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On-site Leak Testing of Negative-Pressure Filtration Units

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Of critical concern on any asbestos abatement project is the containment of asbestos fibers within the Asbestos Containment Area (ACA). One of the major ways to contain fibers is by the use of Negative-Pressure Filtration Units (NPFU). Ironically, these same units can also be the primary cause of release of asbestos fibers outside the ACA due to undetected leaks. Recently there has been more awareness of this problem within the industry. Contamination by NPFUs has been cited in several published articles that contained many conflicting recommendations.

This article will attempt to provide comprehensive guidance for the on-site evaluation of the NPFUs and their effectiveness. This article, however, will not attempt to compare or evaluate the engineering design, concepts, or production quality of various manufacturers of NPFUs or HEPA (High Efficiency Particulate Air) filters.

David W. Crosby, vice president of operations, and Keith Reals, production manager, Air Techniques, (ATI) a Division of Hamilton Associates, Inc., have a total of 43 years' experience in the design, manufacture, and development of test equipment for HEPA filters and respirators for numerous applications and industries worldwide. Air Techniques is a leading manufacturer of aerosol generation and detection equipment for both efficiency and leak testing of HEPA filters, equipment, and systems. For over 25 years, ATI has developed forward light scattering photometer technology to provide a broad range of test equipment for filters and respirators in commercial, governmental, and military applications.

Contractors' Benefits

Obviously, if in-place testing is performed properly by qualified individuals with standardized procedures, we can provide better protection for workers and the public. If complete "on-site" testing is done, compliance with regulations is virtually assured. The quality control procedures that provide the protection to workers, publicly occupied spaces in buildings, and/or the environment will be implemented and documented. What is the potential cost in insurance, litigation and claims when there are inadequate or nonexistent quality control measures and no documentation? Is it achievable and cost effective to do all this testing? Insurance and safety factors show that it is.

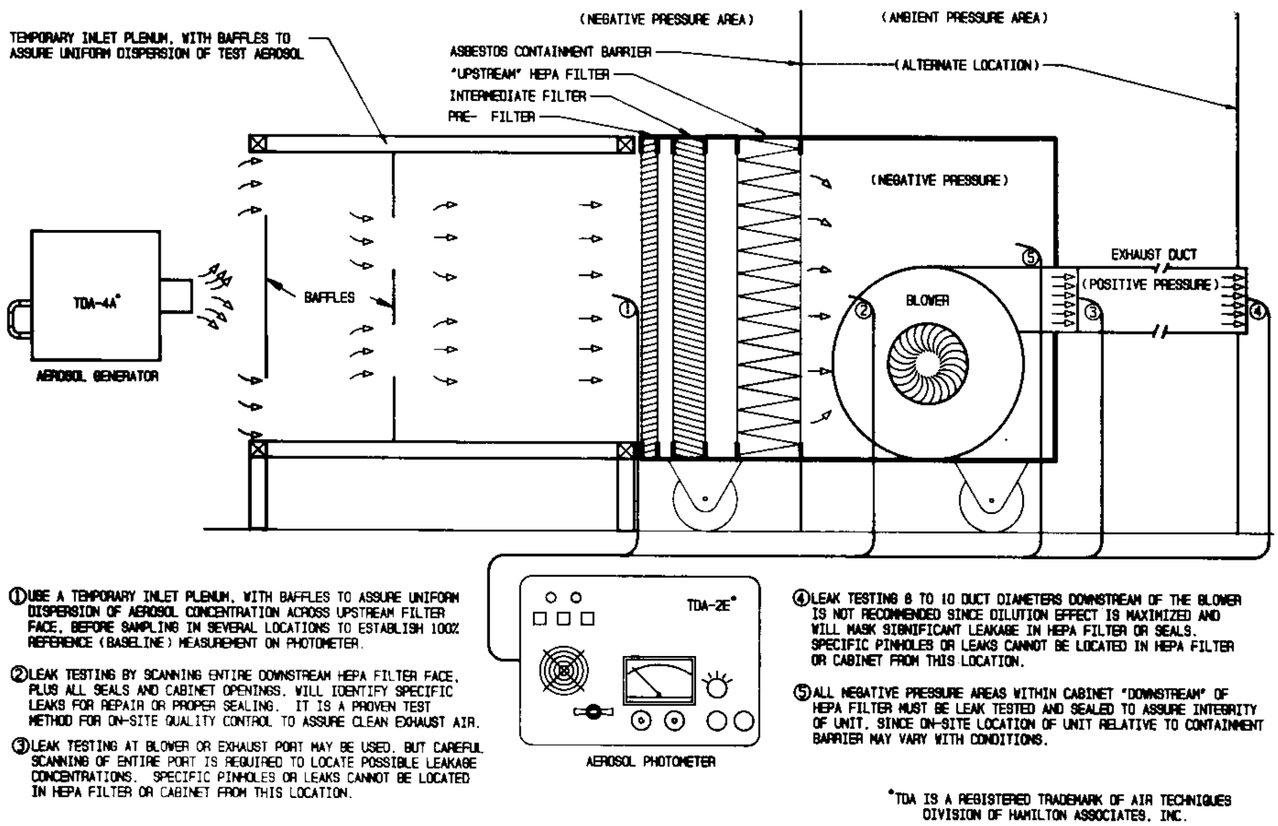
Responsible contractors who maintain a program of on-site testing of NPFUs should be able to petition insurers and successfully negotiate for lower rates. Informal discussions with several underwriters have indicated a willingness to consider such risk-reducing factors when setting rates. To a contractor in a dynamic industry, this cost savings is justifiable and potentially significant. Building owners, managers, and occupants might insist that "on-site testing" of negative-pressure filtration air units be part of the performance parameters of abatement contracts.

The NPFU

Negative-pressure filtration units are portable ventilation sys-

FIGURE 1

NEGATIVE PRESSURE FILTRATION UNIT - WITH "UPSTREAM" HEPA FILTER



tems designed to remove airborne asbestos contaminants. A motor/blower assembly is used to move air through filters inside the cabinet or housing, which is usually equipped with casters for portability. The final filter used is always a HEPA filter.

There are three main purposes of NPFUs in asbestos abatement work: first, to maintain the desired negative pressure (0.02" WG minimum to about 0.04" WG) inside the abatement enclosure; second, to provide adequate air changes within the enclosure for ventilation and worker safety (minimum four per hour recommended—however,

Table 1

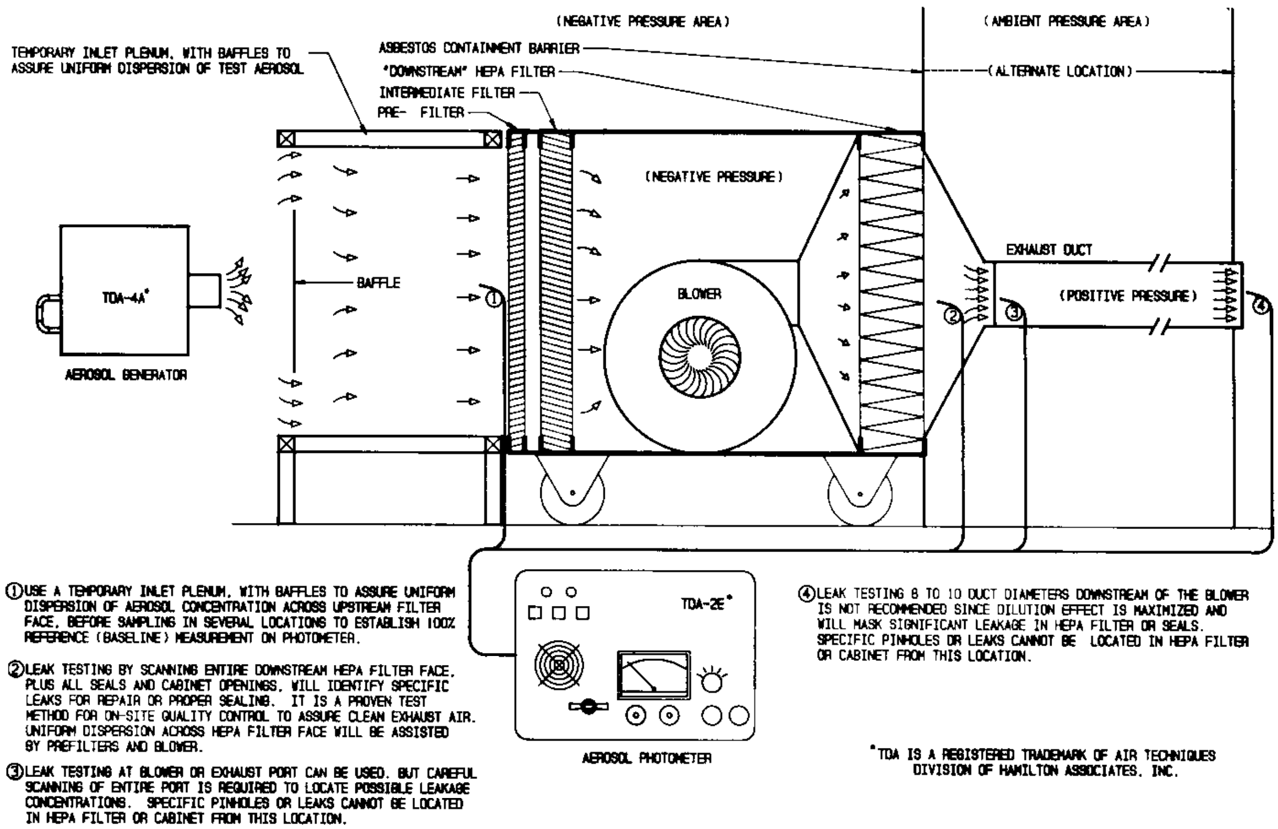
Downstream *vs.* Upstream HEPA Filter Locations In NPFU's

(+) Advantages (-) Disadvantages

Upstream HEPA (Figure 1)	Downstream HEPA (Figure 2)
(-) difficult access to HEPA filter for scanning or leak testing	(+) easier access to HEPA filter for scanning and leak testing
(-) difficult to repair leaks in HEPA filter	(+) easier to repair leaks in HEPA filter
(-) requires mixing chamber to assure uniform mixing of test aerosol	(+) may not require mixing chamber to assure uniform mixing of test aerosol
(+) motor/blower may stay clean (unless HEPA leaks)	(-) motor/blower may become contaminated
(+) cabinet interior may stay clean (unless HEPA leaks)	(-) cabinet interior may become contaminated

FIGURE 2

NEGATIVE PRESSURE FILTRATION UNIT - WITH "DOWNSTREAM" HEPA FILTER



more changes are desirable), and, third, to capture asbestos fibers drawn from inside the abatement enclosure in a HEPA filter to assure that only clean "asbestos-free" air is exhausted to the outside or recirculated within the building.

There are two basic designs of NPFUs: those that "pull" air through the HEPA filter and those that "push" air through it. Therefore, some units have the HEPA filters "upstream" of the motor/blower assembly (see *Figure 1*) and others place the HEPA filters "downstream" of the motor/blower (see *Figure 2*). The advantages and disadvantages in each design concept are summarized in *Table 1*.

The design, materials specifications, and quality of construction vary widely among NPFUs. These variables have a tremendous impact on their overall performance and effectiveness. In particular, the cabinet material must remain rigid and undistorted during shipping, handling, and the rigors of daily operation to prevent the contaminated air from bypassing the HEPA filter. The type and gauge of metal, fabrication methods, braces, holes, cracks, fasteners, welds, gaskets, and seals must be designed, specified, and assembled with potential leakage, durability in service, and maintenance in mind.

Motor/Blower Ratings

Performance capabilities of NPFUs are stated in "airflow capacity." For example, a unit may be advertised as 500 CFM (cubic feet per minute), 1,000 CFM, or 2,000 CFM. Unfortunately, these advertised numbers usually do not reflect real-world performance. Discounting airflow by 20 to 50 percent is a common practice of contractors in anticipation of actual airflow on the job. The motor/blower capacities frequently are not adequate. A new unit with a 24" x 24" x 11⅞" HEPA with a fixed speed motor producing an average linear air velocity of 250 FPM (feet per minute) should be moving 1,000 CFM at 1" WG.

However, this capacity diminishes rapidly as soon as additional resistance to airflow occurs. Ducting and dirt loading on the filters have a dramatic effect on flow rates. For example, if the pressure differential rises to 1¼" WG, the airflow may be reduced by up to 50 percent if the blower has no reserve capacity. Therefore, initial selection of a well-designed unit with sufficient horsepower or reserve will save time and money in the long run. Contractors can then use fewer units and still be assured of adequate airflow, even when the HEPA filters are loaded or units have restricted duct runs.

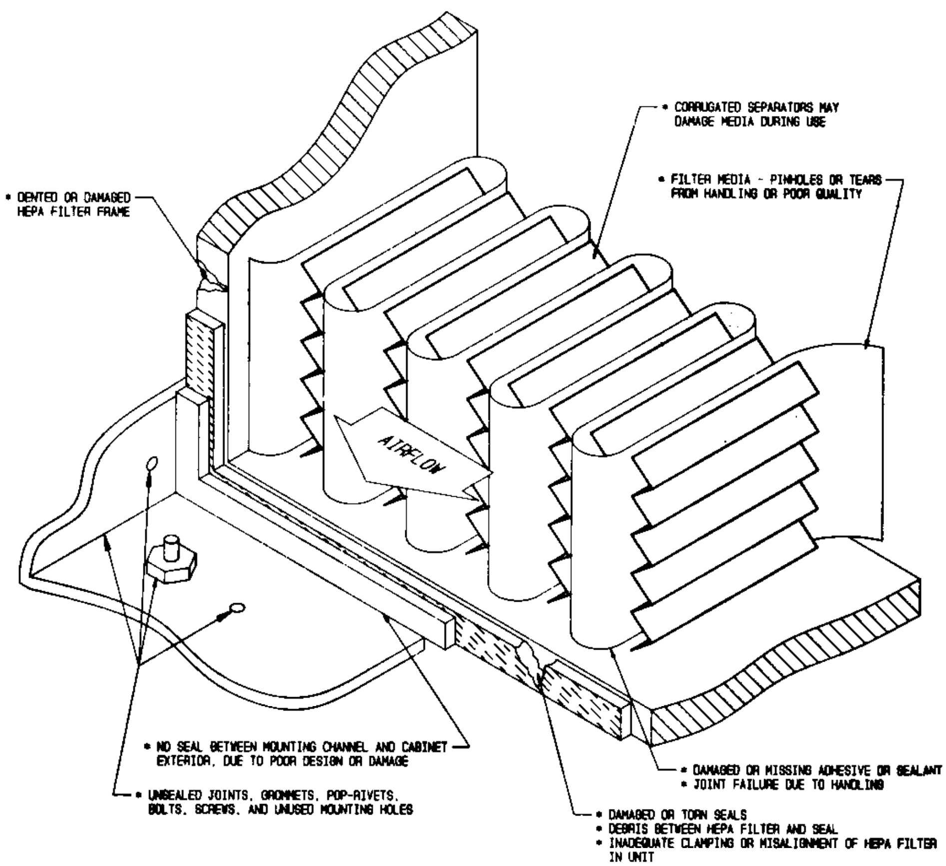
Prefilters and HEPA Filters

Because HEPA filters are expensive to replace, users of NPFUs try to prolong the life of HEPA filters as long as possible. Other than physical damage, the biggest factor influencing the lifespan of HEPA filters is the loading with particulate (asbestos fiber, dust, etc.) and their subsequent increased resistance to airflow. When resistance across the filter exceeds the capability of the motor/blower and airflow drops below the required or acceptable level, the filters must be replaced. NPFUs should always incorporate a prefilter to accumulate the coarse debris, to minimize damage to the HEPA filter, and to help extend its useful life.

A user should select a "prefilter" that maximizes the tradeoff between efficiency and loading capacity. These prefilters must be changed frequently, whenever a visible buildup of dirt or contamination is observed. Their omission or neglect can be costly by accelerating the need to replace expensive HEPA filters. Some units also have an "intermediate" filter, between the prefilter and the HEPA filter, to further protect and prolong the life of the HEPA filter. These filters are often pleated and are much more substantial than lesser efficient prefilters. Again, these filters should be changed as soon as dust loading is visible.

FIGURE 3

TYPES OF LEAKS IDENTIFIED BY ON-SITE TESTING OF HEPA FILTERS AND NEGATIVE PRESSURE FILTER UNITS



The definition of HEPA filters seems to get "confused." Though there are many brands of HEPA filters available in a range of sizes, efficiency ratings, materials, and construction, there is only one basic description for HEPA. By definition, a HEPA filter must be tested at the time of its manufacture and found to be at least 99.97 percent efficient for the removal of all airborne particulate matter 0.3 micrometers in diameter or larger.

Efficiency testing by the HEPA filter manufacturer utilizes a thermally generated, mono-dispersed, 0.3 micron particle size aerosol of dioctylphthalate (DOP) with a concentration of 100 micrograms per liter. This is a true aerosol (a suspension of liquid particles in air) and is not a gas. This aerosol challenge was selected and standardized years ago in MIL STD 282, because the 0.3 micron size was the most difficult for the HEPA filter to remove from the air stream, and smaller or larger particles were easier to trap or filter. Therefore, if a filter is efficient for the 0.3 micron size, its efficiency for all other particle sizes would be at least equivalent, and in most cases, much better. By way of comparison, a human hair has a diameter of about 100 to 300 microns. Many airborne asbestos fibers are as small as 0.3 micron in diameter.

This "efficiency" rating is an overall measurement of the assembled HEPA filter media installed in its filter frame. The challenge aerosol is introduced "upstream" of the filter at prescribed flow rates and within limits for pressure drop across the filter. The filter's overall "efficiency" is determined by readings taken "downstream" of the filter. When purchasing HEPA filters, always specify compliance with MIL STD 282. A problem that occurs in the "after market" for replacement HEPA filters is the availability of inferior, less expensive, so-called HEPA filters that do not meet these rigid specifications when in actual service.

The purchaser/user must be certain that the product he or she is buying is a true MIL STD 282 specification HEPA filter and the pressure drop across the filter does not exceed 1" WG at rated flow. This is significant because some manufacturers put fewer pleats (folds) of filter material into the frame and can pass MIL STD 282, but their filters will exceed the maximum initial filter resistance of 1.0" W.G., causing NPFU airflows to be drastically reduced.

Also available, at significant additional cost, are HEPA filters rated at higher efficiencies, and "certified" filters whose downstream face has been "scanned" for any detectable leakage. Any minor leaks are sealed before the filter is "certified" and shipped, or the filter is rejected. These certification tests for efficiency and leakage are normally conducted under laboratory conditions by the filter or equipment manufacturers. The equipment used for "efficiency" testing of HEPA filters in the factory does not lend itself to use in the field as it is too large and requires permanent installation.

Under normal operating conditions, the "efficiency" of HEPA filters does not degrade. In fact, barring any physical damage, HEPA filters—or any filter for that matter—will become more efficient with use. During normal use, loading with dirt or contaminants simply clogs the "pores" in the media. Eventually, this loading will significantly increase resistance to airflow and require replacement of the filter because airflow cannot be maintained.

A properly manufactured new HEPA filter is designed to handle the specified flow rate and air volume while not exceeding a 1" WG pressure drop. This can and should be verified through acceptance testing by the end user. If the filter's resistance is greater than this value when new, valuable service life will be greatly reduced. As the filter loads with dirt and contaminants, the pressure drop will increase. The motor/blower unit will have to work harder to deliver the required airflow performance. The motor should have the capacity (horsepower) to push or pull (depending on the design of the NPFU) the "advertised" volume of air up to about 1.5" to 2.0" WG. Above that level, it is desirable to change the HEPA filter, which will be visibly loaded with contaminant. The filter may be capable of handling several more inches of pressure drop before blowing out, but motor/blowers with that capacity would be prohibitively expensive. In addition, users of NPFUs can not risk a "blow out" with asbestos fibers–the hazard is too great.

Any number of factors can cause leakage or bypass in HEPA filters. Field testing of HEPA filters to check for damage and to verify leak-free installation is accomplished by "leak testing" rather than by efficiency testing. Leak testing in the field is performed with portable DOP aerosol generation and detection equipment, which is a proven technology that meets or exceeds existing federal, state and regulatory agency standards. This challenge aerosol is "polydispersed" and is generated in lower concentrations than in efficiency testing at the factory. Twenty micrograms per liter is considered a proper minimum challenge concentration. The acceptance criteria for "leak testing" do not directly correlate to the numbers used in "efficiency testing."

Many people confuse these two different types of testing and incorrectly assign "efficiency ratings" to installed filters and their air handling systems. With leak testing, the leakage detected downstream is expressed as a percentage of the upstream aerosol concentration. The value used for a "pass/fail" determination will vary depending on the application. For a negative pressure filtration unit this value should ideally be "zero." In practice, in most industries, an extremely small amount of leakage is acceptable. Currently, testing standards for the asbestos abatement industry do not exist to define leakage values or testing procedures.

Reasons For Testing

Some of the reasons for performing leak testing of both HEPA filters, and those devices that incorporate them in their design are (see *Figure 3*):

1. Poor design of the NPFUs (or other devices).
2. Poor workmanship and inadequate quality control by the NPFU manufacturer.
3. Leaks in the filter media itself.
4. Leaks due to the failure of the adhesive bond between the filter medium and its frame.
5. Leaks between the filter frame and cabinet sealing frame seals.
6. Leaks between the cabinet sealing frame and the cabinet housing.
7. Leaks in the cabinet or housing due to damage in transit or handling.
8. Leaks from misalignment or misassembly of the NPFU and HEPA filter.
9. Leaks resulting from incorrect or inadequate maintenance.
10. Leaks resulting from improper installation and operation of the NPFU at the work site.

Testing Considerations

Recent articles have outlined an overall system efficiency (OSE) test method for the testing of new NPFUs by their manufacturers.[1] However, the OSE concentrates on the unit's cabinet leakage and doesn't address testing for HEPA filter leakage. Although it is laudable to call for the establishment of standards for all manufacturers, contractors and others in the field need a method for the day-to-day testing of the thousands of units already in use and for leak testing of the installed HEPA filter. The OSE test may have been taken from the techniques applied to the leak testing of biological safety cabinets that are in the National Sanitation Foundation (NSF) Standard No. 49[2] and is a step in the right direction. Some reputable manufacturers have already adopted rigorous air flow and leak testing procedures. As a result, design changes have occurred to improve performance, repairs, and service. Appropriate testing methods and procedures for NPFU equipment manufacturers are needed so endusers can be assured of quality equipment that meets or exceeds established standards.

The organizations that provide methods of testing include: the U.S. Government, American Society for Mechanical Engineers[3], Institute for Environmental Sciences[4], American National Standards Institute[5], National Sanitation Foundation[2], National Environmental Balancing Bureau[6], and the U.S. Navy. Of all standards available, only NAVSHIPS 0989-039-9000 for testing HEPA filter vacuum cleaners is applicable to NPFUs and to the testing of HEPA vacuum cleaners used by the asbestos industry.

Some of the designers and manufacturers of negative-pressure filtration units have not given much thought or effort to creating units with "integrity testing" in mind. They often overlook the inclusion of features that would allow access to critical areas to test for leakage.

Access to the downstream face of the HEPA filter for the purpose of scanning in an "Upstream" HEPA NPFU (see *Figure 1*) is virtually impossible in most units. Relatively simple design changes would make this possible in new units. Modification to provide access to HEPA filters in some existing NPFUs may be possible as well. Manufacturers need to "design in" the ability for testers to perform sample probes, to gain access to the downstream face of the HEPA filter, and to allow for repairs and/or adjustments.

Mixing and dilution are important in the accuracy of leak testing HEPA filters and NPFUs. Their significance varies with the location where the test sample is actually taken and is explained in the following paragraphs.

It is important to draw an adequate number of samples of the test aerosol upstream of the HEPA filter to assure the aerosol is dispersed uniformly and in the proper concentration. With "Upstream" HEPA Filter units, a temporary mixing chamber will be necessary to meet this requirement. With "Downstream" HEPA Filter units, if a sample can be taken inside the blower plenum, the temporary mixing chamber may not be necessary due to the dispersion mixing effect of the prefilters and the blower. If a sample can't be taken in this way, then a mixing chamber will be necessary. Testing personnel can assemble temporary mixing chambers from materials on the jobsite.

Downstream measurements of the exhaust airstream can be subject to error due to channeling, the opposite of mixing. The aerosol from a specific leak may simply remain concentrated in a segment of the exhaust air stream. Therefore, testers must perform sampling at various points across the face of the exhaust air outlet, in effect "scanning" the opening. A single point sample is usually not representative of what is in the exhaust air stream.

The same considerations are taken in making air velocity measurements across the exhaust opening or duct in accordance with ANSI/ASHRAE 41.2—1987. A single point reading is not representative.

Repairs and Solutions

The repair of pinpoint leaks or tears in HEPA filters or their adhesive bonds and gaskets can often be accomplished in the field. The most common technique is to apply a silastic sealant, commonly called RTV (Room Temperature Vulcanizing), silicone, or even bathtub caulk. Take care in applying the sealant. It is always best to try to "pinpoint" the leak by being able to see the hole, tear, or crack and marking it, so that it can be sealed completely. Leak sites may migrate, especially when someone attempts to seal a leak between the filter housing or frame and the filter media.

Turn the blower "off" before attempting to seal the leaks. This allows you to push the repair sealant into the leak site more effectively and lets the sealant set before it is retested with the blower "on." In all cases, retest any repairs or patches.

In some situations, you can eliminate leaks by tightening or realigning the HEPA filter or the cabinet/housing components. A common cause for leakage is debris lodged between the filter housing and the filter seal or mounting channel. Therefore, it is advisable to clean these surfaces carefully and thoroughly when installing new HEPA filters. At that time, also watch for and repair damaged or worn seals (see *Figure 3*).

Acceptance Criteria

Leak testing of HEPA-filtered negative-pressure systems is best done by scanning the downstream face of the filter, paying particular attention to the bond between the filter media and its frame, scanning the seal between the filter frame and its housing, and scanning any other potential leak sites (seams, welds, bolt holes, rivets, screws, electrical cord penetrations, etc.) The number and variety of leak sites identified by thorough DOP testing and photometer scanning is often quite great.

When scanning is possible, correct any detection of leakage by sealing, readjusting, tightening, or replacing whatever is necessary and appropriate. Once you've located and sealed any detectable leaks, an overall leakage measurement should be taken at the exhaust outlet of the unit. Allow for no significant detectable leakage at this point.

ANSI/ASME N509—1989 establishes a limit of 0.05-percent leakage for HEPA filtration systems in nuclear power plants. This translates to a removal effectiveness of 99.95 percent for building ventilation systems. We think that value is too high. All other industries (pharmaceuticals, surgical operating rooms, electronics, aerospace) use a maximum allowable leakage of 0.01 percent of the upstream challenge concentration.

NPFUs may never achieve leakage rates of "absolute " zero due to the use of portable instruments used on-site. But we might apply the same logic as we do with quantitative respirator fit testing (QNFT). That is, we want as "leak-free" a system as we can get, but we recognize that absolute perfection is not achievable. It is appropriate, however, to set a more stringent requirement than allowing 0.05 percent leakage. If there are 50 fibers/cc within the containment, which is common, and the NPFUs have 0.05-percent leakage, there would be 708 fibers per cubic foot in the exhaust discharge.

A Contractor's Testing Experience

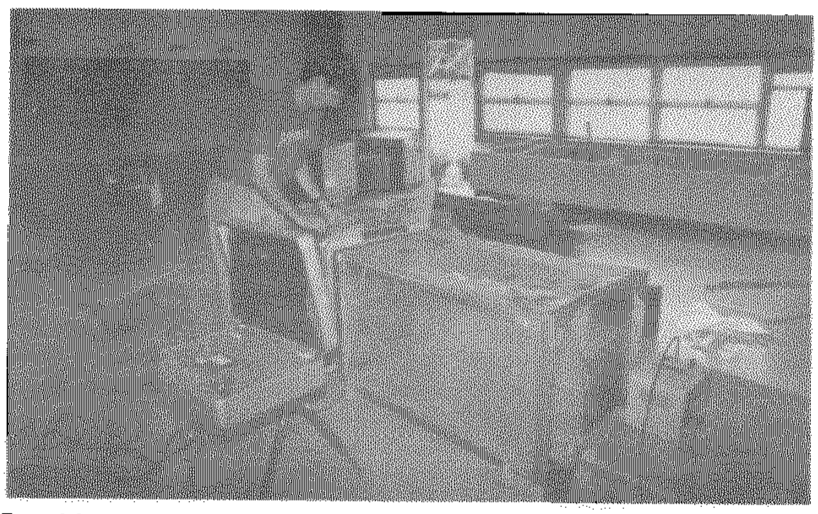
MARCOR, one of the national asbestos abatement contractors interviewed in preparation for writing this article, had some strong views on the importance of testing. Jeffrey T. Paulding, president of their Beltsville, Maryland, operation, one of their eight offices nationwide, said he agreed emphatically on the need to perform in-place testing.

"From a logical point of view, it's got to be one of the most important things you can do to insure that you are not just spewing asbestos over an uncontaminated area," Paulding said.

Their current company policy has two key provisions: to test all negative-pressure filtration units every six months, and to test each unit set up on the job site if circumstances require exhausting the filtered air back into "clean areas" in buildings.

Tom Mastalski, their safety administrator, uses a written step-by-step procedure outlined in their policy manual to conduct the leak testing. The Beltsville location alone has over 70 negative-air units. Testing them all is a big commitment, but one they believe is worthwhile.

Only specially trained personnel perform the tests. Sufficient spare NPFUs are available at each jobsite, so that when a leaking unit or HEPA filter is discovered it can be returned to their shop for repair so that there is no temptation to use it anyway



Tom Mastalski, Marcor's safety administrator, demonstrates setting up a NPFU for on-site leak testing at an abatement project.

NPFUs at the Work Site

The location of the NPFU in relation to the ACA barrier is an important consideration. Basically, two possibilities exist, as shown in *Figures 1* and 2. "Upstream" HEPA filter units (see *Figure 1*) should have everything behind the downstream face of the HEPA filter, outside the asbestos containment area. This keeps the NPFU housing virtually free of contamination, thereby permitting less maintenance for decontamination and easier handling of the unit after use. "Downstream" HEPA filter units (see *Figure 2*) are usually set up inside the contaminated area; therefore, everything except the downstream face of the HEPA filter and the inside of the exhaust ducting will be contaminated.

Several common-sense considerations are also appropriate when moving a NPFU to prevent the spread of asbestos fibers. To ensure against this occurrence, wrap and seal the unit totally in polyethylene and protect it from damage or rough handling. Transportation between worksites will loosen the asbestos fibers in the HEPA filter and in the NPFU. Therefore, a properly trained worker should decontaminate the NPFU. Workers should wear appropriate protective clothing and equipment and use a HEPA vacuum cleaner when working within a HEPA-ventilated work enclosure. Some current state regulations require HEPA filters to be changed for every new abatement project.

As a mandatory quality assurance measure, manufacturers should leak test 100 percent of all new NPFUs before they are shipped. If all manufacturers of NPFU's were "required" to do both "flow & leak testing" to meet appropriate standards users would be assured of proper design, quality, and performance.

Due to the great potential for damage, loosening of seals, vibration of components, etc., during shipment, you should also test new NPFUs and their HEPA filters upon initial receipt and before use. Periodic testing of the NPFU thereafter is dependent on its real-world use and abuse. Ideally, retest anytime the unit is moved or is suspected of possible damage. Every time a HEPA filter is replaced, perform a mandatory "leak test" of the NPFU and the newly installed HEPA filter.

Standardization and Certification

Since NPFUs are in reality portable air handling or ventilation systems, they naturally fall into the realm of HVAC systems. Therefore, the National Environmental Balancing Bureau[6] (NEBB) could assume a role of leadership and act on this need. Their existing Standards can be expanded to include a section devoted to NPFUs and their testing plus HEPA vacuum cleaners. It would seem appropriate for NEBB, National Insulation and Abatement Contractors Association[7] (NIAC), and the National Asbestos Council[8] (NAC) to jointly develop the much needed standard for NPFUs. (See references at the end of this article.)

Even if manufacturers tested or certified all new negative-air units or HEPA-filtered units, there may be risk of damage in shipping, handling, and in-service field use. Therefore, additional testing should be accomplished on receipt of new units prior to their being placed in service. The abatement contractor must be responsible for ensuring that every NPFU placed in service is leak free.

The question arises about the need for "third-party" leak testing of NPFUs just as it does for "final release and clearance testing" of abatement jobs (which is required in some states). If done properly by specially trained personnel, in-house testing of NPFUs can be very effective. It will require proper training, however, to develop proper skills and adherence to standard quality control procedures.

In fact, many are now calling for the "certification" of personnel who conduct integrity tests. Certification and training cannot absolutely insure the integrity of the individual or company conducting the tests. But it can insure that the trained individuals have comprehensive knowledge of the subject, standards, and regulations and have demonstrated skills and competence in the operation of appropriate equipment and procedures.

Until certification is mandatory, appropriate and comprehensive training on the proper operation of test equipment used for NPFUs and HEPA filters is absolutely essential to assure "clean air" is exhausted from every abatement project. In short—test it. . .to be sure.

NEBB currently offers professional training and development programs for Certification of Cleanrooms. It would be a simple matter to offer such a program for certification of NPFUs, HEPA filters, and HEPA vacuums used in the asbestos abatement industry. We trust other professional organizations such as NIAC and NAC will join in supporting establishing professional standards in NIOSH-approved training programs.

Conclusions

The negative-pressure filtration unit is the key to trapping all asbestos fibers and discharging "clean air" in asbestos abatement projects. All NPFUs need to be periodically tested and certified to ensure their proper operation in the field. The methodology should be controlled and standardized by one of our nationally recognized established standards organizations. Responsibility for testing should be borne by both equipment manufacturers and end users for cost and health benefits to both.

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