2. HEPA FILTER INFRASTRUCTURE

The program for producing high-quality HEPA filters and fabricating the filter banks used in nuclear installations has evolved during the past 50 years. This evolution has involved many interrelated assumptions associated with materials, specifications, testing, and use (Burchsted et al., 1976; Frethold et al., July 14, 1997; Johnson et al., 1988; First, 1996).

As the name suggests, HEPA filters are high-efficiency air filters designed to remove extremely fine particles suspended in the air; they do not remove gases. HEPA filters are expendable, extended-pleated-medium, dry-type filters with (1) a rigid casing enclosing the full depth of the pleats; (2) a minimum particle removal efficiency of 99.97 percent of thermally generated dioctalphthalate (DOP) 0.3 micron smoke particles (particles about one- third of one-thousandth of a millimeter in diameter) or larger (i.e., 99.97 percent of these particles are stopped by the filter); and (3) at a maximum a pressure drop of 1 inch of water gauge when clean and operated at rated airflow capacity (Burchsted et al., 1976). Such filters offer a high-volume, high-efficiency cleanup mechanism for relatively low concentrations of airborne particulate contaminants.

Safety analyses for confinement systems using HEPA filters routinely take credit for reductions in airborne contamination by factors of thousands to billions. These reduction factors are reasonable for intact filters installed in well-designed and well-constructed filter banks that are properly maintained. These conditions are difficult to attain, however, partly because of the fragile nature of the filter medium. A very few small holes in the filter medium (on the order of 1–10 mm in diameter) can reduce filter efficiency significantly.

HEPA filters are manufactured by a process similar to that used for making paper, but with fiberglass strands as the principal ingredient. After the medium is formed into a sheet similar in appearance and texture to a large desk blotter, it is carefully folded into a series of accordion pleats (125 pleats in the most widely used standard industrial HEPA filter). The folded medium is then mounted with the edges sealed in a plywood or metal case. This constitutes a single HEPA filter unit. Dozens or even hundreds of such units may be installed in a single confinement filter installation.

2.1 ACHIEVING INITIAL PRODUCT QUALITY

2.1.1 Specifications

HEPA filters are produced with a high degree of quality and uniformity through the application of stringent yet manageable specifications. The foundation for HEPA quality includes sample specifications found in the 1976 Nuclear Air Cleaning Handbook (Burchsted et al., 1976), issued by the Energy Research and Development Administration, and more recently in DOE Standard 3020-97 (DOE-STD-3020-97), *Specification for HEPA Filters Used by DOE Contractors* (U.S. Department of Energy, 1997), together with the numerous standards they cite and the QPL and Filter Test Facility (FTF) testing they call for. Nevertheless, there are ongoing

technical issues associated with each of these building blocks that have serious implications for maintaining the quality of the filters.

The current version of the Nuclear Air Cleaning Handbook is more than 20 years old. In the intervening years, several unsuccessful attempts have been made to revise and update the handbook, primarily to accommodate numerous changes in applicable national standards. In 1996, the Secretary of Energy made a commitment to the Board (O'Leary, March 15, 1996) to have a revised draft available by the end of that year. That draft has not yet been produced, nor are there any indications that a revised handbook may emerge in the near future.

2.1.2 Filter Testing

Both the Nuclear Air Cleaning Handbook and DOE-STD-3020-97 call for manufacturers to retain their QPL[1] listings. This mandate includes, among other requirements, providing representative sample filter units to an independent, certified QPL laboratory for destructive testing at least once every 5 years.

In the past, manufacturers could choose to have their QPL testing done at either the Army's Edgewood Arsenal or the Rocky Flats Environmental Technology Site (RFETS). Today, the Edgewood Arsenal facility no longer performs QPL testing, and the test facility at RFETS is closed. Edgewood Arsenal still has the capability to run such tests, but there is no budget for maintenance of the necessary equipment. During 1997, the QPL test equipment at RFETS was sent to Lawrence Livermore National Laboratory (LLNL), where most of it remains—still crated and unfunded. The Assistant Secretary of Energy for Environmental Management informed the Board in writing (Alm, January 15, 1998) that a QPL testing laboratory would be available for testing of HEPA filters to be used in DOE facilities. No time frame was specified for that commitment, and such a laboratory has not yet been designated.

In addition to QPL testing, both the handbook and DOE-STD-3020-97 call for representative filters to be provided routinely to a designated FTF for the purpose of verifying filter efficiency. The current DOE standard recognizes that manufacturers may themselves conduct tests similar to those performed at a designated FTF. Even in such cases, however, the standard requires that all filters destined for use in DOE facilities be tested at an independent FTF prior to installation.

For years, manufacturers routinely pretested their HEPA filters before sending them to a DOE FTF. Even with this pretesting, rejection rates of 3–6 percent were common at DOE's three FTFs. Such rejection rates support the value of testing at a DOE FTF, since the tests help avoid the unnecessary generation of contaminated waste and contribute to lowering personnel exposure. This avoidance comes about because the filters that fail the FTF tests are not installed, as they would have been in the absence of the tests; thus the need to remove substandard filters contaminated in service is avoided.

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[1] Products on QPLs have met stringent requirements for quality and reliability, demonstrated by periodic independent testing at certified testing laboratories, most of which are operated by the federal government.

Currently, DOE operates only one FTF (at Oak Ridge). Despite the DOE-STD-3020-97 specification calling for FTF testing of HEPA filters prior to installation in DOE facilities, and in the face of DOE's own studies (Lytle, August 1996), there have been repeated proposals to stop testing of filters at the Oak Ridge FTF. Indeed, testing there was stopped in January 1999, but was resumed 2 months later with user fees being imposed for tests. This situation tends to discourage FTF usage and increase per-filter test costs. Ongoing attempts to find a programmatic solution have thus far been unsuccessful.

2.2 MAINTAINING PERFORMANCE

HEPA filters cannot simply be installed and forgotten. Once installed in safety systems, they are subject to significant operating constraints to ensure the desired level of performance. Typically, these constraints involve TSRs and/or OSRs (U.S. Department of Energy, April 30, 1992) that specify a maximum pressure drop for system operation and a level of efficiency as demonstrated by periodic in-place leakage tests. Operating procedures, specific surveillance actions, and scheduled maintenance are usually prescribed to ensure that these performance requirements are met.

Industry consensus standards for in-place HEPA filter testing stress the need for visual inspections and system-specific procedures (American Society of Mechanical Engineers, December 15, 1989). Although specific procedures addressing filter operation are required by industry standards, they are typically lacking throughout the defense nuclear complex (Conway, January 30, 1998) and have not been made mandatory by DOE. These procedures are important for ensuring the safety of workers, the public, and the environment. Only the Savannah River Site has employed them extensively.

For most other systems and components, meeting TSRs ensures that a constrained or challenged item will perform its intended function as called for by the design. This assumption is not valid when nondestructive in-place field tests address only the tightness of the filter's fit against the frame and the absence of other gross leakage paths. There is a widespread assumption that periodic in-place DOP field testing demonstrates the ability of a HEPA filter to perform under accident conditions. Yet, experience has shown that filters can be severely weakened and still successfully pass these in-place tests (Frethold et al., July 14, 1997; Johnson et al., 1988; First, 1996). Under accident conditions, such filters are vulnerable to subsequent failure in use, for example, after becoming heavily loaded with smoke particles.

The question of whether a HEPA filter will perform as intended in the future cannot be answered simply by examining adherence to existing TSRs. Filter performance does not lend itself to a simple "go-no go" test. With today's technology, that assurance is available only through a reliable and effective infrastructure that addresses all aspects of HEPA filter quality—design, manufacture, installation, operation, and maintenance.

2.3 CHALLENGES

2.3.1 Fires

The largest potential threat to the public from a facility that houses processes in which relatively large quantities of radioactive materials are handled is most commonly a fire accident scenario. Since fires often generate large volumes of smoke, they pose a potential threat to the effective functioning of filtration systems because the filters can become rapidly loaded with smoke particles. This increases the pressure drop across the filter, potentially leading to a breach of confinement. There are times during some fire scenarios when it may be necessary to stop flow to the filter systems to prevent their destruction. Such scenarios need to be carefully evaluated ahead of time; a mitigating strategy must be developed, clearly captured in procedures, and rigorously practiced (Defense Nuclear Facilities Safety Board, March 20, 1995; Conway, January 30, 1998; Klein, April 24, 1998).

In the event of a breakthrough of the filter during a fire, the particulate material deposited on the filters is readily lifted by buoyancy into the atmosphere, where it can be further dispersed in potentially unfavorable downwind patterns. As a result, some fires can be more serious than explosions, which generally drive much of the particulate matter into surrounding structures rather than elevating it into the atmosphere and dispersing it via prevailing winds.

2.3.2 Heat and Elevated Temperatures

Because of their materials of construction, HEPA filter installations can easily be damaged or destroyed by heat if they are not properly designed and maintained. Exposure of the filter medium to temperatures of 700–750°F for only 5 minutes can significantly reduce filter efficiency (Burchsted et al., 1976). Fires involving burning metals, which may be encountered in many defense nuclear facilities, can produce flame temperatures of several thousand degrees. With sufficient flow of cooler air, these high temperatures can be reduced to acceptable levels in the downstream HEPA filters. If this cooling effect is to be provided, however, detailed plans and designs are essential. Such plans and designs in turn require appropriate guidance.

In this connection, DOE Handbook 3010 (DOE-HDBK-3010-94) (U.S. Department of Energy, December 1994) implies that HEPA filters can withstand temperatures substantially greater than 1500° F for tens of minutes without losing their nominal efficiency of 99.97 percent. This is not correct, since fiberglass will melt before reaching such temperatures. This erroneous information was used in a recent Basis for Interim Operation (U.S. Department of Energy, April 1998) in which a filter efficiency of 99.8 plus percent was assumed in calculating dose assessments. In this instance, recalculation determined that the temperature likely to be encountered at that facility would not have reached 750°F. However, the same error (i.e., the assumption of no filter damage and filter availability for dose reduction) could recur if the handbook is not revised.

2.3.3 Wetting

Like paper, HEPA filter medium is especially susceptible to water damage, despite the fact that water repellents are applied to the medium during manufacture. When installed fire suppression systems are activated to protect systems, structures, and components inside confinement, the moisture-laden air carried downstream to the HEPA filters can seriously degrade filter performance—at a time when high-efficiency filter performance is crucial.

2.3.4 Filter Strength

The remaining strength of HEPA filters must be adequately considered, especially under challenging conditions, such as having to cope with a fire. Making this determination is particularly difficult, however, since no nondestructive in-place test is available. Further, many unpredictable factors can degrade the filter installation's strength without the operators' knowledge. Filter strength is affected by such factors as manufacturing variables, aging, loss of binder, loss of water-repellent capability, shelf life, history of prior wetting, exposure to high temperature, exposure to high radiation, exposure to chemicals, and exposure to moisture-laden air (Frethold et al., July 14, 1997; Bergman et al., 1994; Carbaugh, 1982; Johnson et al., 1988; Moeller, 1982; First, 1996). While many of these factors have been investigated, a quantitative assessment does not appear possible at this time. More important, a conservative limit on filter life is not currently mandated by DOE.

2.3.5 Air Leaks

Careful design, attentive operation, and disciplined maintenance of a HEPA installation can be negated by air leaks in the negative pressure region of the system downstream of the filters and upstream of the fans. Leaking gaskets, fan seals, and damper actuator penetrations are particularly vulnerable. These regions are not routinely checked for leaks (Frethold et al., July 14, 1997; Roberson, March 3, 1997). When RFETS addressed this issue, such leaks were found.

2.4 RESULTS OF PRIOR RESEARCH

The literature is replete with studies that examine possible negative influences on HEPA filter performance (Frethold et al., July 14, 1997; Bergman et al., 1994; Johnson et al., 1988; Robinson et al., 1985). The data presented in these studies are based almost entirely on HEPA filters less than 15 years old. A few of the filters examined in the studies were 15–20 years old, and a very few were older than that (the age of these filters typically includes both shelf and service life).

Frethold's work (Appendix 4, Figure 4-1) (Frethold et al., July 14, 1997) shows some unused but aged filters with less than minimum specified initial tensile strength of 2.5 pounds per inch for unfolded media and 2.0 pounds per inch for folded media. "Folded" versus "unfolded" here is significant because the most commonly observed failure point on a HEPA filter is on the downstream fold. Further, Frethold's work (Figure 6-1) reveals variability for this parameter by factors of 2–3 for the same manufacturer.

The loss of water-repellent capability has also been observed by several investigators. This can be a significant factor if moisture carryover or sprays from firefighting efforts impinge on the filters. Filters untreated for water repellency are expected to absorb some fraction of the

impinging moisture or water. This moisture absorption can dramatically increase the pressure drop across the filter and lead to filter failures. According to Frethold (Figures 2-1 and 2-2), loss of the ability to repel water does not appear to be a problem in storage, but can be significant in service. Johnson's data (Johnson et al., 1988) show a 57–100 percent loss of water-repellent capability among filters in service for 13–14 years.

These data suggest that remaining strength and ability to repel water are important considerations for continued HEPA filter use, but it is not possible to specify an exact service life. Qualitatively, however, the data clearly indicate that filters cannot stay in service indefinitely. Since an exact service life cannot be determined and data variability is significant, individual vulnerability assessments that examine the expected efficiency, life, and mission for installed HEPA filters would appear to be desirable.

Frethold (Appendix 3) presents the results of soaking a HEPA filter, drying it, and then testing the dried media for tensile strength. This investigation was designed to simulate the effects of direct impingement spray testing for fire protection purposes. The results revealed that one soaking can reduce the strength of the filter media to less than the initial purchase specification value. Additional tests conducted by Frethold without presoaking also demonstrated weakening of the filters. On the basis of these data, the safety significance of the application, and a consideration of future building use, one DOE site (RFETS) decided to replace various previously wetted HEPA stages (in Buildings 371 and 707). The choice appears to have been a prudent one.

It should be noted that most of the investigations cited above were carried out under funding provided by DOE and its predecessor agencies. Today almost no funding is available for conducting such investigations, even though there are many unanswered questions. No programmatic office within DOE has stepped forward to set priorities regarding the additional information required.

Taken collectively, the published data also suggest that there could be some unused HEPA filters in storage—ready to be installed in safety systems—that would not meet newly purchased filter specifications. Further, the data suggest that installed HEPA filters could be so degraded by age and loss of ability to repel water that they might not perform their expected safety function when called upon to do so.

Several attempts have been made to establish an age limit for HEPA filters, taking into consideration the weaknesses observed during testing. First (1996) of the Harvard Air Cleaning Laboratory recommends 5 years for HEPA filters used in biological cabinets. The Savannah River Site has a 5-year limit in place, including both shelf life and service life. LLNL previously proposed an 8-year limit, and is currently proposing a 10-year limit. Some DOE facilities have filters in service that were installed more than 20 years ago. A prominent filter manufacturer claims a 3-year shelf life, but only under proper storage conditions. No other age limits at DOE facilities have been proposed to date. Nor have any additional routine measurements or assessments to evaluate the residual strength of HEPA filters been proposed.

3. REVIVING THE INFRASTRUCTURE

To be effective, any management system requires feedback. In the case of HEPA filters, there are many indications that an acceptable program for feedback of experience is either absent or seriously degraded. At a time when additional HEPA filter investigations may be called for, budgets have been cut to the point that meaningful research in this area is no longer possible. Moreover, after nearly 50 years of continuing support for the Nuclear Air Cleaning Conferences, DOE has decided to withdraw support for future conferences, seriously compromising opportunities for feedback from peer review and a free exchange of ideas. Reconsideration of this decision is warranted in order to restore vigor to this important safety-related research area and to provide better assurance of adequate information exchange on the subject of ventilation filtration. This report should be regarded as an impetus for a revitalized feedback and improvement program for DOE's HEPA filter program, following the tenets set forth in Board Recommendations 95-2, *Safety Management*, and 98-1, *Integrated Safety Management*.

There is physical evidence that some HEPA filters presently in service may be too weak to perform their safety function effectively (Frethold et al., July 14, 1997), and there is continued reliance on a field test that provides no information on the filters' remaining physical strength. Indeed, physical evidence suggests that even unused but aged filters may not meet minimum strength requirements. These findings indicate a need to strengthen quality assurance and quality control programs for HEPA filters. At the same time, however:

- The QPL laboratory committed to by senior DOE management is not yet in place.
- The existence of the last remaining FTF is tenuous.
- An updated Nuclear Air Cleaning Handbook, a draft revision of which was originally committed to by December 1996, is not yet available.
- There is a serious need to update a related DOE Handbook to correct errors that could lead to nonconservative analyses, as has occurred at least once.

To address these issues and restore vitality to its filter program, DOE should give serious consideration to the following actions:

- Designate a location and firmly commit to providing funding, personnel and physical resources, and continued programmatic support for a replacement for the QPL laboratory, on an expedited schedule.
- Ensure continued operation of the Oak Ridge FTF.
- Identify needed resources and assign responsibility for early publication of a revised Nuclear Air Cleaning Handbook, in order to make accurate, up-to-date guidance on the subject available.

- Revise, update, and implement DOE-HDBK-3010-94 to eliminate confusing guidance regarding the performance characteristics of installed HEPA filters, and to improve the quality and reliability of assumptions supporting safety analyses involving these critical components of confinement systems protecting workers, the public, and the environment.
- Establish a conservative maximum age limit for HEPA filters involved in safety-related service. Such a limit should be established, simply because the filters degrade with time, and only 10–15 years of meaningful data is available to justify extended service life. Any age limit established should be supported by a systematic evaluation of how the strength of HEPA filters varies over time, for both installed filters and those in storage.

The above actions are called for to restore DOE's failing infrastructure supporting its HEPA filter program. At this time, however, higher priority should be attached to prompt completion of a vulnerability assessment of each facility relying on HEPA filters for accident mitigation. Filters specifically required to operate (and those being stored in place that could interact with these filters—as in the case of standby, bypass filter banks) in a stressed situation (e.g., in fires, during sprays, or in high temperatures) while called upon to perform a safety function should be assessed for their ability to perform acceptably. Installed filters that have already exceeded their useful life should be replaced on a prioritized basis. Finally, systematic evaluations of the anticipated performance of installed HEPA filters compared with the tasks they are expected to perform should be completed. These evaluations should be based on reasonable but conservative assumptions regarding potential mechanisms for filter degradation, pending the conduct of meaningful research aimed at definitively establishing a better understanding of how filter strength varies with time.

This report has described a significantly degraded DOE infrastructure for HEPA filters. Confinement viability demands high dependability of these filters. An acceptable level of reliability can be assured only if the robust infrastructure required to support continued assurance of their performance is restored.

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GLOSSARY OF ACRONYMS

Abbreviation	Definition
Board	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DOP	Dioctalphthalate
FTF	Filter Test Facility
HEPA	High-Efficiency Particulate Air
LLNL	Lawrence Livermore National Laboratory
OSR	Operational Safety Requirements
QPL	Qualified Products List
RFETS	Rocky Flats Environmental Technology Site
SAR	Safety Analysis Reports
TSR	Technical Safety Requirements