UCRL-ID- 125048

Requirements for a Cleanable Steel HEPA Filter Derived From a Systems Analysis

Werner Bergman
Lawrence Livermore National Laboratory
P.O. Box 808, Livermore, CA 94551

June 1996

Lawrence Livermore National Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REQUIREMENTS FOR A CLEANABLE STEEL HEPA FILTER DERIVED FROM A SYSTEMS ANALYSIS

Werner Bergman
Lawrence Livermore National Laboratory
P.O. Box 5505, Livermore, CA 94550

ABSTRACT

We have conducted a systems analysis to determine the customer requirements for a cleanable high efficiency particulate air (HEPA) filter in Department of Energy (DOE), Environmental Management (EM) facilities. The three principle drivers for the cleanable steel HEPA are large cost savings, improved filter reliability, and new regulations. These drivers provide a strong incentive to DOE customers to use cleanable steel HEPA filters.

Input for the customer requirements were obtained from field trips to EM sites and from discussions with selected investigators. Most existing applications require that cleanable steel HEPA filters meet the size and performance requirements of the standard glass HEPA filter (size: 2' x 2' x 1'; efficiency: 99.97% for 0.3μm DOP; pressure drop: 1 inch water; flow rate: 1,000 cfm; weight: 50 lbs). Applications in new facilities can relax the size, weight, and pressure drop requirements on a case-by-case basis.

We then obtained input from commercial firms on the availability of cleanable steel HEPA filters and conducted a systems analysis which compared customer needs to currently available technology. Our analysis showed that currently available technology was only able to meet customer needs in a limited number of cases. Further development is needed to meet the requirements of the EM customers. For the cleanable steel HEPA to be retrofitted into existing systems, the pressure drop and weight must be reduced. The pressure drop can be reduced by developing steel fiber media made from 0.5 μm diamter steel fibers. The weight can be reduced by packaging the steel fiber media in one of the standard glass HEPA configurations. Both developments will significantly reduce the filter cost. Although most applications will be able to use the standard 304 or 316L alloys, an acid resistant alloy such as Hastelloy or Inconel will be needed for incinerator and other thermal processes.

I. INTRODUCTION

Cleanable steel filters have been used for many years by various industries, including the nuclear industry, to provide high efficiency filtration with minimal maintenance. These filters were made from steel powder that was sintered together and formed into a hollow cylinder. Compressed air pulses were directed into the interior of the cylinder to dislodge particle deposits that had formed on the outside of the cylinder. Figure 1 illustrates the basic concept of the cleanable steel filter having multiple filter elements in a single housing, a blow-back gas for cleaning, and a hopper for collecting the particles. This is a well established design used with many other filter elements such as cloth bags, ceramic tubes, and polymeric tubes. Design variations include other filter shapes than cylinders such bayonets, stacked plates, hollow panels, etc. All filter elements have an exterior surface for collecting the deposited particles and an interior volume through which the cleaned gas exits and through which a blow-back gas is used to dislodge the deposited particles.

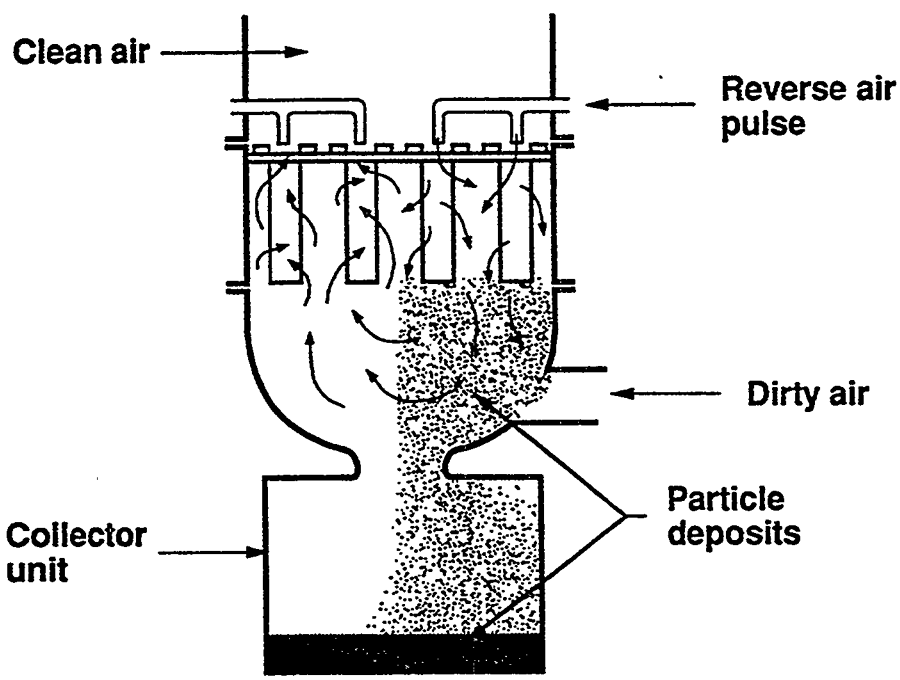

Figure 1. Typical cleanable filter with multiple cartridges and a blow-back cleaning apparatus.

The applications for these filters ranged from recovery of catalysts in petroleum refineries to off-gas filtration in incinerators. Rocky Flats had used sintered metal filters to remove the suspended particulate from a fluidized bed incinerator that burned transuranic waste contaminated with plutonium [1]. The sintered metal filters were repeatedly cleaned by reverse air pulses. Kirstein et al [2] also showed that sintered metal filters had excellent performance in both removal efficiency and reverse air-pulse cleaning for applications in another incinerator. The filters are robust and require minimal maintenance. Despite the excellent performance of the sintered metal filters, they only had about 60% DOP efficiency when clean and had relatively high pressure drops [3].

In the early 1980s, researchers in Europe had developed high efficiency air filters using the new filter media from Bekaert that was made from 2 μm steel fibers. Dillmann et al [4,5] described the use of 2 μm stainless steel fibers to make deep bed filters for use as vent filters in nuclear power reactors. The deep bed filters had efficiencies comparable to the glass HEPA filters but were much larger and could not be cleaned. Klein and Goossens [6] showed major improvements in filter efficiency with decreasing diameter of the steel fibers from 12 to 4 mm. However, the efficiencies were far below HEPA grade. They also showed that deposits of methylene blue aerosols could be efficiently cleaned from a cylindrical filter by washing with a water spray.

By the late 80's, Pall Corp. had developed cylindrical filter elements using steel media having separate layers of sintered steel fibers and sintered steel powder. Randhahn et al [7] described a stainless steel filter from Pall Corp. that had efficiencies comparable to a HEPA filter, but they did not report any pressure drops. The filter consisted of two layers of 5μm fiber media and one layer of fine powder metal. Our tests showed that the filter had a pressure drop of 2.2 psi (61 inches of water) at 13 cfm, which is equivalent to 1,000 cfm through a standard size HEPA filter [8]. A variation of the Pall filter with lower pressure drop and lower efficiency was installed as a prefilter in all of the French nuclear power plants [9].

In 1990 Bergman et al showed that by eliminating the use of steel powder and using the smallest available steel fibers, filters could be made that had the same efficiency as a HEPA filter and a pressure drop only three times as great [10]. Bergman then used this new filter to begin developing a cleanable steel HEPA filter [11].

II. SURVEY OF DOE CUSTOMER REQUIREMENTS

We have conducted a series of site visits and contacted various researchers to document the requirements for cleanable steel HEPA filters and their specifications. Although the focus of this survey was on potential applications for the existing and proposed treatment processes for mixed waste, information was also obtained on other applications having a need for HEPA filters. This survey was not intended to be comprehensive by identifying every DOE application requiring HEPA filters, but rather to provide sufficient documentation to determine whether the commercially available steel filters would satisfy DOE needs, especially those in the mixed waste area. If the survey indicated that commercial steel filters were not adequate, then an additional task was to document the requirements for developing a new cleanable steel HEPA filter. The information presented here is grouped according to the facility from where it is was obtained.

Idaho National Engineering Laboratory (INEL)

We visited several facilities and discussed filtration requirements with several different groups at INEL.

Waste Experimental Reduction Facility (WERF): Les Parsons reviewed the WERF and indicated that the cleanable steel HEPA filters could eliminate the current bag house filters in the incinerator exhaust train and also eliminate the additional air cooling, thereby resulting in significant cost and operations savings. The HEPA filtration system consists of 32 HEPA filters in two stages. The first stage HEPA filters are replaced every 2-4 years and processed there by removing the glass media and melting it in the incinerator. The steel frames are discarded as solid waste. The bag house filter has a significant amount of maintenance due to filter clogging. The bags must be replaced about every two years. To be used in the WERF, the steel HEPA filter would be required to meet the existing size and performance requirements for HEPA filters.

Although Les Parsons thought the cleanable steel filter would be excellent in this application, he said that WERF was scheduled to be shut down by about the year 2000. There would not be enough time to develop the cleanable steel HEPA and use it for long in the WERF. He indicated that the WERF was being replaced with the Advanced Mixed Waste Treatment Project. Unfortunately, no information was available on this project because the bids were issued without specifying the technology to be used.

New Waste Calciner Facility (NWCF): Jim Law reviewed the existing off-gas treatment that consists of 24 filters arranged in three stages. The first stage HEPA filters are changed once per month. The exhaust has a high moisture content and contains a significant amount of halides. An attractive feature of this application is that there is an existing washing system for cleaning deposits off the glass HEPA filters. In contrast to the glass filters, which are totally destroyed in the washing, the steel HEPA filter could be washed and reused repeatedly. However, the off-gas environment would cause the steel HEPA filters made from 304 and 316 stainless to corrode. In this application, the steel HEPA filter would have to be made from acid resistant fibers such as Hastelloy of Inconel. To be useful in this application, the steel HEPA filter would have to have the same dimensions and performance as the standard glass HEPA. Unfortunately, that is not yet possible with the acid resistant alloys.

Liquid Effluent Treatment (LET): Jim Law also reviewed the LET disposal facility that uses 8 HEPA filters that are replaced with remote manipulators. The glass HEPA filters are rapidly plugged in this operation, which also contains high moisture and halide concentration in the exhaust. The steel HEPA filters would have to be made from Hastelloy or Inconel and have the standard HEPA dimensions and performance in this application.

Plasma Hearth Process: Steve Bates reviewed the different plasma hearth processes (PHP) that were underway at INEL Nearly all of the effort in the different projects is focused on getting the plasma process operational. Although the PHPs had air pollution control systems with glass HEPA filters, there was no information on the expected performance. Once data becomes available, it will be possible to assess the applicability of steel HEPAs. Typically the exhaust will reflect the composition of the waste being burned. Acid resistant alloys of Hastelloy or Inconel would be needed for those applications burning halogenated wastes. If the PHPs generate a lot of particulate, the cleanable steel HEPAs will be useful in this application.

The steel HEPA filters would not have to have the same size as glass HEPA filters for PHP applications, although that would be preferred. Used HEPA filters are now placed in 55 gallon waste drums for disposal.

He added that the steel HEPA filters would be attractive in the off-gas because of its greater strength and temperature resistance. Locating the steel HEPA before the acid scrubber unit would significantly reduce the radioactive loading on the waste liquid. This concept is being explored at the PHP in Butte.

An important contribution of the steel HEPA filter to the PHPs is the improved prospect of having the technology licensed by regulatory agencies because of the high reliability of the steel HEPA filters.

General Filtration Needs: Brian Chesnovar, who heads the filtration group at INEL and is responsible for all filter testing and replacement, provided an overview of the general filtration needs at INEL. There are about 2,000 HEPA filters installed at INEL. He stated that the typical HEPA filter at INEL is only replaced after 8-10 years of service. Thus, a cleanable steel HEPA would only be cleaned 3-4 times during a 30 year life of a facility. He stated that the cleanable steel HEPA filter would require retrofit into existing housings to be considered at INEL. The steel HEPA filters would also have to have the same dimensions as current glass HEPAs to be compatible with existing filter handling and disposal systems. Many of the filters at INEL are changed remotely because of the radiation. One of the problems they have is the lack of storage for contaminated HEPA filters.

Savannah River Site

We visited the Savannah River Site (SRS) and met with various people working on the Consolidated Incinerator Facility (CIF), the Defense Waste Processing Facility (DWPF), and the SRS Filter Test Group (FTG) to assess the need for cleanable steel HEPA filters.

Off-gas Components Test Facility (OCTF): Dan Burns reviewed his OCTF, which is a 1/10 scale pilot facility of the CIF and is used for evaluating off-gas components including HEPA filters. There are three HEPA filters in the exhaust of the OCTF and are exposed to 2,500 cfm at 250 F. A demister made from stainless steel and glass fibers is placed upstream of the HEPA filters to extend the life of the HEPA filters. They found that the HEPA filters were structurally damaged after operating for about 10 days and reaching a pressure drop of 3 inches of water. The HEPA filters had long tears in the media along the downstream pleats. They suspect the HEPA filter was tearing because of moisture accumulation even with an efficient mist eliminator.

Consolidated Incinerator Facility (CIF): Heather Burns and Will Fleming reviewed the full scale CIF and found similar damage with the HEPA filters as in the OCTF. The full-scale CIF uses 18 HEPA filters that are changed every 10 days. Using cleanable steel HEPA filters in the CIF would avoid the problems with HEPA damage and eliminate the need for purchasing and disposing of about 450 HEPA filters each year. The cleanable steel HEPA filter would have to be fabricated from a corrosion resistant alloy such as Hastelloy or Inconel to avoid chemical attack from HCl and salt. The preferred dimensions of the steel HEPA filters would be the standard HEPA size, although other sizes could be used.

Defense Waste Processing Facility (DWPF): Herbert Elder reviewed the DWPF facility and identified the melter off-gas as a good application for the cleanable steel HEPA filter. Although the existing glass HEPA filters have been performing well, Elder is concerned about rapid HEPA failure during off-normal conditions and would like to use steel HEPA filters if available. The filters would have to be retrofitted into the existing filter holders and be resistant to the halogenated gases and particles.

General Filtration Needs: Maynor Dykes, of the Filter Test Group, stated that SRS uses about 1,000 HEPA filters per year. Although they have imposed an official 5 year administrative life on the HEPA filters because of the decreased filter strength with age [12], they have been practicing that policy for many years. The general practice has been to replace HEPA filters before their useful life is used to prevent the filters from being classified as transuranic (TRU) waste (concentration of alpha emitters greater than 100 nCi/g). This practice allows SRS to dispose of the HEPA filters as low level waste and thereby save in waste disposal costs. According to our previous study [13], the disposal cost of a HEPA filter classified as Low Level

Waste (LLW) is $140, whereas the same filter classified as TRU waste would cost $6,200. Despite their efforts, SRS still disposes about 10% of its filters as TRU waste. Because of its 5 year administrative life time, most of the HEPA filter applications at SRS would be good candidates for the cleanable steel HEPA filter. However, these applications generally would require the steel HEPA filters be retrofitted into existing housings.

Hanford Reservation

Hanford Waste Vitrification Plant (HWVP): Discussions with Mike Harty of Bechtel Hanford indicated that cleanable steel HEPA filters would be used extensively in several new waste treatment facilities. The planned Hanford Waste Vitrification Plant (HWVP) for processing the high level waste from the Hanford tanks would use cleanable steel HEPA filters in both the melter off gas and the building ventilation system [14]. Procurement specifications, that were modeled after commercially available units, were prepared for the steel filters [15]. The filters were not intended to be retrofitted into existing HEPA filter systems. Previous studies by Hanford indicated that the commercially available steel filters are cost effective. Further development of the steel filters would make them even more attractive by reducing cost and improving performance. A second vitrification plant for processing low level waste would also use cleanable steel HEPA filters. The two planned vitrification plants would require over 400 steel HEPA filters. Although the programs were canceled to allow commercial firms to bid on the jobs, Harty expects the new contractors will also use cleanable steel HEPA filters because of the significant cost and performance advantages over glass HEPA filters and sand filters.

Tank Farms: Jim Kriskovich described the filter vents used in the storage tanks for high level radioactive liquid and sludge waste. The vent filters consist of 9 prefilters followed by 18 HEPA filters in two, back-to-back stages. These filters are exposed to moisture and acid fumes. Some of the tanks are at elevated temperatures and contain flammable gases. Although the tanks will eventually be drained and the liquids processed in the vitrifiers, the steel HEPA filters could be used in many of the tank vents to provide increased reliability if the filters could be retrofitted into the existing housings and cost $5,000 or less. The economic advantage of the steel HEPA filters could not be assessed at this time because of the lack of data on the life of the glass HEPA filters.

In-Situ Vitrification: Ja-Kael Luey of Pacific Northwest Labs (PNL) stated that the off gas from the in-situ (ground) vitrification consisted of a bag house prefilter followed by HEPA filters. He reviewed the commercial steel filters from the Pall Corporation and did not consider it because of the high cost and the lead time for fabricating the filters. The bag-house prefilter and HEPA filter are functioning fine, and Luey does not believe the HEPA filters have a loading problem to warrant the use of a cleanable filter. However, the in-situ process is relatively new, and there is little data on the HEPA life to assess the economic advantage of the cleanable steel HEPA filter.

Western Environmental Technology Office (WETO)

We visited the WETO in Butte Montana and met with Dan Battleson, Mike Willis, and Stephan Kujawa of MSE, Inc. to review the requirements for off gas treatment from DOE's thermal waste treatment systems and to find potential applications and requirements for a cleanable steel HEPA filter. They have a slip stream from the exhaust of a plasma arc furnace in which various air pollution control devices are placed for evaluation. The first element in the off-gas system was a silicon carbide ceramic filter (pilot scale) made by Pall Corporation to remove the particulate. Although the inlet temperature for the evaluation was intended to be 1600 F, it was only 375 F because of extensive cooling in the long lines from the furnace. To overcome this difficulty, MSE intends to install a variable heater to increase the temperature up to 1600 F for the off-gas tests. MSE issued a contract to Pall Corp. for a full-scale ceramic filter with reverse pulse cleaning for evaluation in their facility. The ceramic filter is intended for use as a prefilter.

MSE also issued a contract to Pall Corp. for a cleanable steel HEPA filter using reverse air pulses for evaluation in the off-gas at 750 F. The motivation for a cleanable steel HEPA filter was to have the filter capture radioactive particles upstream of the wet scrubber and thereby reduce the contamination in the liquid waste stream. The efficiency and pressure drop requirements were 99.97% for 0.3 um DOP aerosols and 1 inch water at 1,000 cfm. Since there are no commercially available high-temperature, cleanable HEPA filters that also meet the size requirements, this parameter was relaxed in the specification. The filter can not be retrofitted into existing HEPA filter systems. An important consideration is that the HEPA filters need to be resistant to the HCl in the off-gas. The MSE evaluation of cleanable, high-temperature HEPA filters will establish the baseline performance of the commercial cleanable HEPA filters in hot gas filtration applications.

Oak Ridge Reservation (ORR)

We visited the K-25 facility at Oak Ridge to review the TSCA Incinerator and the Transportable Vitrification System (TVS) for potential applications of the cleanable steel HEPA filter.

Toxic Substance Control Act (TASCA) Incinerator: James Dunn, Group Leader for the TSCA engineering, provided a tour and a description of the incinerator. The off-gas treatment system consisted of a wet scrubbing system and a low efficiency (65%) particulate removal system. The particulate removal system was similar to wet electrostatic precipitators but was far less efficient. According to Dunn, the TSCA incinerator will not need to have HEPA filters.

Transportable Vitrification System (TVS): Frank Van Ryn provided an overview of the TVS that was still under evaluation at Clemson University. The TVS uses conventional glass HEPA filters in the off-gas treatment and does not have a reason for switching to a cleanable HEPA filter based on the surrogate tests at Clemson. They found that the wet scrubber that preceded the HEPA filter was very efficient and caused little loading on the HEPA filter. However, the limited tests are insufficient to determine the expected life of the glass HEPA filter and thus the economic advantage of the steel HEPA. If tests on radioactive wastes indicate a cleanable steel HEPA is advantageous, then the commercially available units would be acceptable. The TVS does not have a size or weight restriction on the filtration system.

DOE Complex

The customer needs reviewed in this paper were focused primarily on the applications of treating mixed wastes. Because many of the mixed waste treatment systems generate halides, the cleanable steel HEPA filters must be made from acid resistant media such as Hastelloy or Inconel. In addition to these specific needs, there are other needs that apply to all DOE installations including EM facilities.

Fire Protection Systems: Fire protection engineers recognize that the recommended practice of using water sprays in HEPA filter plenums as a fire protection strategy may damage the HEPA filters but are reluctant to eliminate the water [16]. They see the cleanable steel HEPA filter as a solution to the problem. Since the filter plenums with water spray systems are widely used throughout the DOE complex, the steel HEPA filter would have to be retrofitted into existing housings and have similar efficiencies and pressure drops as the glass HEPA filters. The steel HEPA filters can be made from 304 and 316 stainless steel.

Decontamination and Decommissioning (D&D): A large number of portable and temporary ventilation systems with HEPA filters will be used as EM completes the D&D of its facilities. The HEPA filters in these ventilation systems will plug rapidly and require frequent replacement. Cleanable steel HEPA filters can greatly reduce the use of HEPA filters in D&D operations. The requirements are that they be interchangeable with current glass HEPA filters. The steel HEPA filters can be made from 304 and 316 stainless steel.

Security Filters: There are a number of applications such a Pu storage and handling operations that require the highest degree of reliability. Although glass HEPA filters are subject to a number of failure modes that decrease the reliability of the filters, there are no commercial alternatives. Steel HEPA filters that have the same dimensions and performance as the glass HEPA filters would be used in these applications. These safety filters can be made from 304 and 316 stainless steel.

General Ventilation Systems: The majority of the approximately 31,000 glass HEPA filters within the DOE complex can be replaced with cleanable steel HEPA filters based on cost savings from handling and disposing of the contaminated filters. Once a maximum service life is imposed on the glass HEPA filters (a strong possibility), then all of the 31,000 glass HEPA filters can be replaced with steel HEPA filters based on cost savings. The details of these savings are described in the analysis section dealing with cost savings. The requirements for the steel HEPA filters are that they can be retrofitted into existing HEPA filter holders, and have the same efficiency and pressure drop and similar weight as the glass HEPA filters. The composition of the general ventilation steel HEPA filter can be 304 or 316 stainless steel.

III. SURVEY OF COMMERCIALLY AVAILABLE STEEL HEPA FILTERS

Since steel HEPA filters are made from steel fiber media, which in turn, are made from steel fibers, all three parameters are included in our survey. This is necessary since the manufacturer of the HEPA filter is generally different from the fiber and media manufacturer.

Steel Fibers

The steel fibers from which the media and filters are made are the most critical part of steel HEPA filters. The fiber diameter determines the basic filtration properties such as efficiency, pressure drop and the weight of the filter media. Smaller fiber diameters result in higher efficiencies and lower pressure drops and lower media weights. The chemical composition determines the temperature and chemical resistance. Fibers having chemical composition with higher temperature and chemical resistance are more difficult to make into smaller diameters. The largest fiber production company in the world is Bekaert with headquarters in Belgium and offices in Georgia. Memtec is the U.S. successor of the former Brunswick company, that first developed the microfibers using a multi-wire drawing process. There are Japanese firms that also provide microfibers, but they are not available in the U.S..

Table 1. Commercially Available Steel Fibers

Company	Composition	Diameter
Memtec Deland, FL	304 and 316	1, 2, 4, 8um and larger
	Hastelloy	8, 12, 15 um
	Inconel	12 um
Bekaert Marietta, GA	316L	1.5, 2, 4, 8um and larger
	Hastelloy	8, 10, 22 um

Steel Media

The steel media is generally produced from chopped fibers using the paper making process as is done with the conventional glass media. This process involves forming a water suspension of fibers and then forming a mat on a continuous screen while draining off the water. After the fiber mats are formed, they are heated in an oven to bond (sinter) the fibers together into a sheet. Memtec uses the dry process of carding (combing) steel wool followed by compaction and sintering. The following companies produce the steel fiber media that are closest to HEPA filter grade and are available in the U.S.:

Table 2. Commercially Available Steel Fiber Media

Company	Medium	Smallest Fiber Diameter
Bekaert Marietta, GA	316L	1.5um
Memtec Deland, FL	304 or 316	2 um
Pall Cortland, NY	316L	1.5um
Tomoegawa Wheeling, IL	316L	1 um

Steel Filters

There are three major companies in the U. S. that can produce high efficiency steel filters for use in DOE facilities: Pall Corporation of Cortland, NY; Memtec Corporation of Deland, FL; and Puralator of Greensboro, NC. Two designs have been developed to date: an assembly of multiple cartridges housed in a standard 2' x 2' x 1' frame and multiple cartridges housed in a pressure vessel. We developed the basic design parameters for the steel filter that can be retrofitted into the standard HEPA housing [17]. This filter design consists of 64 individual filter cartridges housed in a standard HEPA filter frame of 2' x 2' x 1'. Figure 2 shows a photograph of a typical filter cartridge that was used in the standard HEPA housing. The cleanable steel filter, shown in Figure 3, consists of 64 cartridges assembled into the HEPA filter housing.

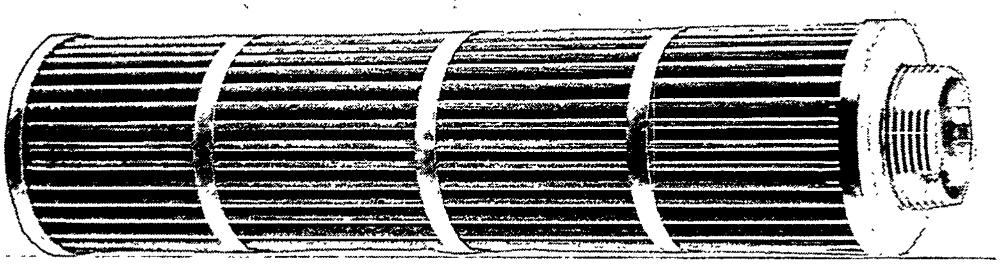

Figure 2. Typical filter cartridge

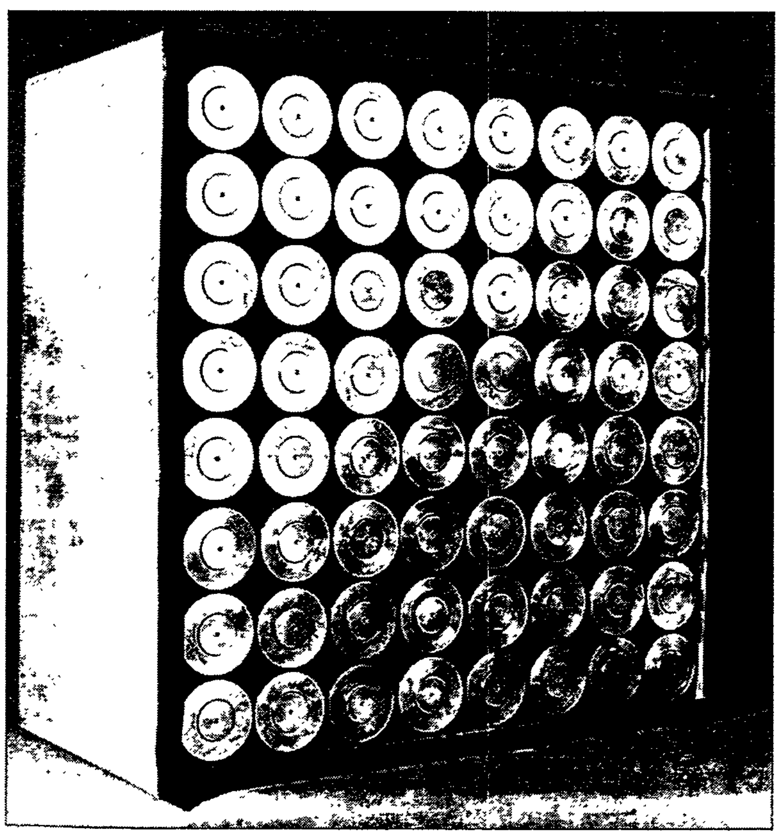

Figure 3 Photograph of the assembled cleanable steel filter using the flat panel design with 64 cartridges

We made two cleanable steel filters using filter cartridges from Pall and Memtec and evaluated their performance [17]. The key parameters are shown in Table 3.

Table 3. Performance parameters of cleanable steel filters

	Pall	Memtec
dimensions	2'x2'x1'	2'x2'x1'
weight	225 lbs	210 lbs
Media composition	316L	304
fiber diameter	2 um	2 um
flow rate	1,000 cfm	1,000 cfm
pressure drop	3.1 in.	3.1 in.
DOP penetration	0.01%	0.01%

The performance parameters shown in Table 3 are not acceptable for the cleanable filter to be used as a HEPA filter. The filter weighs too much, and the pressure drop is too high for retrofit applications. The cost for the panel unit is about $70 K. No high efficiency filters have been fabricated using the acid resistant fibers of Hastelloy or Inconel.

We developed a reverse air-pulse cleaning method for the cleanable filters and evaluated their performance using Arizona road dust from Powder Technology Inc.. Figure 4 shows the filter clogging and cleaning cycles for a test on the Pall filter. The performance with the Memtec filter is similar.

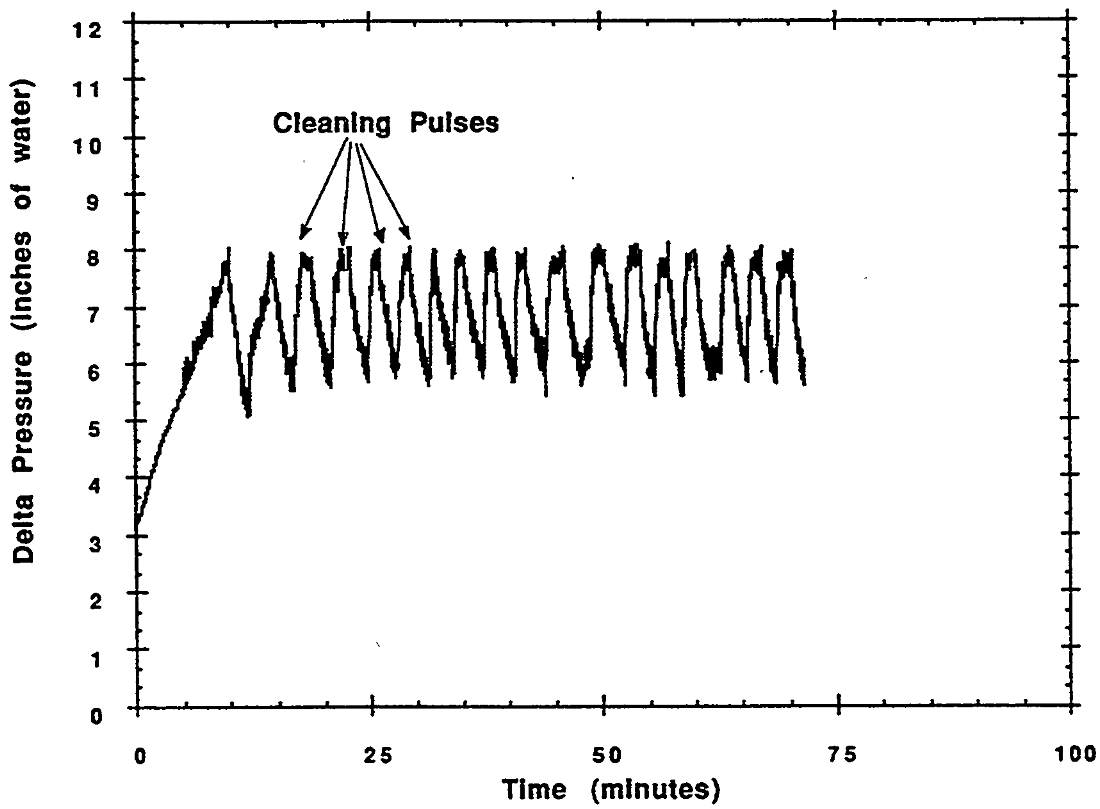

Figure 4. Filter clogging and cleaning cycles for steel filter

In addition to the panel filter design shown in Figure 3, the cleanable steel filter can be designed as a pressure vessel for use in applications that do not require retrofitting into existing housings. Pall Corp. has built several units in which multiple cartridges are housed inside a pressure vessel as shown in Figure 5. This is the design that was to be used in the vitrification plant at Hanford.

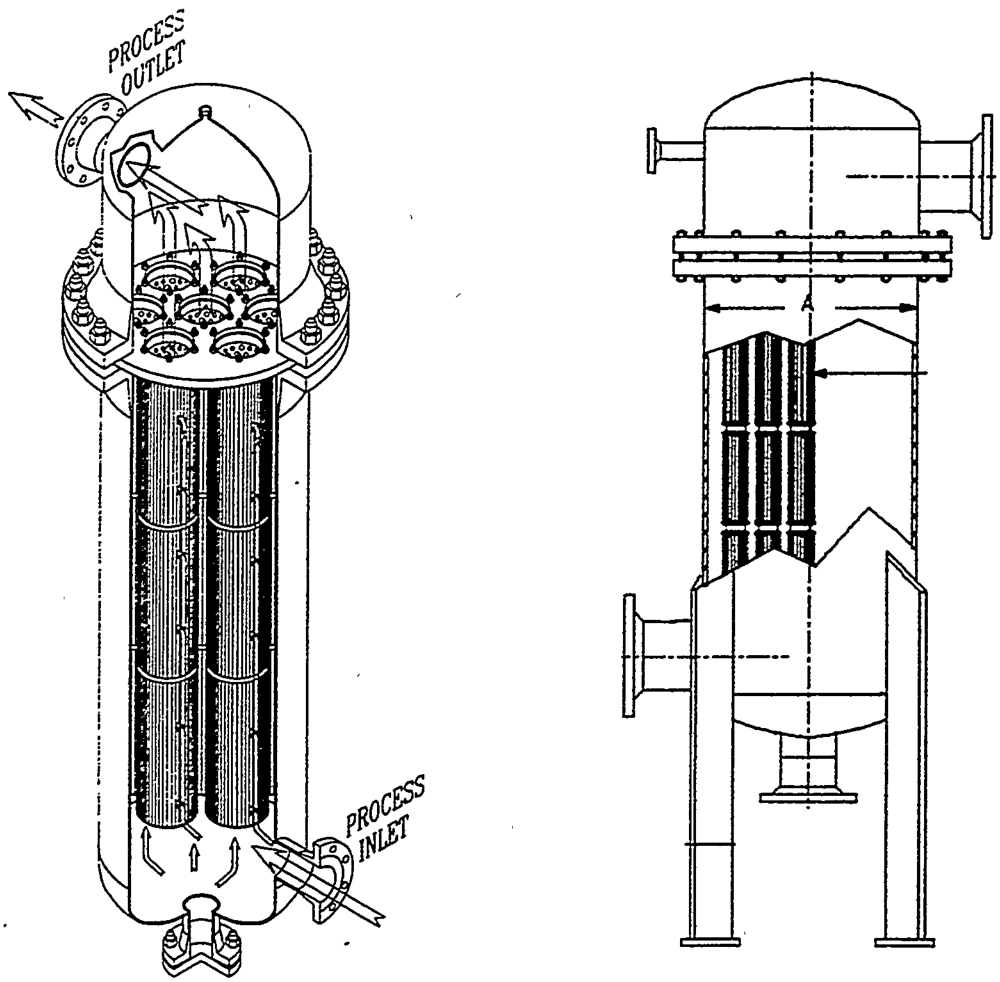

Figure 5. Drawing and schematic of the cleanable steel filter with filter cartridges housed in a pressure vessel.

The filter in Figure 5 is cleaned using a reverse water flush. Tests by Pall using Arizona road dust show that fully loaded filters can be efficiently cleaned using the water wash [25,26]. The estimated cost for a pressure vessel filter unit is about $109K.

IV ANALYSIS OF CUSTOMER REQUIREMENTS COMPARED TO COMMERCIALLY AVAILABLE TECHNOLOGY

The survey of customer requirements for cleanable steel HEPA filters did not provide a clear mandate for further development of this technology. In some cases, such as the CIF at SRS and the NWCF at INEL, the present glass HEPA filters are replaced every 2-4 weeks, and improved HEPA technology is clearly needed. In other cases, such as general filtration applications, the glass HEPA filters already have a long life, and further extension of filter life with more expensive filters did not make sense to the users. Several of the new waste treatment processes such as the in-situ vitrification at PNL and the TVS at ORR do not have sufficient experience with the HEPA life to determine whether improvements are needed. At Hanford, cleanable steel HEPA filters were judged to be the most economical for the two vitrification plants, but plant construction was halted and bids were submitted to commercial firms to restart the process from the beginning.

Although most of the customer needs were based on economic considerations, a few customers cited increased reliability as the primary need. For example, the cleanable steel HEPA was attractive for use in the melter off-gas filter in the DWPF at SRS because of concerns over glass HEPA filter rupture and the resulting plant shut-down for clean-up and safety considerations. Fire protection engineers also favored steel HEPA filters because of similar concerns with HEPA filter rupture during fires.

The customer requirements for cleanable steel HEPA filters could not be established directly from the survey of individuals and facilities reviewed in this study for several reasons. Although cost was the primary factor cited, there were generally insufficient data to make a detailed cost comparison. Important information such as filter life, operating environments, and anticipated life of the facility or operation were frequently not available. The specific sites visited and individuals interviewed were also limited to primarily mixed waste treatment operations. These operations represent a small, but important, fraction of EM's and DOE'S needs in filtration.

To determine customer requirements for a cleanable steel HEPA filter more accurately than merely summarizing anecdotal information from individual visits, we identified the primary drivers for this technology and conducted an analysis of these drivers with input from our survey. There are three principal drivers for the cleanable steel HEPA filters: cost savings, improved reliability, and new regulations. The specific driver that governs the requirements for the steel HEPA technology varies with the EM site and the specific waste treatment technology.

Cost Savings for Cleanable Steel HEPA Filter

The initial driver that was responsible for the early development work of the filter was the cost saving that resulted from reducing the large waste disposal costs by cleaning the filter and reusing it [6]. We found that during the 1987-1990 period, DOE facilities used an average of 11,478 HEPA filters per and had an annual estimated cost of $55 million [13]. We estimated that replacing all of the glass HEPA filters with steel HEPA filters would reduce the annual costs to $13 million and save $42 million per year [17]. However, since the total savings is dependent on the quantity of HEPA filters used, the potential savings have decreased significantly during the past few years because of decreased usage.

The major factors that determine the total cost savings from using cleanable steel HEPA filters are (1) the number of glass HEPA filters used per year, (2) the average filter life for the glass and steel HEPA filters, (3) the initial purchase price for the glass and steel HEPA filters, (4) the installation, test, removal and disposal cost for a glass or steel HEPA filter, and (4) the cost for cleaning the steel HEPA filter.

Figure 6 shows the number of HEPA filters that were qualified at the DOE filter test stations from 1970 to 1995. The data was obtained from published reports [13,18-21] and personal communications with the managers of the filter test stations. The number of HEPA filters from 1970 to 1980 were only for DOE facilities, while the remaining data included a small number for commercial firms. No data was available from 1981-1983. We see that DOE used between 10,000-15,000 HEPA filters per year from 1970 to 1990. Since 1990, the HEPA filter usage decreased dramatically except for an increase in 1993. We have assumed that the number of HEPA filters that were tested equals the number that are used by DOE facilities.

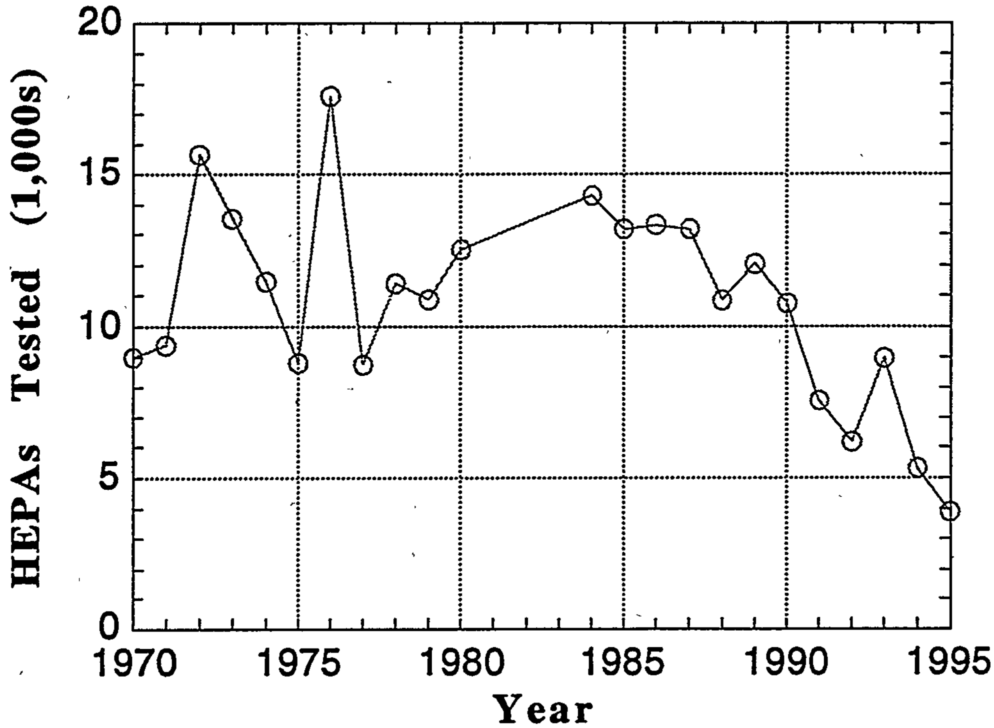

Figure 6. Number of HEPA filters passing the qualification tests at the DOE filter test stations.

The decreased filter usage can be attributed to the cessation of nuclear weapons production, leaving most of the DOE facilities in a maintenance mode. Since the ventilation systems must still operate in facilities even with no work, the effect will be a significant extension in HEPA filter life. During the period from 1991 to 1995, DOE initiated a number of programs to treat the accumulated radioactive waste and to decontaminate and decommission (D&D) facilities. The number of HEPA filters from 1991 to 1995 thus represents the maintenance replacement plus the filters used in EM operations.

Although the number of HEPA filters used per year as of 1995 is about 4,000, this number should increase dramatically as the bulk of the radioactive waste is processed and the existing facilities are

D&D'ed. We cannot predict the number of HEPA filters that will be used in the EM operations at the present time because of the uncertainty in the specific waste treatment methods and the techniques to be used in the D&D operations. Assuming that the waste treatment and D&D operations generate a similar amount of airborne contaminants as did the weapons production operations, we estimate about 12,000 HEPA filters will be used by DOE each year once the EM operations are in full operation. Based on DOE's EM five year plan, we also assume that this level of effort will continue for about 30 years [22]. The number of HEPA filters used is an important parameter in assessing the total potential cost savings when using cleanable steel HEPA filters.

Another important factor that determines the cost savings for cleanable steel HEPA filters is the frequency of filter replacement (or conversely, filter life) for the present glass HEPA filters. The average filter life for the glass-paper HEPA was estimated to be 3 years from a study of filter usage during 1977-1979 [23]. If we assume that the number of facilities and operations remain constant during this period, then it is possible to estimate the total number of filters in DOE facilities by multiplying the number of filters tested each year by the average life. For the period between 1977-1979, DOE tested an average of 10,352 filters and therefore had 31,055 filters in its facilities.

Once we have the total number of filters, we can estimate the average filter life by dividing the total number of filters by the annual number tested. Assuming the total number of active filters is still about 31,000, we estimate that the average filter life is (31,000/4,000 = 7.8) 7.8 years. This estimate is reasonable based on the filter age data from Lawrence Livermore National Laboratory as of 10/13/94 that is shown in Figure 7. As noted before, the average HEPA life is expected to significantly decrease with a corresponding increase in the number of HEPA filters used as DOE begins to process its radioactive waste and D&D its facilities. For our analysis, we will assume the average filter life will fall within the range of 3 years for full production and 7.8 years for primarily idle operation. The average is 5 years.

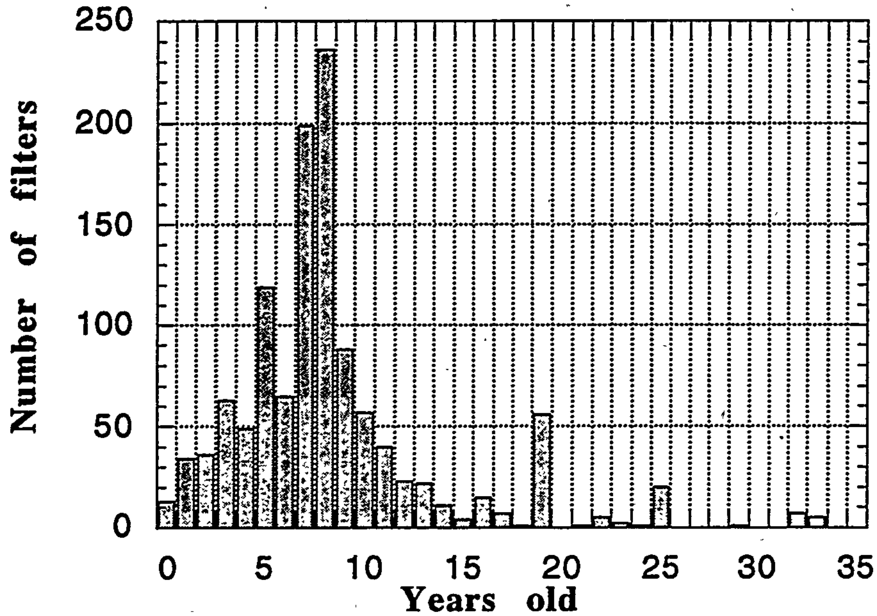

Figure 7. Distribution of HEPA filter age at LLNL as of 10/13/94. The filters are size 5.

In addition to the number of filters and the average filter life, there are several additional parameters that are needed to estimate the cost savings for cleanable steel HEPA filters. The present cost of a cleanable steel filter with 3-4 inches pressure drop and weighing 200 pounds is about $70,000 [24]. In contrast a standard glass HEPA. filter, which weighs about 40 pounds, costs about $300. We have assumed that the cost of the steel HEPA filter can be reduced to $5,000 through further development work and with efficiencies in mass production. The cost for the installation, test, removal, and disposal was $4,450 as obtained from a survey of life-cycle costs of glass HEPA filters for the period 1987-1990 [13]. We assumed that this cost would be the same for both the prototype and the steel HEPA filter. The prototype steel filter would have a higher cost because of its greater weight, but we have ignored that because it is hard to estimate and is small compared to the initial cost.

The final parameter to be considered in our cost analysis is filter cleaning costs. We have assumed reverse pulse air cleaning or filter removal and off-line washing would be the primary cleaning methods. Pall has also developed and successfully tested an on-line water cleaning method for their pressure vessel design [25,26]. We have estimated that each cleaning cycle would cost $500 based on labor costs. The associated capital costs for the cleaning hardware (e.g. blow back tubes) would be lumped into the initial cost for the filter element housing or in the initial cost the steel HEPA filter.

We have summarized the various costs and parameters for the glass HEPA filter, the commercially available steel filter, and the fully developed cleanable steel HEPA filter in Table 4. We have also computed the total filtration cost for a given HEPA filter installation over 30 years. The total filtration cost for the HEPA filters are given by:

$$C_{GT} = (30/L_{GF})(C_{GF} + C_M) \quad (1)$$

$$C_{ST} = (30/L_{SF})(C_{SF} + C_M) + N_C(C_C) \quad (2)$$

where C_{GT} = total filtration cost for glass HEPA in a single installation over 30 years.

C_{ST} = total filtration cost for steel HEPA filter in a single installation over 30 years.

L_{GF} = Life of glass HEPA filter, years

L_{SF} = Life of steel HEPA filter, years

C_{GF} = Initial cost of glass HEPA filter

C_{SF} = Initial cost of steel HEPA filter

C_M = Maintenance cost of installation, test, removal and disposal

C_C = Cleaning cost of filter

N_C = $30/L_{GF}$ = Number of cleanings

Equation 2 incorporates the assumption that the steel HEPA is cleaned prior to disposal at the end of its useful life. The cost of the cleaning system that is required for retrofit applications is included in the cost of the cleanable steel HEPA because it is small compared to the cost of the filter. The cleaning system would either consist of an in-duct reverse air pulse jet or the filter would be removed for off line cleaning in a liquid bath.

Once the costs for glass and steel HEPA filters are determined from Equations 1 and 2 respectively, a variety of other cost figures can be computed such as annual costs per filter location, total and annual cost savings for steel HEPA filters compared to glass HEPA filters, and total DOE filter costs and total savings. We have made these computations in Table 4.

Table 4. Comparison of costs and parameters for glass HEPA and cleanable steel HEPA filters.

	Glass-paper HEPA	Stainless steel HEPA	
		Commercial	After Development
Filter element (1000 ft^3/min)	$300	$70,000	$5,000
Installation, test, removal, and disposal	$4,450	$4,450	$4,450
Cleaning	$0	$500/cleaning	$500/cleaning
Average filter life	5 years	30 years	30 years
life costs for one location(30 years)	$28,500	$77,450	$12,450
life savings per location	$0	-$48,950	$16,050
cost per location per year	$950	$2,648	$415
annual savings per location	$0	-$1,698	$535
total DOE cost per year (31,055 filters)	$29.5M	$82.2M	$12.9M
total DOE savings per year (31,055 filters)	$0	-$52.7M	$16.6M

As seen in Table 4, the commercially available steel filter is not cost effective because of the high purchase cost of $70,000 and the few cleaning cycles for applications having an average HEPA life of 5 years. This explains why these filters are not being used in applications where conventional glass HEPA filters are used. The steel HEPA filter becomes more cost effective with increasing cleaning cycles because of the $4,450 in handling and waste disposal costs that are saved with each cleaning. Table 4 also shows that the steel HEPA filter costing $5,000 is very cost effective for the given assumptions. We believe that this cost reduction is achievable with additional development and improvements in production methods.

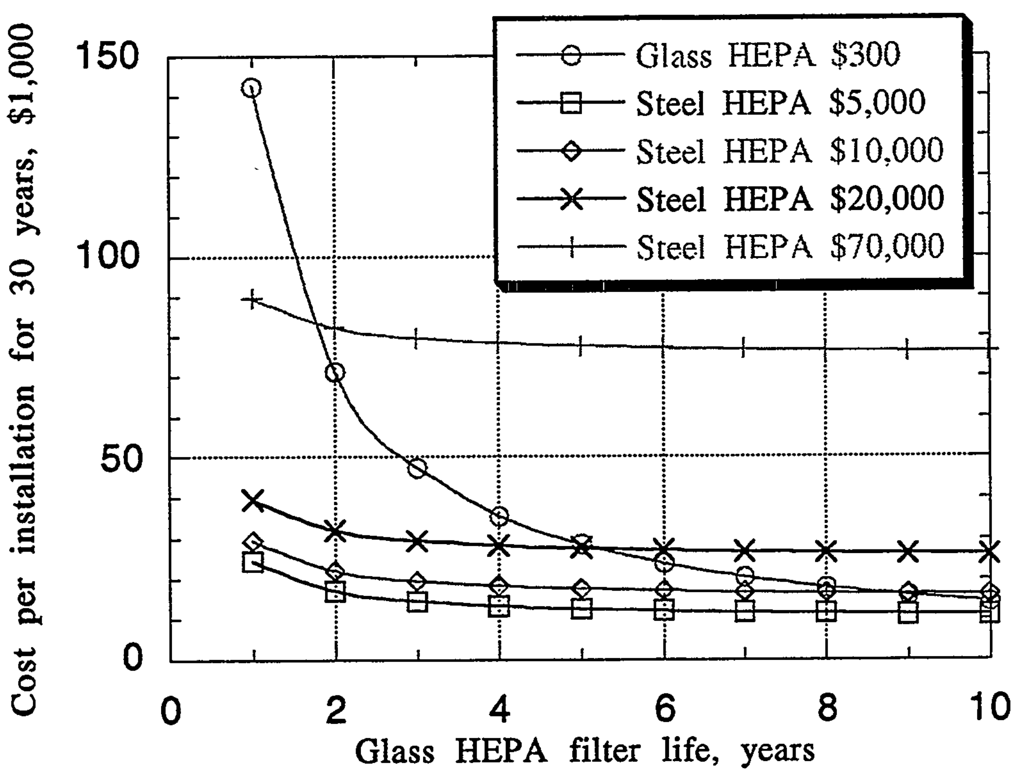

Figure 8. Cost of HEPA filtration in one installation site over 30 years as a function of the service life of a glass HEPA filter.

To assess the sensitivity of the filtration costs and cost savings to variations in the key parameters in Table 4, we used Equations 1 and 2 to determine the total cost as a function of the glass HEPA life (or cleaning frequency), the purchase cost of the steel HEPA filter, and the service life of the steel HEPA. The results of this sensitivity analysis are shown in Figures 8-12.

Figure 8 shows the obvious result that the total filtration cost is high for an installation with a glass HEPA filter that has a short life (i.e. one that must be frequently replaced). With increasing filter life, the filtration costs rapidly decrease. In contrast, the cleanable steel HEPA filter has a relatively constant filtration cost, except at a very short glass HEPA life. The intersection of the glass and steel HEPA filter curves represent the break-even point, where the glass and steel HEPA filters have the same cost. These trends are explained by the glass HEPA filter having a low purchase cost and a high maintenance cost, while the cleanable steel filter has a high initial cost and a low maintenance cost.

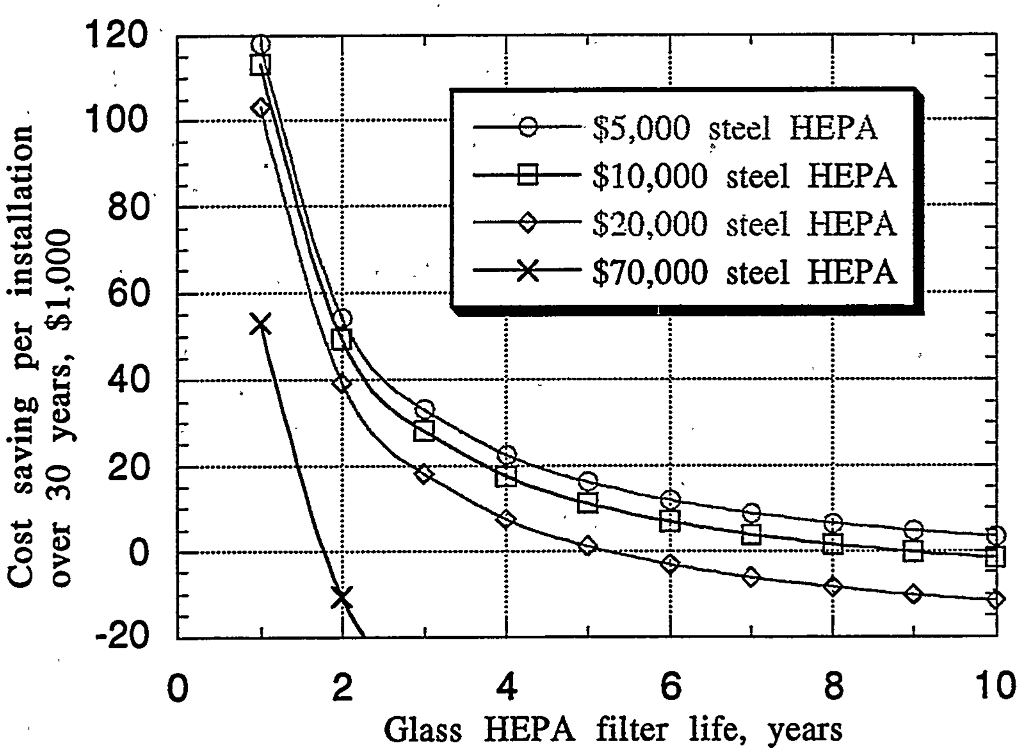

Figure 9. Cost savings from replacing glass HEPA filter with cleanable steel HEPA over its 30 year life.

The cost savings that result from replacing the glass HEPA filter with a cleanable steel HEPA filter are shown in Figure 9. The data in Figure 8 were obtained by subtracting the steel HEPA costs (Equation 2) from the glass HEPA costs (Equation 1). The results in Figure 9 show that the greatest savings occur with filter installations that require the glass HEPA filter to be replaced frequently. As the service life of the glass HEPA filter increases, the purchase cost of the cleanable steel HEPA filter represents a greater fraction of the total cost and is less cost effective. The break-even cost occurs when the curve crosses the zero savings line. Thus the cleanable steel HEPA filter is only cost effective in installations where the glass HEPA has a shorter life than the break-even point. Figure 9 shows that a $5,000 steel HEPA filter installed in a facility where the average glass HEPA life is 5 years will have a cost savings of about $16,000 over its 30 year life.

One of the major assumptions in our analysis is that the cleanable steel HEPA filter will have a useful life of 30 years. For most applications this is a good assumption because the steel media is made from 316 or 314 stainless steel fibers and will be resistant to a large variety of particles and environmental conditions. However, for many of the proposed thermal treatment processes, the off-gas will contain a significant amount of halides from the combustion of plastics. Although most of the halide particles and gases will be removed by wet scrubbers, there will be a small quantity that will be captured by the steel HEPA filter and can cause corrosion over time. Although the corrosion may be mitigated by frequent washings, this approach is not attractive because of secondary waste. A better solution is to use a more acid resistant material such as Hastelloy or Inconel in the filter.

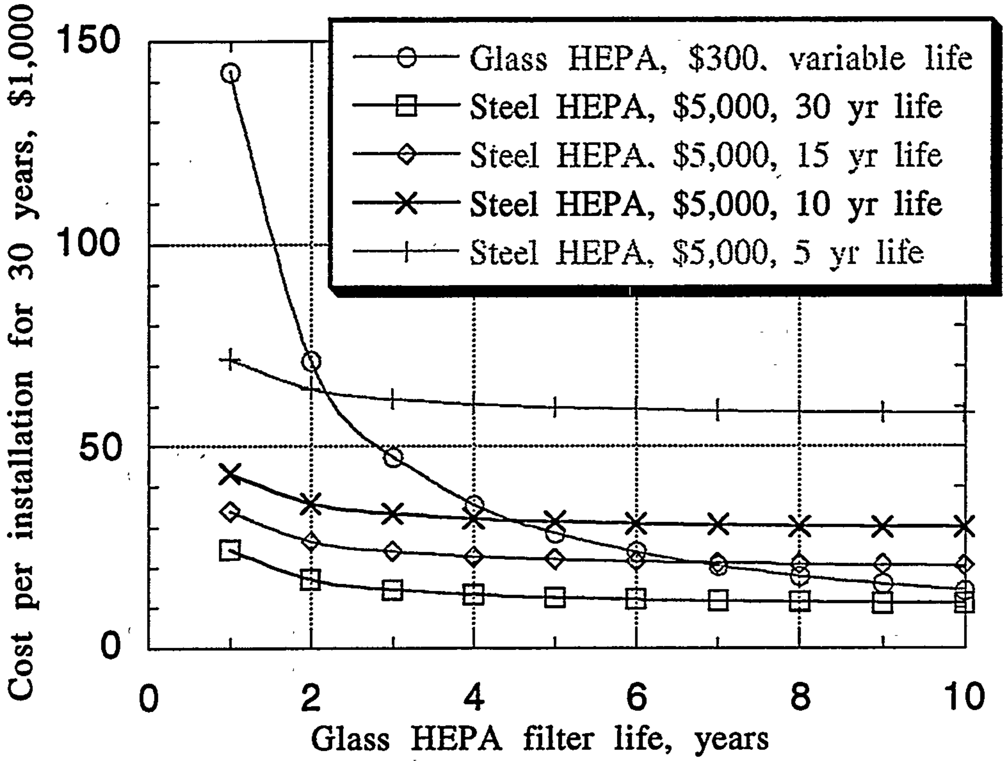

Figure 10 Cost of HEPA filtration for a $5,000 steel HEPA filter and a standard glass HEPA filter in an installation site over 30 years as a function of the service life of a glass HEPA filter.

To assess the effect of a shortened filter life on the steel HEPA, we have computed the filter costs with filter lives from ranging from 5 to 30 years using Equation 2. The results for steel filters costing $5,000 and $10,000 are shown in Figures 10 and 11 respectively. We have also included the cost for the glass HEPA filter for comparison. The results in Figures 10 and 11 show that the decreased filter life increases the total filter cost in a similar manner as increased purchase cost.

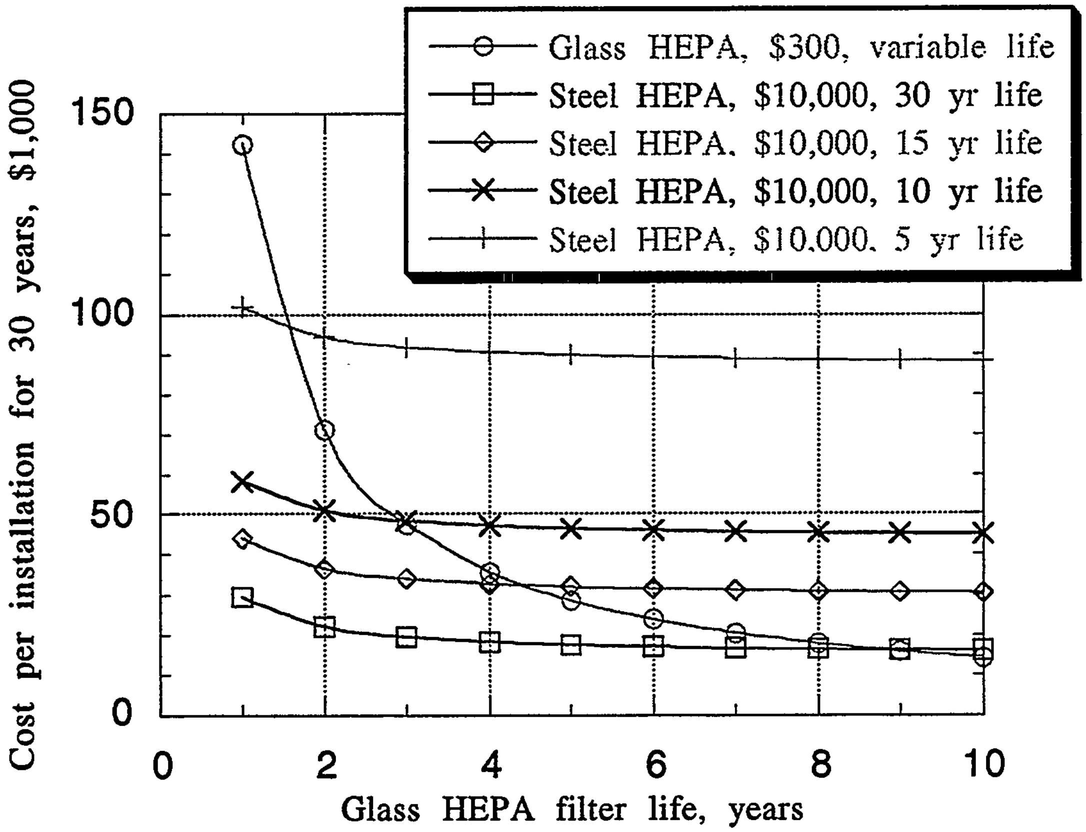

Figure 11 Cost of HEPA filtration for a $10,000 steel HEPA filter and a standard glass HEPA filter in an installation site over 30 years as a function of the service life of a glass HEPA filter.

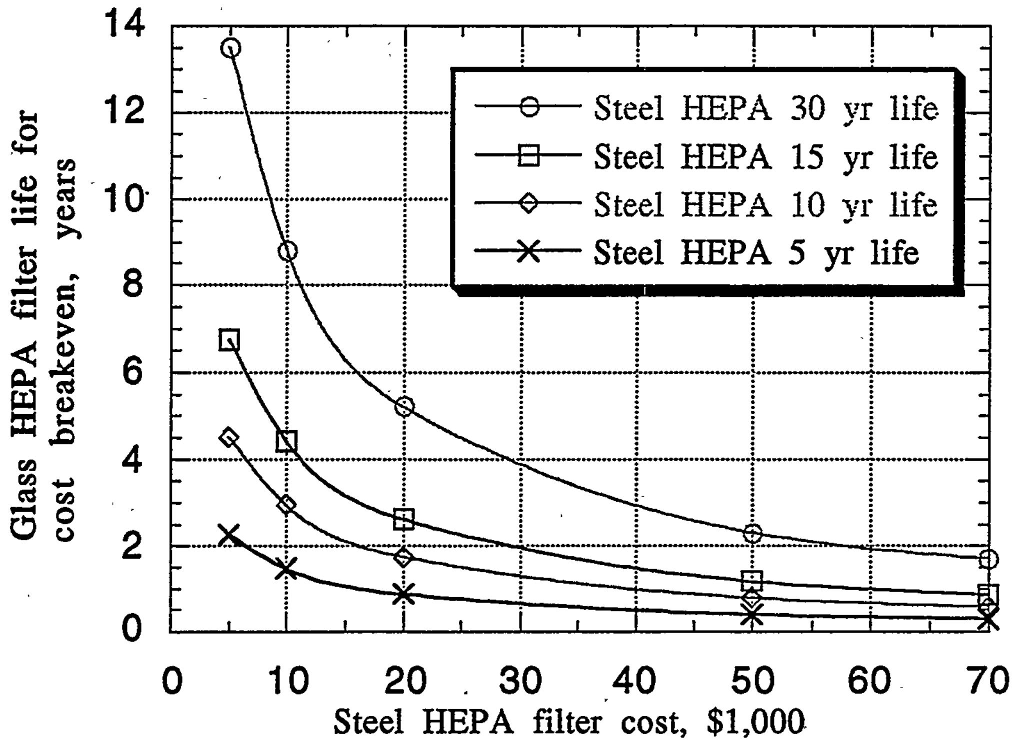

Figure 12 Break-even costs for cleanable steel HEPA filter having different filter lives as a function of purchase cost.

The data presented in Figures 8-11 are summarized in Figure 12 which defines the break-even costs as a function of glass HEPA life, steel HEPA cost, and steel HEPA life. Using a steel HEPA filter will be cost effective for any combination of glass HEPA life and steel HEPA cost that lies below the curve defining a given steel HEPA life. Figure 12 shows that more expensive steel HEPA filters are only cost effective with long steel filter life and short glass HEPA life. Conversely, lower cost steel filters can be cost effective with higher glass HEPA filter lives and lower steel HEPA lives.

We can estimate the cost savings to DOE by using cleanable steel HEPA filters instead of glass HEPA filters from the data in this section. The glass HEPA life was estimated to be 5 years based on the average between full production during 1970-1990 (3 years) and near idle in 1995 (7.8 years), We assume the steel HEPA when fully developed will cost $5,000 and have a service life of 30 years. Using these values and others shown in Table 4, we compute that DOE will save $16.6M per year by using steel HEPA filters in place of the glass HEPA filters. This saving is expected to increase considerably because of the increase in filter usage (i.e. shorter glass HEPA life) when the waste treatment processes go into production and D&D activities are underway. Based on the 1992 study [13], about 75% of all DOE filters were for the EM facilities at Rocky Flats, Savannah River, Oak Ridge, and Hanford Reservation. The average purchase, handling and disposal cost per HEPA filter is $4,750 based on the 1992 study. This cost is also expected to increase substantially in the future due to insufficient waste disposal sites. Thus, the estimated $30M that DOE now spends each year on HEPA filters is expected to increase significantly. Using cleanable steel HEPA filters will therefore result in even greater savings than the estimated $16M per year.

In addition to the direct cost savings shown in Table 4, there are additional cost savings due to the increased reliability of the steel HEPA filters. Steel HEPA filters have a much higher reliability than the present glass HEPA filter, which can be damaged or destroyed under a number of operational and accident conditions involving fires, explosions, tornadoes, or water exposure. When the HEPA filters are damaged, radioactive contaminants can escape and cause environmental contamination. The typical consequence of a accidental release is a facility shut down and an environmental clean-up operation.

This consequence has appreciable costs associated with it. For example, a small Pu release in LLNL's Pu building in 1980 from a HEPA leak due to a faulty gasket caused the Pu building to shut down for 9 months to investigate and correct the problem. The 9 month shut-down effectively cost about $9M. In 1994, Pantex shut down its facilities for two months because of leaking filters. This shut-down resulted in a substantial cost, in the millions. Replacing the fragile glass paper HEPA filters with steel HEPA filters will greatly reduce these costs and thereby result in additional cost savings. We have not estimated the potential cost savings that would result from an accident involving a damaged HEPA filter.

Cleanable Steel HEPA Filters Have Much Greater Reliability Than the Glass HEPA Filter

Glass HEPA filters are prone to structural failure when the filters get wet, old, hot or overpressured. We have recently completed a literature review of the performance of new filters and parameters that may cause deterioration in the filter performance such as filter age, radiation, corrosive chemicals, seismic and rough handling, high temperature, moisture, particle clogging, high air flow and pressure pulses [27]. The deterioration of the filter efficiency depends on the exposure parameters; in severe exposure conditions the filter will be structurally damaged and have a residual efficiency of 0%. Figure 13 shows a photograph of an aged HEPA filter that was subjected to 13 inches of differential pressure. The strength of the old filter had deteriorated sufficiently to allow the higher pressure to blow out the filter media.

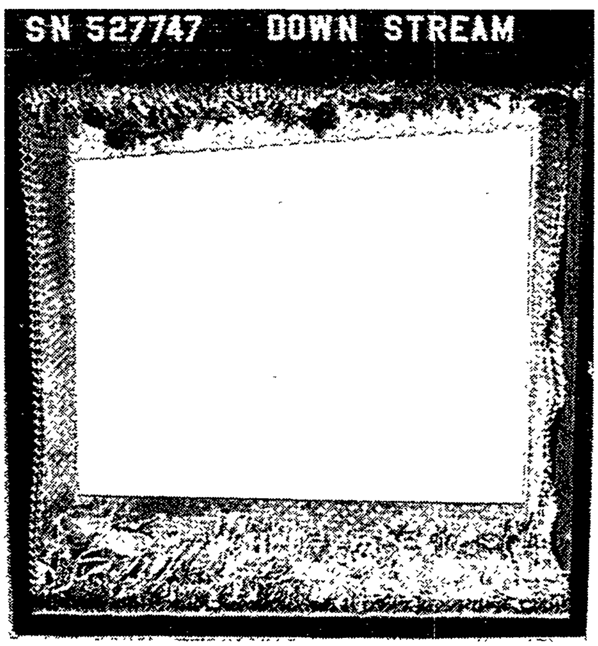

Figure 13. Photograph of 15-19 year old HEPA filter blown out after subjected to a 13 inch differential pressure [28].

One of the most serious accidents that can occur in a nuclear facility is a fire. The recommended practice in DOE facilities is to have a fire suppression system consisting of a water spray in front of the HEPA filters [16]. Although this approach will put out the fire, it may also result in HEPA filter blow-out. This potential was demonstrated under controlled laboratory studies [27] and in an actual field fire [29]. The fire protection standard recognized the potential for filter damage resulting from the spray and recommended mitigating action "by altering ventilation flow rates by throttling back fan controls or by providing redundant filters". Unfortunately, no studies have been performed that either define the extent of the problem or the potential for mitigating the problem. Figure 14 shows HEPA filters blown out of their housings as a result of the water suppression system that was activated during a fire at the Rocky Flats Plant in 1980 [29].

Figure 14. Photograph of blown out HEPA filters in a plenum following a fire at Rocky Flats.

Although Figures 13 and 14 illustrate catastrophic failures in which the entire filter media is blown out of its housing, in most typical cases, only a portion of the filter is damaged. An example of this would be the HEPA filter damage that occurs regularly at the Consolidated Incinerator Facility (CIF) at the Savannah River Site. They found that the HEPA filters in the central portion of the exhaust system would have tears along the length of the filter even though the pressure drop never exceeded 4 inches. The researches suspected that moisture accumulation was responsible for the damage.

The use of stainless steel HEPA filters greatly improves the reliability of the filters by virtue of the much higher strength of the steel media. The filter can withstand high temperatures, water exposure, and high differential pressures with no loss of structural strength. Steel HEPA filters still suffer from the same degree of filter plugging as glass HEPA filters since that phenomenon is not dependent on the composition of the filter media. Steel filters also may corrode in environments exposed to halides, and therefore require special materials in these environments. High nickel alloys such as Hastelloy or Inconel are relatively resistant to halide acids and salts.

The increased reliability of steel HEPA filters will favor their use in critical DOE installations once reasonable price steel HEPA filters become available. The comprehensive analysis performed for the Safety Analysis Report (SAR) in radioactive facilities defines those applications were HEPA filters are critically needed to meet health, safety, and environmental standards. Cleanable steel HEPA filters are especially attractive in these applications.

New Regulations Will Favor Cleanable Steel HEPA Filters

New regulations are beginning to be imposed on glass HEPA filters to mitigate the effects of filter deterioration and damage. The Savannah River Site (SRS) has set a five year storage life and a five year service life on glass HEPA filters to limit the deterioration in filter strength with age [12]. These limits were set based on studies that show large reductions in filter strength with age [28,30]. Because of this policy, the maximum life of all HEPA filters used at the SRS will be 5 years [31]. This policy strongly favors the use of cleanable steel HEPA filters in all of the installations at the SRS.

The Defense Nuclear Facilities Safety Board (DFNSB) has recently informed DOE Undersecretary, Mr. Grumbly, about its concern with the deterioration of glass HEPA filters with "radiation exposure, aging, repeated wettings, and certain adverse environmental conditions" [32]. The DFNSB stated "There is no DOE standard or consensus industry standard that provides definitive criteria for HEPA filters subject to high radiation exposure, aging, and adverse environmental conditions." The Board specifically identified "criteria for HEPA filter operational limitations" as a critical item to be addressed in its letter to Mr. Grumbly.

It is very likely that one of the results of DOE's response to the DFNSB concerns will be the enactment of administrative life times as has been done at SRS. In addition, the potential for failure of new glass HEPAs under various accident conditions will encourage the use of high strength HEPA filters such as the cleanable steel HEPA filters.

Comparison of Customer Requirements to Commercial Availability

Although the drivers for cleanable steel HEPA filters clearly show a strong need for the technology, there are no cleanable steel HEPA filters installed in the many DOE ventilation systems. This condition exits despite an extensive marketing effort by Pall Corporation and others. The problem is that the commercially available filters do not meet the customer requirements. The major discrepancies between requirements and availability are (1) inability to be retrofitted into existing filter systems, (2) existing filters not made from acid resistant fibers, and (3) existing filters are too expensive. Each of these points will be explained in greater detail.

Commercial filters not retrofittable: The cleanable steel filter shown in Figure 3 has the overall dimensions of a standard glass HEPA filter, but has an unacceptable high pressure drop and weighs too much. The commercially available steel filters have 3 inches of water pressure drop when new instead of the required 1 inch. As the filter loads with particles and undergoes several cleaning cycles, the pressure drop will fluctuate between six and eight inches. In comparison, the standard glass HEPA filter is replaced when the pressure drop increases to 4 inches because of an unacceptable restriction on the air flow. Since a minimum air flow is very important to control radioactive contamination, the decreased air flow with the steel HEPA filter is not acceptable. Installing more powerful blowers to overcome the high resistance is also not acceptable because of the extra cost and the misbalance introduced into the building and system ventilation system.

The commercial steel filters weigh more than 200 pounds each. Special lifting and positioning equipment would be needed to install and remove the filters. In our field demonstration of the cleanable filter, we built a specially designed alignment table and mounted it on a scissors lift in order to install the steel filter [33]. Even if the added expense and effort with the positioning equipment were acceptable, most existing HEPA filtration systems are not accessible with the equipment.

Commercial steel filters not acid resistant: Many of the mixed waste treatment systems generate HCl and NaCl in the off-gas because of the chlorine compounds present in the waste. For example, the waste calciners, plasma hearth processes, CIF and other incinerators, DWPF melter off-gas at SRS, plant and in-situ vitrification generally contain sufficient chlorides in the exhaust to cause accelerated corrosion in the standard 304 and 316L alloys that are used in the steel filters. The acid resistant alloys of Hastelloy and Inconel and others are not available in the commercial filters.

Commercial steel filters are too expensive: The current steel HEPA filter costs about $70,000 compared to $300 for the glass HEPA filter [24]. This is the cost of the steel filter shown in Figure 3. The cost for the pressure vessel design shown in Figure 5 is estimated at $109K [24]. Our cost analysis shows that the steel filter is not economical in most cases because the glass HEPA filters are not replaced frequently enough to recover the steel filter costs. However, even in those applications where the glass HEPA filter is frequently replaced, the assumptions in the cost analysis may change during the operation and the savings disappear. For example, the assumed 30 year operation may terminate after 15 years, thereby loosing half the potential savings.

V REQUIREMENTS FOR DEVELOPING A CLEANABLE STEEL HEPA FILTER

The requirements for developing a cleanable steel HEPA filter follow the reasons why the commercial filters are not used in DOE facilities despite the overwhelming need for such filters.

Develop A Steel HEPA Filter That Can Be Retrofitted Into Existing Systems

One of the most important requirements for the cleanable steel HEPA filter is that it be readily installed and used in existing filtration systems. The primary factors that prevent this are the excessive pressure drop and the weight.

Reduction in pressure drop: The commercially available steel filters have a pressure drop of 3 inches of water. In order to reduce the pressure drop to the required 1 inch, the steel fiber media must be made from fibers having diameters about 0.5 µm instead of the present 2.0 µm diameter. Figure 15 shows the general relationship between the minimum efficiency and the pressure drop for a standard 2' x 2' x 1' filter at 1,000 cfm as a function of the fiber diameter of the filter media. This graph was obtained from the measured efficiency and pressure drop of commercially available filters and the average fiber diameter of the fiber media used in each filter.

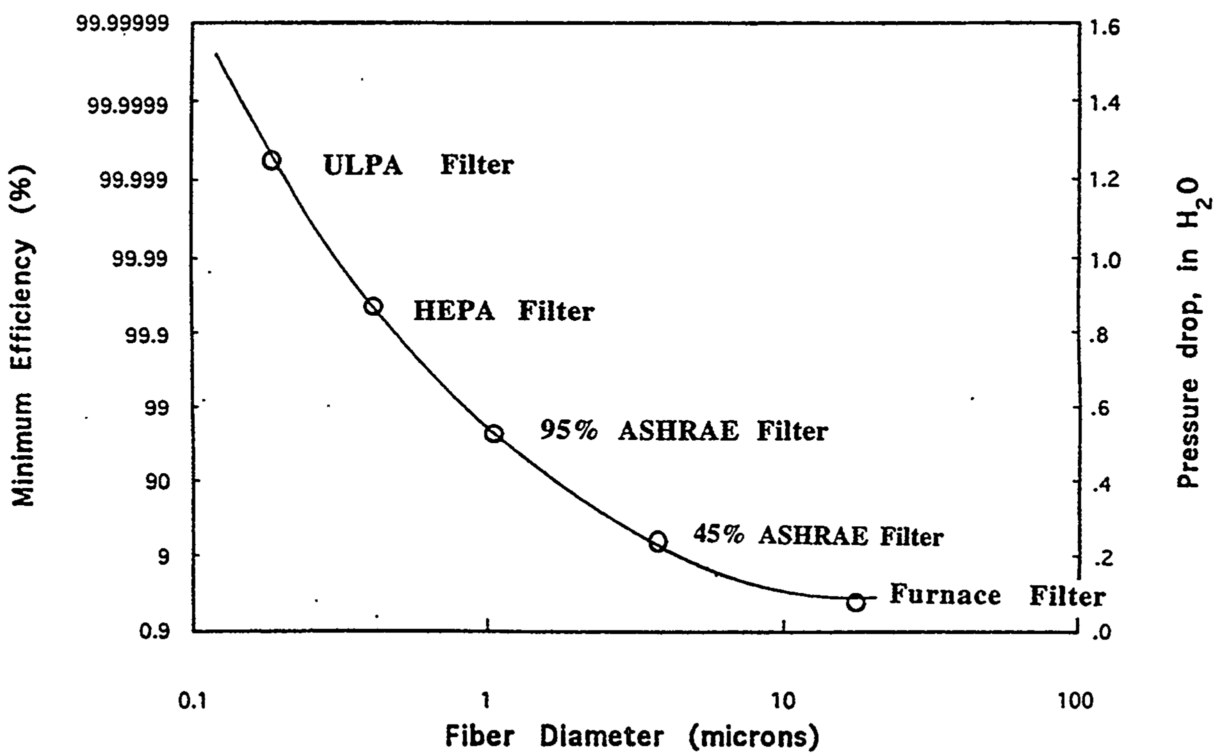

Figure 15. Relationship between the minimum efficiency, pressure drop and fiber diameter in commercial filters.

Using Figure 15, we can illustrate the two approaches that are used to obtain filters with the desired efficiency and pressure drop. For a filter medium having a fixed fiber diameter, higher efficiencies are obtained by adding more layers of media. For example two layers of a 95% efficient ASHRAE filter with 1 μm fiber media will yield a filter with a combined efficiency of 99.75% (E= 1-(1-.95)(1-.95)= 0.9975). The pressure drop for the combined layers is twice the single layer (0.5 inch), or 1.0 inch. Alternatively, by using a filter media with 0.7 μm diameter fibers, we can reach the same efficiency but only have a pressure drop of 0.7 inches.

In order to obtain a steel HEPA filter with the required efficiency of 99.97% and a pressure drop of 1 inch, it will be necessary to use steel media with a fiber diameter of 0.5 μm. The commercial steel filter with 2 μm diameter fibers meet the efficiency requirement, but has a pressure drop of 3 inches. We have recently fabricated a filter element using steel media obtained from Tomeogawa that was made from 1 μm fibers [34]. The fibers were made from 316L stainless steel. Test results showed the filter met the requirements for the efficiency and had a pressure drop of 1.5 inches.

Since there are no commercial sources that can make 0.5 μm steel fibers, we used fundamental laboratory techniques based on the wire bundling and drawing process to make a small quantity of these steel fibers. Unfortunately, the process is extremely labor intensive and not suitable for prototype development.

We then made a small sample of stainless steel fiber media from the 0.5 μm steel fibers using the paper making process followed by sintering [34]. Figure 16 shows an electron micrograph of the media. Laboratory tests at 3.5 cm/s face velocity yielded an efficiency of 99.998% for 0.3 μm dioctyl sebacate (DOS) aerosols. Figure 17 shows the penetration (1-efficiency) measurement of the media as a function of particle size. The pressure drop was 1.15 inches. The media had a greater quantity of fibers than was needed to achieve the desired efficiency value. We estimate that reducing the quantity of fibers to yield an efficiency of 99.97% will result in a media pressure drop of 0.8 inches. Unfortunately, we did not have sufficient fibers to do the test.

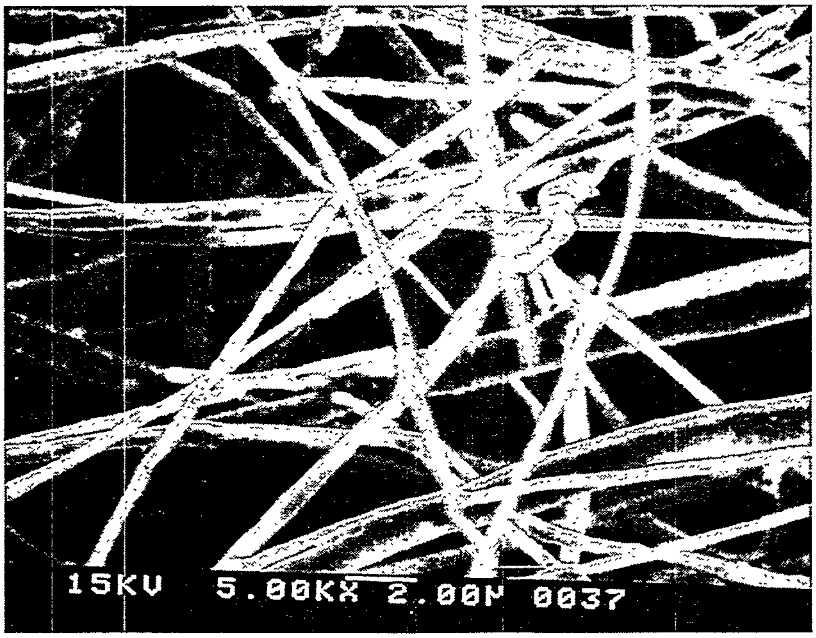

Figure 16. Electron micrograph of the steel fiber media made from 0.5 µm steel fibers.

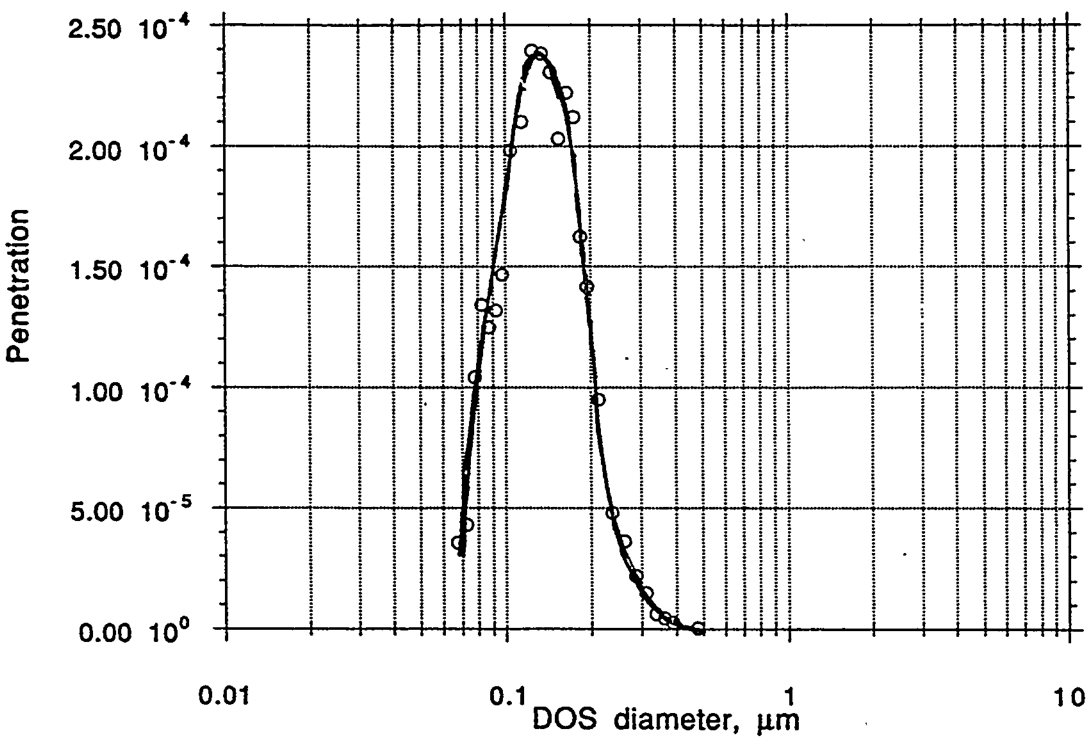

Figure 17. Aerosol penetration measurements at 3.5 cm/s face velocity through steel fiber media shown in Figure 16. Pressure drop was 1.15 inches.

We have already shown the feasibility of developing a steel HEPA filter that meets the efficiency and pressure drop requirements for HEPA filters. However, the laboratory bench scale process must be scaled up in order to produce a sufficient quantity of fibers and media to make several prototype HEPA filters. This represents the next step in the development of the cleanable steel HEPA filter.

The primary effort in developing the steel HEPA filter should be directed at developing the process for making 0.5 μm steel fibers. In general the process involves a series repetitive steps in which wires are bundled together into a rod and then reduced in diameter by drawing through progressively smaller dies. Figure 18 shows a rod consisting of a bundle of wires being reduced in diameter through progressively smaller dies. The individual wires have a coating to prevent sticking to the other wires. Figure 19 shows a cross section of the rods, starting with the original rod and going through the first, second and nth bundling. When the desired fiber diameter is reached, the rod is dissolved in a suitable solvent and the fibers dispersed.

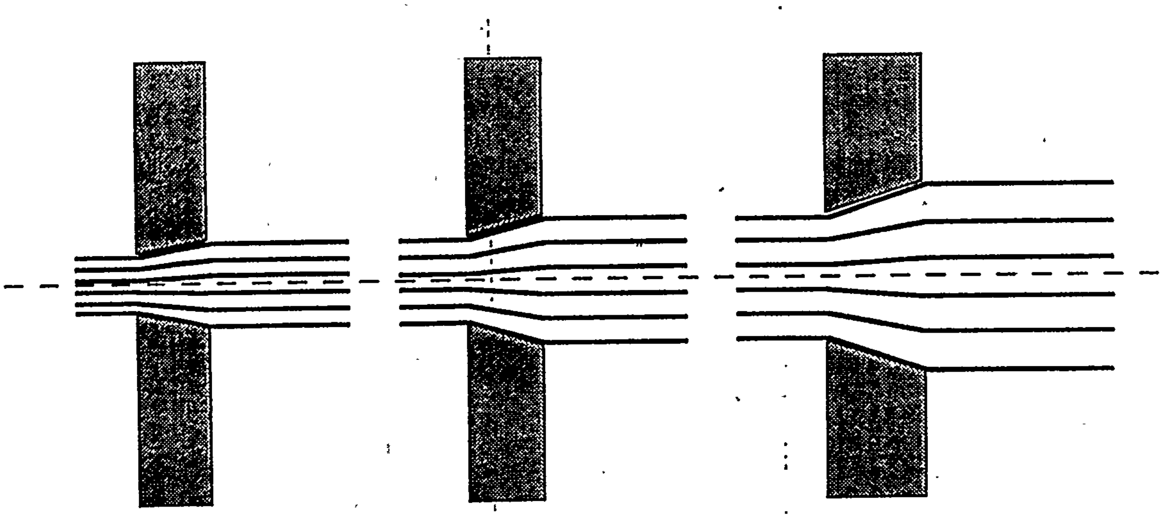

Figure 18. Wire drawing is used to produce smaller diameter steel fibers.

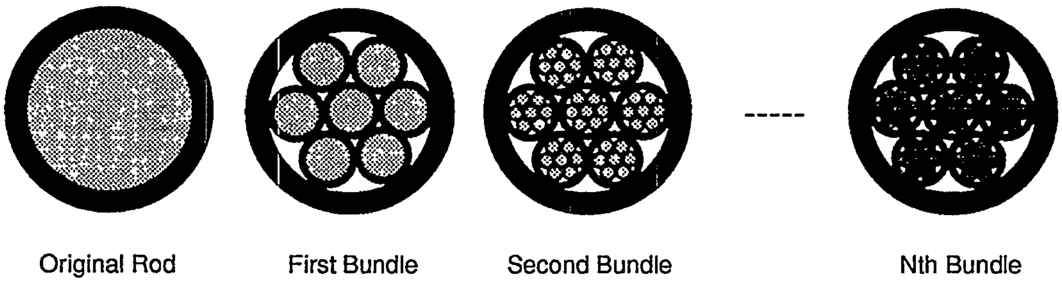

Figure 19. Cross section of steel rods from the original to increasing iterations of bundling and drawing

After a sufficient quantity of fibers are produced, they must then be processed into media using the paper making process followed by sintering. These process have not been developed for the 0.5 μm steel fibers and are a necessary step. Once the steel fiber media is available, it can be formed into the desired filter configuration such as shown in Figure 3.

Reduction in weight: Since the filter media for the steel HEPA is expected to weigh about 10 pounds for 200 square feet (glass fiber media would weigh 3.3 pounds), most of the weight is due to the support structure. The filter design that consists of multiple pleated cylinders as shown in Figure 3 would require a considerable amount of heavy metallic support elements and end plate on which to attach the cylinders. This design can not be used to fabricate a steel HEPA filter that has a comparable weight to the steel-framed HEPA with glass fiber media. To achieve the weight objective, it will be necessary to use a similar design as used for glass fiber HEPA filters. Figure 20 shows a design using corrugated separators. Since the steel media is much stronger than the glass media, it also is possible to eliminate the separators. The final weight of the filter is expected to be less than 60 pounds, compared to the 200 pounds for the commercial units today. Details of the design and fabrication must be developed. This task will be undertaken after the steel fiber media is developed.

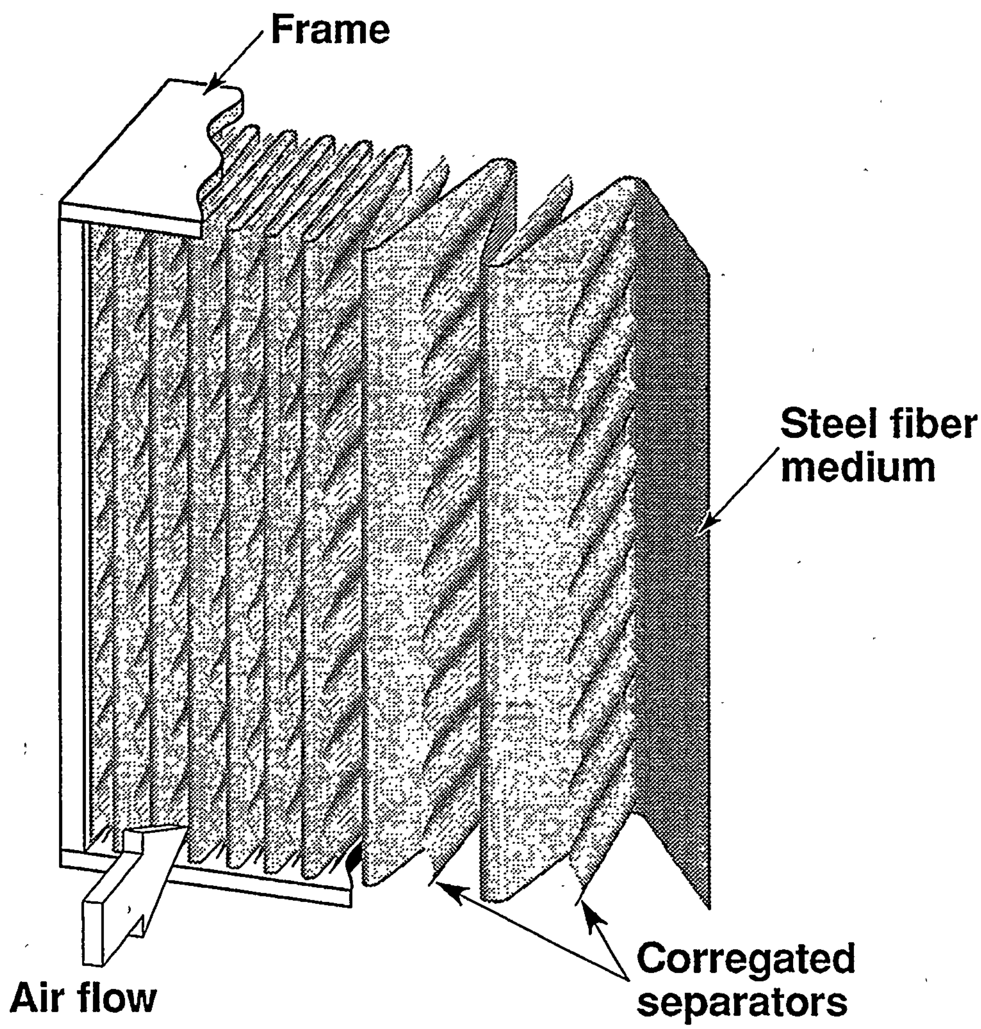

Figure 20 Cleanable steel HEPA filter with the deep pleat and separator configuration,

Develop A Steel HEPA Filter That Is Resistant to HCl and NaCl

The major problem with developing a steel HEPA filter that is resistant to HCl and NaCl is the lack of small diameter fibers made from acid resistant materials. The smallest diameter of fibers made from Hastelloy is 8 µm and from Inconel is 12µm. From Figure 15, filters made from these fibers have very low efficiencies and would require many layers of media to achieve HEPA efficiency. Such a filter would have an unacceptably high pressure drop. Thus, the major task in developing an acid resistant HEPA is to develop a technique for reducing the fiber diameters. The wire bundling and drawing technique shown in Figures 18 and 19 would be the initial starting point for this task. Once an acceptable fiber diameter is obtained (2μm is probably reasonable to expect) then the remaining processes described in the previous section would be used to develop the acid resistant steel HEPA filter.

REDUCE THE COST OF THE CLEANABLE STEEL HEPA FILTER

Successfully completing the development of the steel HEPA filter will automatically reduce the cost of the filter. A steel HEPA made from media with 0.5 μm fibers needs one fourth the mass of fibers needed for media made from 2 μm fibers. Although the cost of the 0.5 μm fibers will be slightly greater than that of the 2 μm fibers, the total cost will be drastically reduced because only one fourth of the fibers will be needed. The second major cost in the steel HEPA filter is the intensive amount of labor required to hand fabricate the pleated cylinders and the many components within each cylinder. By using the designs in the standard glass HEPA filter as shown in Figure 20, the labor should be reduced enormously. The final source of cost reduction is due to the efficiencies of production compared to that used in prototype fabrication.

REFERENCES

1. D.L. Ziegler and A.J. Johnson, "Disposal of HEPA filters by fluidized bed incineration" in Proceedings of 15th DOE Nuclear Air Cleaning Conference, CONF-780819, NTIS, Springfield, VA 22161, pp.111-116, 1979.

2. B.E. Kirstein, W.J. Paplawsky, D.T. Pence, and T.G. Hedahl, "High efficiency particulate removal with sintered metal filters" in 16th DOE Nuclear Air Cleaning Conference, CONF-801038, pp. 719-744, 1981.

3. W. Bergman, "Comments to paper by Kirstein" in 16th DOE Nuclear Air Cleaning Conference, CONF-801038, pp. 742-744, 1981.

4. H.G. Dillmann and H. Pasler, "Experimental investigations of aerosol filtration with deep bed filters" in Proceedings of 17th DOE Nuclear Air Cleaning Conference, pp. 1160-1174, CONF-820833, 1983.

5. H.G. Dillmann and Pasler, " A filter concept to control airborne particulate release due to severe reactor accidents and implementation using stinless-steel fiber filters" in Proceedings of 18th DOE Nuclear Air Cleaning Conference, pp. 1417-1428, CONF-840806, 1985.

6. M. Klein and W.R. Goossens " Aerosol filtration with metallic fibrous filters" in Proceedings of 17the DOE Nuclear Air Cleaning Conference, pp 504-522, CONF-820833, 1983.

7. H. Randhahn, B. Gotlinsky, and S. Tousi "The development of all metal filter for use in the nuclear industry" in Proceedings of 20th DOE/NRC Nuclear Air Cleaning Conference, CONF-880822, pp 726-748, 1989.

8. W. Bergman," Evaluation and modification of commercial sintered metal filters" LLNL memorandum, July 7, 1989.

9. M. V. Kaercher, "Design of a frefilter to improve radiation protection and filtering efficiency of the containment venting system" in Proceedings fo the 22nd DOE/NRC Nuclear Air Cleaning and Treatment Conference, pp 443-452, CONF-9020823, 1993.

10. W. Bergman, J. Conner, G. Larsen, R. Lopez, C. Turner, G. Vahla, C. Violet, and K. Williams, "High efficiency steel filters for nuclear air cleaning" , in Proceedings of 21st DOE/NRC Nuclear Air Cleaning Conference, CONF-900813, pp. 733-761, 1991.

11. W. Bergman, "Cleanable steel HEPA filters" in Environmental Technology Program Annual Report FY90, pp.44-47, Lawrence Livermore National Laboratory report UCRL-LR-105199, January 2, 1991.

12. Air Filter Specifications, Manual No. 5Q1.10, Section 7, Westinghouse Savannah River Company, Savannah River Site, Health Protection Department, 1995.

13. P. Moore, W. Bergman, and H. Gilbert, "Survey of Life-Cycle Costs of Glass-Paper HEPA Filters" in Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning Conference, Denver, Co, August 24-27, 1992. UCRL-JC-109768, December, 1992.

14. O.L. Kruger, "Hanford Waste Vitrification Plant Applied Technology Plan", WHC-EP-0417, January 1992.

15. Procurement Specification, Filter, High Efficiency Metal, W-320-P3, January 24, 1995

16. DOE (Draft) Standard, Fire Protection Design Criteria, "DOE-STD-1066, May 1996.

17. W. Bergman, G. Larsen, F. Weber, P. Wilson, R. Lopez, G. Valha, J. Conner, J. Garr, K. Williams, A. Biermann, K. Wilson, P. Moore, C. Gelner, D. Rapchun, K. Simon, J. Turley, L. Frye, and D. Monroe, "Development and Evaluation of a Cleanable High Efficiency Steel Filter" in Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning Conference, CONF-9020823, PP586-616, JULY 1993.

18. C.A. Burchsted, "A review of DOE filter test facility operations: 1970-1980, 17th DOE Nuclear Air Cleaning Conference, CONF-820833, pp.775-787, 1983.

19. J. F. Bresson, "HEPA filter test activities at the Department of Energy" 19th DOE/NRC Nuclear Air Cleaning Conference, CONF-860820, pp. 852-862, 1987.

20. J.A. McIntyre "Review of Department of Energy Filter Test Facility and Filter Test Facility Technical Support Group", 21st DOE/NRC Nuclear Air Cleaning Conference, CONF-900813 ,pp.385-393, 1991.

21. J.A, McIntyre, "Review of Department of Energy HEPA Filter Test Activities, FY 1990-FY 1992", Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning and Treatment Conference, CONF-9200 ,pp. 177-190, 1993.

22. U.S. Departmen of Energy, "Environmental Restoration and Waste Management Five-Year Plan" Fiscal Years 1994-1998, DOE/S-00097P,1993.

23. E. Carbaugh, "A survey of HEPA filter experience" 17th DOE Nuclear Air Cleaning Conference, CONF-820833 , p. 790-800, 1983.

24. P. Dittman "Cost estimate for steel HEPA filters", Pall Corporttion, Cortland, NY, May 28, 1996.

25. L. Weber, "Pall Technical Brief: HEMF-5, Demonstration of efficiency measurements and in-situ cleaning"Pall Corporation report, December 31, 1992.

26. L. Weber, "Pall Technical Brief: HEMF-6, Study to investigate backwash regenerability and maintenance of integrity by ASHRAE test", Pall Corporation report, December 31, 1992.

27. W. Bergman, M.W. First, W.L. Anderson, H. Gilbert, and J.W. Jacox "Criteria for calculating the efficiency of deep-pleated HEPA filters with aluminum separators during and after design basis accidents" in Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning and Treatment Conference, NTIS, Springfield, VA, CONF-940738 , pp 563-598, February , 1995

28. J.Johnson, D. Beason, P. Smith, and W. Gregory, "The effect of age on the structural integrity of HEPA filters" Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, CONF-880822, PP. 366-382, 1989.

29. J.K. Fretthold "Summary report of incineration plenum fire, Building 771, July 2, 1980" May 31, 1995.

30. H. Gilbert, J. Fretthold, F. Rainer, W. Bergman, and D. Beason "Preliminary studies to determine the shelf life of HEPA filters" in Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning and Treatment Conference, Buffalo, N.Y.,July 25-28, 1994, available from NTIS, Springfield, VA, CONF-940738 , pp 613-638, (also in LLNL report UCRL-JC-115891Rev.1, February 1995) February , 1995

31. Personal communication with D.M. Dykes, June 1996.

32. J.T. Conway, Chairman Defense Nuclear Facilities Safety Board, letter with attached report on "Safey of HEPA filter units in Hanford B-Plant exhaust ventilation system" to Under Secretary T.P. Grumbly, May 9, 1996,

33. W. Bergman, G. Larsen, R. Lopez, K. Wilson, K. Simon, and L. Frye "Preliminary field evaluation of high efficiency steel filters" in Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning and Treatment, CONF-940738 , pp 195-213, February , 1995

34. W. Bergman "Feasibility demonstration of a steel HEPA filter" in Proceedings of DOE Mid-Year Technical Review, Vol 5, Off-Gas Treatment, Department of Energy Mixed Waste Integrated Program, April, 1994.