the design considerations and factors that can avoid problems with HEPA filters used in containment applications. Common issues associated with filter malfunction or failure include the following: improper installation, exposure to moisture, high aerosol loading rates, gases and fumes from equipment; and process upset conditions including fires.

INTRODUCTION

High Efficiency Particulate Air (HEPA) filters are commonly employed throughout the nuclear community to control particulate matter emissions from processes involving radioactive materials. HEPA filters are used in many applications: exhaust plenums, supply systems, down draft units, glove box supply and exhaust, room air zone supply, and exhaust, vacuum cleaners, tank vents / breathers, respirators, storage and shipping containers (drums and waste boxes). These items are routinely the final element in an off-gas processing system and the primary barrier preventing emission of radioactive aerosols.

The design of effective nuclear containment systems requires extensive identification and characterization of hazards that must be controlled. This inventory of hazards is used to determine a design basis for the operating envelope of the system. Special attention needs to be paid to protecting functionality of HEPA filters.

Fibrous glass HEPA filters have definite operational limits with respect to maximum temperatures, differential pressure, and volumetric airflow. These units routinely represent the weakest structural component of the overall air treatment system. Each application of HEPA filters used in nuclear containment systems needs to be characterized sufficiently to ensure proper function under a clearly defined set of conditions.

Different applications of filter systems require special design considerations. The Department of Energy has sponsored development and maintenance of the Nuclear Air Cleaning Handbook DOE-HDBK-1169-2003 (NACH) to provide a uniform guidance

document for designing HEPA filter systems.[1] This document should be the main source for direction on filter system design, filter applications, filter units (air movers, down draft units & vacuums) and in-place testing. The NACH gives general design guidance as well as addressing a variety of specialty applications. Chapter titles for the NACH are given in Table I.

Table I. Section Titles for the Nuclear Air Cleaning Handbook.

Chapter	Title
1	History of the Development of Air Cleaning Technology in the Nuclear Industry
2	System Considerations
3	Filters for the Nuclear Industry
4	Housing Design and Layout
5	External Components
6	Small Air Cleaning Units
7	Glovebox Filtration
8	Testing
9	Special Application Requirements
10	Fire Protection
11	Occupational Safety & Health
App A	Care and Handling of HEPA Filters
App B	Receiving Inspection Direction and Checklist
App C	Determination of HEPA Filter Life

The NACH currently calls for use of HEPA filters that meet a commercial consensus standard, specifically the American Society of Mechanical Engineers (ASME) AG-1 Standard for Nuclear Air and Gas Treatment.[2] This standard addresses the full range of equipment used in air treatment activities and has several sections dedicated to filtration or adsorption of materials from the air stream. Those sections in the Table of Contents for AG-1 that address filtration are given in Table II.

Table II. Sections from the Table of Contents for AG-1 that Address Filtration.

Section	Title
FA	Moisture Separators
FB	Medium Efficiency Filters
FC	HEPA Filters
FD	Type II Adsorber Cells
FE	Type III Adsorbers
FF	Adsorbent Media
FG	Mounting Frames, CONAGT Air-Cleaning Equipment, Nuclear Safety-Related Equipment
FH	Other Adsorbers
FI	Metal Media Filters (In the Course of Preparation)
FJ	Low Efficiency Filters (In the Course of Preparation)
FK	Special Round and Duct-Connected HEPA Filters
FL	Sand Filters (In the Course of Preparation)
FM	High Strength HEPA Filters (In the Course of Preparation)

Nuclear containment HEPA filtered air systems may be considered to be vital to containment of radiological material. In May of 1999 the Defense Nuclear Facilities Safety Board (DNFSB) released Technical Report 23 entitled *HEPA Filters Used in the Department of Energy's Hazardous Facilities*. [3] This report expressed concerns for the potential vulnerability of HEPA filters used in vital safety systems. Later that same year DOE initiated a response to the DNFSB's Recommendation 2000-2 by implementing measures with regard to 100 percent quality assurance testing of HEPA filters and a review of vital safety systems in general. [4] Of particular concern are the threats to filter performance posed by exposure to water and/or smoke. Other areas of concern included the effect of aging on filters and the potential for detecting improper installation of filters, particularly leakage around seals.

General System Design Considerations

There are a number of general factors that need to be taken into account to avoid problems in design of new systems. The factors listed in the Tech 23 report reflect issues that have been identified in safety reviews conducted overtime by the board. Considering each of these Tech 23 issues provides insight into some of the key considerations for preventing failures of systems.

Topics listed in the Tech 23 report focuses on factors associated with fire, process upset conditions, filter age, and filter installation. The most significant upset condition that is typically taken into account is a fire because it involves rapid, heavy loading of the filter with smoke along with introduction of water/ humidity and high temperature into the air stream. Two general filter performance factors are associated with this, particle size and moisture effects. Obviously a very high loading rate from dense smoke can rapidly blind a filter. However, a closer look at these filter-loading factors will aid in identifying data that are important to system design.

Aerosol Particle Size

Both the chemical and physical nature (particle size and shape) of the challenge particulate matter (PM) will have a direct impact on the lifetime of a filter as defined by the absolute mass of particulate matter removed. Fig. 1 displays photos of the front surface of two filters after each has been loaded to a differential pressure of six inches water column (1495 Pa) by one of two challenge agents. [5,6] The filter loaded with soot (left) reached the target differential pressure after capturing less than 10% of the mass captured by the filter loaded with KCl (right). Soot used in this series of tests had a count median diameter of approximately 70 nm with virtually no particles greater than one micrometer while the KCl aerosol had a mass median diameter of three micrometers.

The results reflected in Fig. 1 were generated at a low relative humidity (RH). However, aerosols such as KCl that are hygroscopic begin to increase in size and change the morphology of how they buildup on filter fibers at RH values above 65% or so. This points out the need to have a good understanding of both the particle size distribution of

the challenge material and also of the RH. It is important to keep in mind how widely the RH can vary when elevated temperature air streams are cooled.

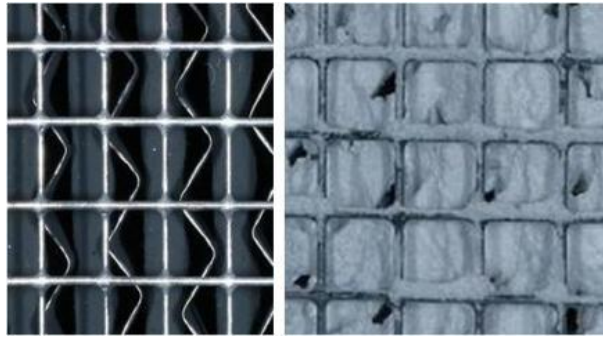


Fig. 1. Photos of the front surfaces of HEPA filters that have been loaded with soot (left) and KCl (right). Each filter was loaded to six inches water column (1495 Pa) differential pressure.

The effect that particle size has on filter loading capacity has direct bearing on the functional life expectancy of the filter. It is important to have a good understanding of all parameters influencing the particle size distribution of challenge aerosols and to make use of these data to estimate the life expectancy of system filters. Numerous models are available for such predictive studies and should be selected based on the design basis scenario.[7,8] Filter lifetime may need to be extended by incorporation of prefilters into the design.

Moisture

The other obvious threat to filter performance that can rapidly defeat air filtration systems is liquid/water aerosols. Exposure to excessive moisture may result in a rapid increase in differential pressure across an operating HEPA filter and thus result in premature failure of the filter. Studies have shown that filters experiencing an increase in differential pressure as a result of short exposure to moisture may not immediately fail. Filters that become wetted for a short period of time can return to a near normal operating state once the medium has dried.[5,6] Exposure to excessive moisture will, however, result in a weakened filter media reducing the life of the filter and/or its ability to withstand a second exposure to moisture or excessive particle loading. The same weakening of the medium can occur when filters are exposed to elevated RH values for an extended period of time. This degradation can occur even if the filtration system is in idle. This emphasizes the need to incorporate sensors that will alert the operator to wetting of the filter and to have operational procedures for requiring filter change out if a filter becomes wet – even if it does not demonstrate failure.

There are periodic system tests that can also introduce additional water into the air stream. A prime example of this is testing the fire protection system. It is necessary to ensure that conduct of such tests or exercising of subsystems will not jeopardize filter operability.

System Operating Temperature

The ASME AG-1 standard sets maximum temperature limits for HEPA filters described in its sections. Establishing the acceptable range of operating temperature is essential for not only limiting the maximum temperature, but also determining the relative humidity range that may exist. Some air filtration systems are designed in a manner to control temperature while many are not. Systems need to be designed to deal with condensation that may occur. This is particularly true for systems where there are wide changes in temperatures due to seasonal variability or fluctuations in process operations.

Temperature fluctuations may also influence specifics of the filter design specified for use in the system being designed. Potting material used to secure the filter pack to the filter frame establishes the temperature operational range for the unit. Selection of Gasket/seal material will influence the maximum temperature for the filter. Systems that will see wide swings in airstream temperature may indicate use of gel seals as opposed to gasket seals for filters.

Aerosol Source and Chemical Composition

There are additional general considerations that need to be taken into account in design activities based on what the filters may be exposed to. Aerosols generated from process activities or spills that involve acidic or caustic agents can be a problem for the filters and associated system components. These aerosols are likely to be hygroscopic and capable of absorbing a large amount of water. This can degrade the filter medium, cause corrosion in unprotected material and require that all sensors be protected by in-line HEPA filters, preferably metal media in-line units.

Other Airstream Contaminants

Process fumes may generate sub-micrometer aerosols by condensation that could lead to differential pressures increasing at a faster than anticipated rate. Fumes may also include oily materials or other condensed organic materials. These can cause significant problems not only with the HEPA filters but with prefilters also. Fumes of this type are emitted by motorized equipment ranging from forklifts to dump trucks or heavy equipment operating within the containment area during decontamination and decommissioning (D&D) activities. D&D activities will frequently involve generation of large amounts of dust or dirt within the containment area that will be difficult to characterize before beginning operations. It is wise to anticipate an increased dependence on use of prefilters and be prepared to modify this portion of the air cleaning system as activities move from one area to another.

Gaseous emissions from some sources are flammable, corrosive, and or toxic. The presence of flammable gasses can necessitate installation of spark arrestors. Their presence may also lead to pressure transients in the event of an explosion or fire, so additional measures must be taken to ensure operability of the system. Toxic gases in the

air stream will necessitate implementing protective measures for personnel testing or maintaining the operating system.

For this discussion, the term corrosives is intended to include any chemical or material capable of degrading the integrity of ductwork, filter components, or other elements of the air treatment system. Chlorides are capable of embrittlement of stainless steel. Organic compounds may adversely affect the functional integrity of seals. Radiation levels can degrade plastics and other materials. It is obvious that materials must be selected that are capable of withstanding the environment that they will be exposed to. Proper selection of materials and/or incorporation of design components to control exposures is predicated on an effective review and identification of corrosive components that may be in the air stream and their bounding limits.

Operating Envelope Parameters

The AG-1 standard restricts the maximum media velocity of virtually all of the HEPA filters it describes to five feet per minute (2.54 cm/s). This maximum media velocity coupled with the surface area of medium contained in the filter establishes the maximum rated flow for the unit. The number of air exchanges per hour coupled with containment volume drives the process of sizing the components of the air filtration system.

Normal operating parameters for the system will include establishing volumetric airflow, temperature, differential pressure, and relative humidity limits. This is to be accompanied by a set of standard operating procedures. These include procedures for monitoring system operation and for conducting routine maintenance activities. Procedures for changing filters will include specification of how removal is to be conducted, personal protective measures to be taken, material handling, installation of new filter, and in-place testing of the newly installed filter.

Procedures will also be developed to control operation outside the limits of normal operation. Of specific interest will be the maximum amount of time that filters can be operated above change out differential pressure, temperature, relative humidity, or volumetric flow rate. This will include steps to be taken and time limits for implementing these steps to prevent filter failure during upset conditions. Attention should be paid to ensure that time limits for implementing control strategies are consistent with the ability of filters to withstand the upset conditions for that length of time. Verification of this will require use of filter loading models and limited uncertainty with respect to the bounding nature of accident conditions. It is likely that this process will need collection of test data to validate projected performance/loading times for filters.

Filter Installation, In-place Testing, and Change Out

Maintenance of the filtration system will include routine change out of filters. Systems are designed to use either remote change or safe change filters. Safe change filter housings vary with respect to size, number of filters employed, and number of stages. A major functional aspect of the system design deals with access to the filter housing.

Access to the filter housing is necessary to facilitate change out and in-place testing activities.

There are numerous factors that can and have been employed to identify when filter change out needs to occur. The most common criterion is when the filter has reached a pre-determined differential pressure. However, other factors such as wetting of the filter can necessitate change out. A flow chart has been developed by the Savannah River Site to assist in the decision making process to change out filters. A copy of this flow chart is included below (see Fig. 2) and can also be found in Appendix C, page C-2 of the 2003 version of the NACH.[1]

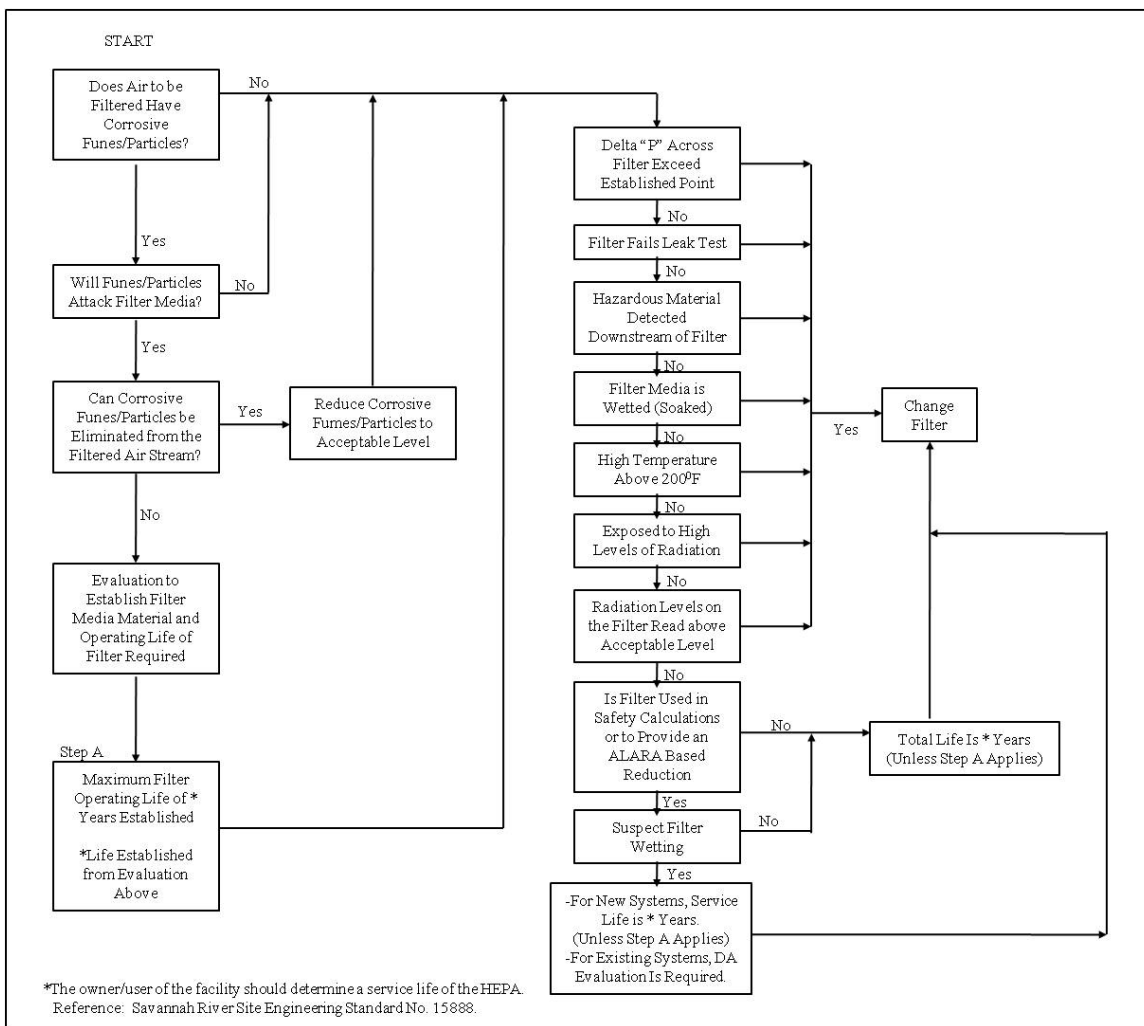


Fig. 2. Nuclear Air Cleaning Handbook (DOE-HDBK-1169-2003) Appendix C, page C-2 flow chart to assist in the decision making process of HEPA filter change out. Flow chart developed by Savannah River Site.

The reader should also recognize that the decision boxes on the left side of the flow chart can prove useful in reviewing design considerations for the system along with selection criteria for the HEPA filters that will be used.

Whatever the conditions triggering filter change out, it is important to ensure that personnel conducting the filter removal/installation during change out have been properly trained. Procedures for conducting the change out need to be detailed to prevent spreading of contamination, causing undue exposure to workers, ensure proper handling of contaminated material, and ensure proper installation of the new filter.

While not a result of failure of the filter itself, excessive leakage may be caused by improper installation of the filter. Improper installation may result in failure of the seal (gasket or gel) between the filter and the filter housing. Fig. 3 illustrates a filter that may have been improperly installed resulting in leakage between the filter's neoprene gasket and the filter housing [5,6]. Such improper installation may be the result of failure to properly tighten the filter within the housing, misalignment of the filter within the housing, or damage to the sealing surface of the filter housing. This emphasizes the importance of conducting in-place testing of the filter to assure proper installation.



Fig. 3. Photographs illustrating seal leakage due to improper filter installation.

Confinement Selection

The design of a containment filtration system needs to pay particular attention to the nature of the radiological material being removed from the air stream. Exposure levels that may be encountered for exchanging the filters dictates whether remote or safe change filters and housings will be employed. There are additional considerations such as how large will be the work (exposure) zones, what activities can be conducted in them, what are the time restrictions for workers, and what protective equipment will be required. Sufficient space is necessary to perform these activities. If supplied air respirators are required, a safe air supply must be provided.

Example Exhaust Systems

Exhaust systems range in size from less than a cubic meter per minute to thousands of cubic meters per minute. While most utilize a single stage of HEPA filters, some employ multiple stages of HEPA filtration. The following will provide some examples of exhaust ventilation systems to demonstrate size and variability of application. This sampling of units is not intended to be comprehensive, but rather to point out examples of considerations necessary to avoid problems in operation.

Figs. 4A and 4B provide photos of two different scales of filter housings/plenums. Fig. 4A provides a photo showing a model of a large, walk-in plenum with four stages of HEPA filters. Each stage is comprised of 44 24x24x11.5 inch (61x61x29 cm) axial flow AG-1 Section FC filters. This provides for 44,000 cfm (1245.9 m³/min) of exhaust ventilation.

Fig. 4B is a photo of a housing for eight 2000 cfm (56.6 m³/min) radial flow filters. Notice the flanged ductwork on the extreme right side of the filter where air enters and the ductwork on the top of the housing for air to be discharged. This unit predates the recently published Section FK of the AG-1 that provides an American standard for this type of filter.

Figs. 4C and 4D show another examples of exhaust system filter housings for rectangular axial flow filters. The photo in Fig. 4C is a two-stage filter bag-in bag-out housing and can be skid/pad mounted for use with tanks or suspended from a ceiling inside a process area. The unit displayed in this photo is positioned on casters and can be move to various locations for use. Notice the magnehelic gauges on the top of the housing for monitoring differential pressure across each filter.

Fig. 4D is a smaller version of a mobile filter unit. Systems that are portable or movable need to be restricted in use to only those applications they are compatible with. The same considerations that would go into ensuring compatibility of filters, housing, and ductwork for a fixed system need to be taken into account before using a unit like this.

Special apparati are needed for in-place testing of individual filters in the walk-in unit shown in Fig. 4A and the housing shown in Fig. 4B needs to have specially plumbed tubing to challenge the radial flow filters. The design of filter systems using equipment like those shown above need to be completed in concert with how filters will be changed out and tested in-place.

Additionally, units should have all ancillary equipment, sensors, etc. that are compatible with the environment they will be used in. Explosion proof or waterproof electrical connections and switches are examples of such considerations. A variety of sensors for explosive, toxic, or corrosive gases may also be required. Consideration should also be given for how the system will be decontaminated.

Finally, it is essential that mobile units like the ones shown in Figs. 4C and 4D above need to have in-place testing of all filters any time the unit has been moved. This testing must be completed once the unit has been reconnected and is ready for use even though the filters may not have been changed.

Filter systems used with waste tanks are particularly prone to condensation because of the temperature and humidity of air leaving the tanks. Special consideration needs to be taken into account to protect the HEPA filters from water and to make allowance for draining water from the ductwork.

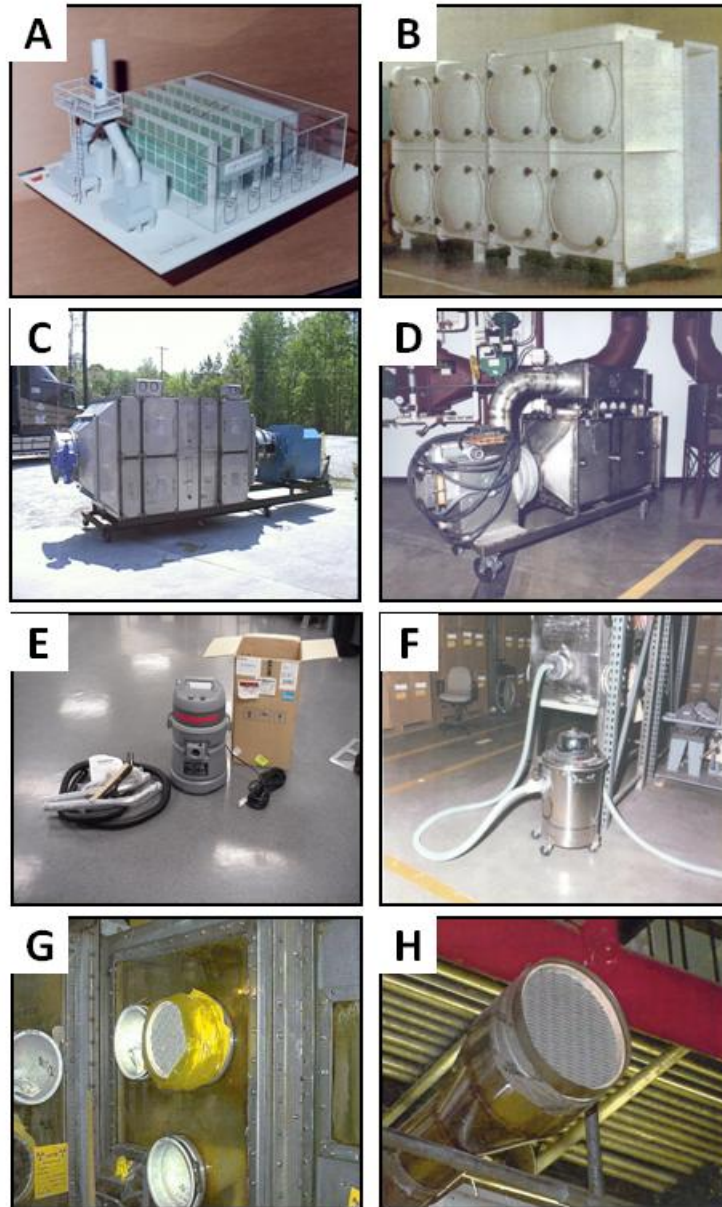


Fig. 4. **A:** Model of a large, walk-in plenum with four stages of HEPA filters. **B:** Housing for eight 2000 cfm (56.6 m³/min) radial flow filters. **C:** Example of two-stage filter bag-in bag-out filter housing for rectangular axial flow filters. **D:** Smaller version of a mobile exhaust system filter unit. **E:** HEPA filtered vacuum routinely used for cleaning and housekeeping activities. **F:** HEPA filtered vacuum used to provide negative pressure in a glove box. **G:** Example of circular, axial flow filters used during D&D activities installed into a containment area to allow additional ventilation. **H:** Example of circular axial flow filter installed into the end of a duct.

HEPA filtered vacuums such as those shown in Fig. 4E are routinely used for cleaning and housekeeping activities. However, they have also seen temporary duty such as providing negative pressure in a glove box as shown in Fig. 4F. This is not appropriate

for long-term use of glove box applications. Exhaust air from these units needs to be managed in a responsible manner and procedures need to be established and followed for changing filters in a manner similar to those used in larger systems (Fig. 4A-D). Filter changes and removal of wastes from the units need to be followed by testing of filters for performance/leaks. Uses like this should only be allowed for short periods of time and under very closely controlled conditions.

Decontamination and decommissioning (D&D) activities are prone to encourage innovation. Figs. 4G and 4H show a couple of such instances. Fig. 5C shows temporary installation of a circular axial flow filter into containment area to allow additional ventilation during D&D. Fig. 4H shows how a similar filter has been installed into the end of a duct. This action has been taken to prevent contamination of the duct as it is being disassembled. Each installation should be accompanied by leak testing and a new filter should be used when the next run of duct is disconnected from the system.

A final example is included to identify at least one piece of apparatus that is not recommended for use such as a unit used in asbestos abatement. Units such as these are designed to function in high humidity environments and include a prefilter to reduce loading on the HEPA filter, but the housing and other pieces of the assembly are not likely to be consistent with the AG-1 standard. Only those units that can meet the AG-1 should be used in DOE nuclear applications.

CONCLUSIONS / RECOMMENDATIONS

Use of HEPA filters in nuclear containment needs to be based on careful review of hazards to their operation specific to that application. The system is to be designed in accordance with guidelines spelled out within the Nuclear Air Cleaning Handbook and based on an accurately described design basis incident.

Specification of materials used for fabrication of ductwork and housing need to be resistant to adverse effects of chemicals contained within the airstream. Temperature, volumetric flow rate, relative humidity, particle size distribution, and mass loading rate for the filter need to be controlled to levels consistent with proper filter function. HEPA filter type should be appropriately selected for the specific application. The filter housing or filter unit should be designed for the type application and operation conditions.

System design considerations are to include access to the housing and ductwork to conduct in-place filter testing and for installation/removal of filters. In-place ports for filter testing should be included in proper locations.

Trained personnel should conduct filter installation. Qualified personnel should conduct in-place testing of filters.

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