Filters and Filtration for Nuclear Applications

A Critical Review

By

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Abstract

This paper presents a critical review of recent developments in particulate filtration applicable to the nuclear industry since the last review in 1980. (1) Current and future developments and industry needs are also discussed.

I. Introduction

First and Gilbert have reviewed the history and development of particulate filtration in the nuclear industry up to 1980 in previous editions of these Proceedings. (1-3) Although many of the topics in this paper have been discussed in the previous reviews, their inclusion in this paper reflects new developments, continued research, or heightened interest in a particular subject. At the time of the last review in 1980, nuclear power generation was robust in the leading industrial nations, the Cold War was operating at full speed, nuclear accidents like at Three Mile Island were reasonably well controlled, and significant research and development programs were devoted to nuclear air cleaning. In 1998, the climate has changed dramatically with nuclear power plants viewed as liabilities in many industrial nations, the Chernobyl nuclear accident caused wide-spread contamination, the Cold War came to an end, United States and Russia disclosed the enormous magnitude of the work required to clean-up the radioactive waste legacy from the Cold War, and research and development programs in nuclear air cleaning were drastically

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reduced. Between 1980 and 1998, significant developments occurred in filtration theory, HEPA filter design and construction, filter housing design, filter testing, and filter codes and standards. New tests on HEPA filters and field experience also showed the standard glass fiber HEPA filter is subject to failure during fires by smoke, water, or high temperature. In addition, some nuclear facilities are creating additional problems by not replacing HEPA filters even after 30 years of service. It is ironic with newly discovered filter susceptibilities and with many new developments in filter performance, that so little is being done to improve HEPA filter reliability.

II. Air Filtration Theory

Air filtration theory has been very important in the development of HEPA filters. It continues to be important for improving the performance of HEPA filters because of the large time and cost savings from reducing the number of tests required to optimize the filter and media design parameters. The early air filtration theories are reviewed by Dorman (4,5), Davies (6), Pich (7), and Kirsch and Stechkina (8). These early theories model air filters as the air flow and particle capture by single fibers. The single fiber theories included the interference effect of neighboring fibers by using cell flow models such as the Kuwabara cell. (6) Closed form algebraic solutions were obtained to describe the pressure drop and particle capture efficiency as a function of system variables (air flow, temperature, pressure), particle variables (size, density), and filter variables (fiber diameter, fiber volume fraction, filter thickness, filter area).

For HEPA filters in the nuclear industry, the theories provided information on the most penetrating particle size and guidance on designing filter media and filters to obtain the highest efficiency at the lowest pressure drop. The most penetrating particle size was important because a single penetration test at the most penetrating particle size would guarantee a minimum efficiency for any unknown particle challenge. Although Freundlich demonstrated the existence of a most penetrating particle size through filters as early as 1922, the mechanism for this phenomenon was not developed until years later. (6) Kaufmann in 1936 and Langmuir in 1942 showed the particle capture efficiency is due to a combination of Brownian motion and interception. (Kaufmann also included particle inertia.) [6] Ramskill and Anderson extended Langmuir's theory by including particle inertia and provided experimental verification of the resulting theory. [9] Based on Langmuir's theory, the U.S. military mandated that all gas mask filters be tested with the most penetrating particles of 0.3 um diameter. [1] This requirement was extended to HEPA filters and is in effect today in the U.S.. Filtration theory also was used to improve the filter media performance by decreasing the diameter of the filter fibers. By using smaller fiber diameters, it is possible to greatly increase filter efficiency with only a minor increase in pressure drop.

More recent theoretical studies up to 1993 have been reviewed by Brown. [10] Many of the studies are extensions of the earlier single fiber studies with additional capture mechanisms due to electrostatics, particle adhesion and bounce, air flow slip by small diameter fibers, filter loading, inhomogeneities in filter structure, and distributions of fiber diameters. Brown also briefly reviews his work on multi-fiber systems. [10] Unfortunately, Brown did not review the various multi-fiber studies using computational fluid dynamics (CFD). These were rather difficult and severely limited studies because much of the major effort for writing computer CFD codes and the lack of high speed computers. The paper by Henry and Ariman illustrate the work required to study rather simple two-dimensional fiber arrays. [11] The fiber arrays were limited to those that provide periodic flow so as to limit the computer time.

However, the wide availability of commercial CFD computer codes that can be used by the non-specialist has dramatically changed the nature of filtration theory. These computer codes allow more realistic, three dimensional filter structures to be modeled. In addition, the dramatic increase in computing power now allows fast computations of the particle collection without requiring the artificial separation of Brownian motion, interception and the inertial collection mechanisms.

Bergman et al used commercially available fluid dynamics codes based on Navier-Stokes theory and the Langevin particle equation of motion to compute the particle capture efficiency and pressure drop through selected two- and three-dimensional fiber arrays.[12] The approach they used was to first compute the air velocity vector field throughout a defined region containing the fiber matrix. The particle capture in the fiber matrix is then computed by superimposing the Langevin particle equation of motion over the flow velocity field. Using the Langevin equation combines the particle Brownian motion, inertia and interception mechanisms into a single equation. In contrast, most previous investigations treat the different capture mechanisms separately. They have computed the particle capture efficiency and the pressure drop through a 2-D and two 3-D fiber matrix elements.

The particle capture in the fiber matrix is then computed by superimposing the particle equation of motion over the flow velocity field. The resulting particle dynamics is given by:

$$\frac{d\underline{v}}{dt} = B(\underline{u}-\underline{v}) + \underline{A}(t) \qquad (1)$$

where,

$\underline{v}$ = particle velocity vector
$\underline{u}$ = fluid velocity vector
B = friction coefficient
$\underline{A}(t)$ = random Brownian acceleration, time dependent
t = time

The friction coefficient B is defined as

$$B = \frac{6\pi\ \mu a_p}{C_s\ m} \qquad (2)$$

where,

μ = fluid viscosity
a_p = particle radius
m = particle mass
C_s = Cunningham slip correction factor

The solution of equation 1, called the Langevin equation, can be obtained assuming a constant fluid viscosity and a constant value of B.

Bergman and Corey used commercial CFD codes to compute the air velocity through the 3-D fiber structure shown in Figure 1.[12] Once the air velocities are determined throughout the region, the trajectory of each particle through the maze is computed using Equation 1. Figure 1 illustrates the trajectories from three different size particles that are designated as Brownian motion, interception, and inertial impaction as in the early filtration theories. In the computer simulation, there is no such artificial separation of different collection mechanisms.

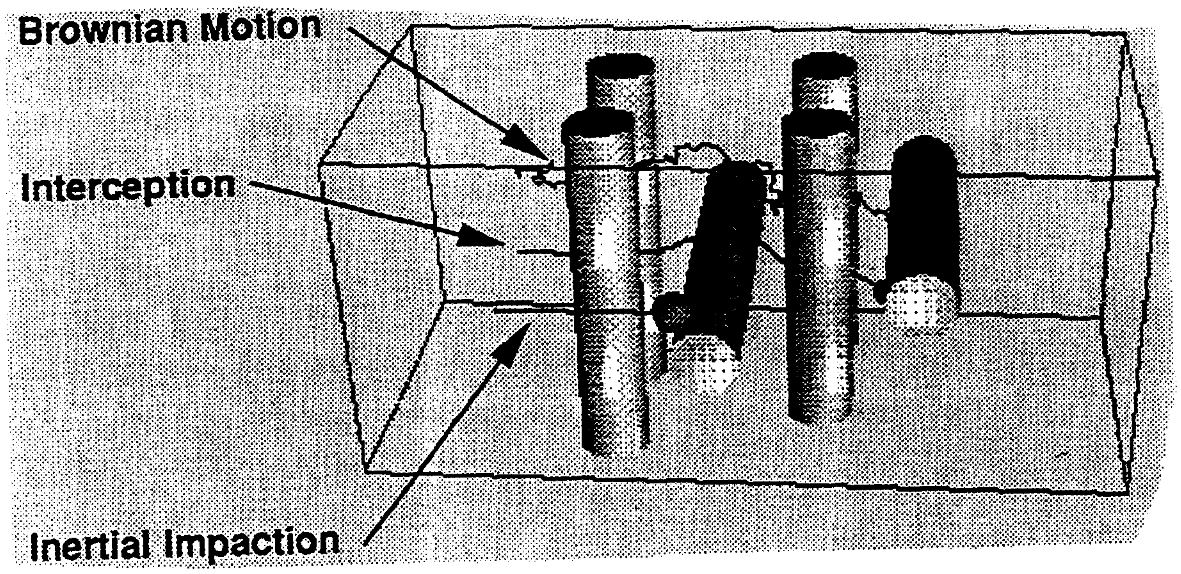

Figure 1 Trajectories of three different diameter particles through the fiber matrix. Particle diameters were selected to illustrate conventional mechanical collection mechanisms: 0.01μm for Brownian motion, 0.1μm for interception, and 0.4μm for inertia.

To compute the efficiency versus particle size curve in Figure 2, thousands of trajectories were computed for each particle size beginning at a random location at the inlet of the fiber matrix. Figure 2 shown the typical experimental efficiency curve for a prefilter media. Bergman and Corey also showed filter efficiency computations at different air flows that are in agreement with experimental trends. With continued development in low cost computers and further simplification of the CFD codes, it is highly likely that accurate computer simulations will replace the approximate equations used today in filtration theory.

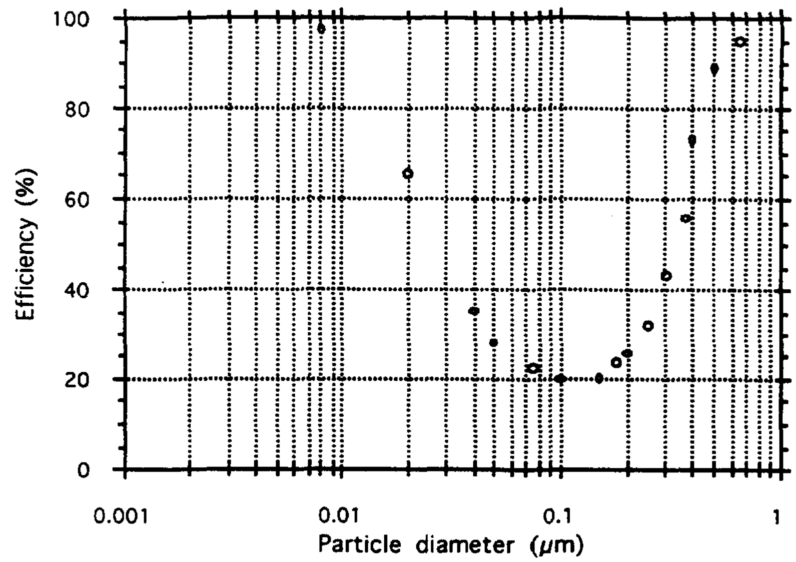

Figure 2 Filter efficiency computed for different particle diameters (density 1 g/cm^3) passing through the crossed fiber matrix in Figure 1 with uniform inlet air velocity of 20 cm/s. The pressure drop across the fiber matrix element is 4.4 x 10^{-5} inches of water.

In addition to optimizing filter media, new theoretical studies based on CFD computations have optimized the design of filter pleating. Chen et al have studied the effect of various pleat parameters on the filter pressure drop based on CFD computations through the filter pleat channels and the media. (13) Figure 3 shows the computed pressure drop across the HEPA filter as a function of pleat count for an inlet air velocity of 100 ft/min. Note the pleat count/ in. decreases with increasing pleat height. Since a typical HEPA filter has 250 ft/min. inlet air velocity and 11 inches pleat height, the curves in Figure 3 are not directly applicable to nuclear grade HEPA filters.

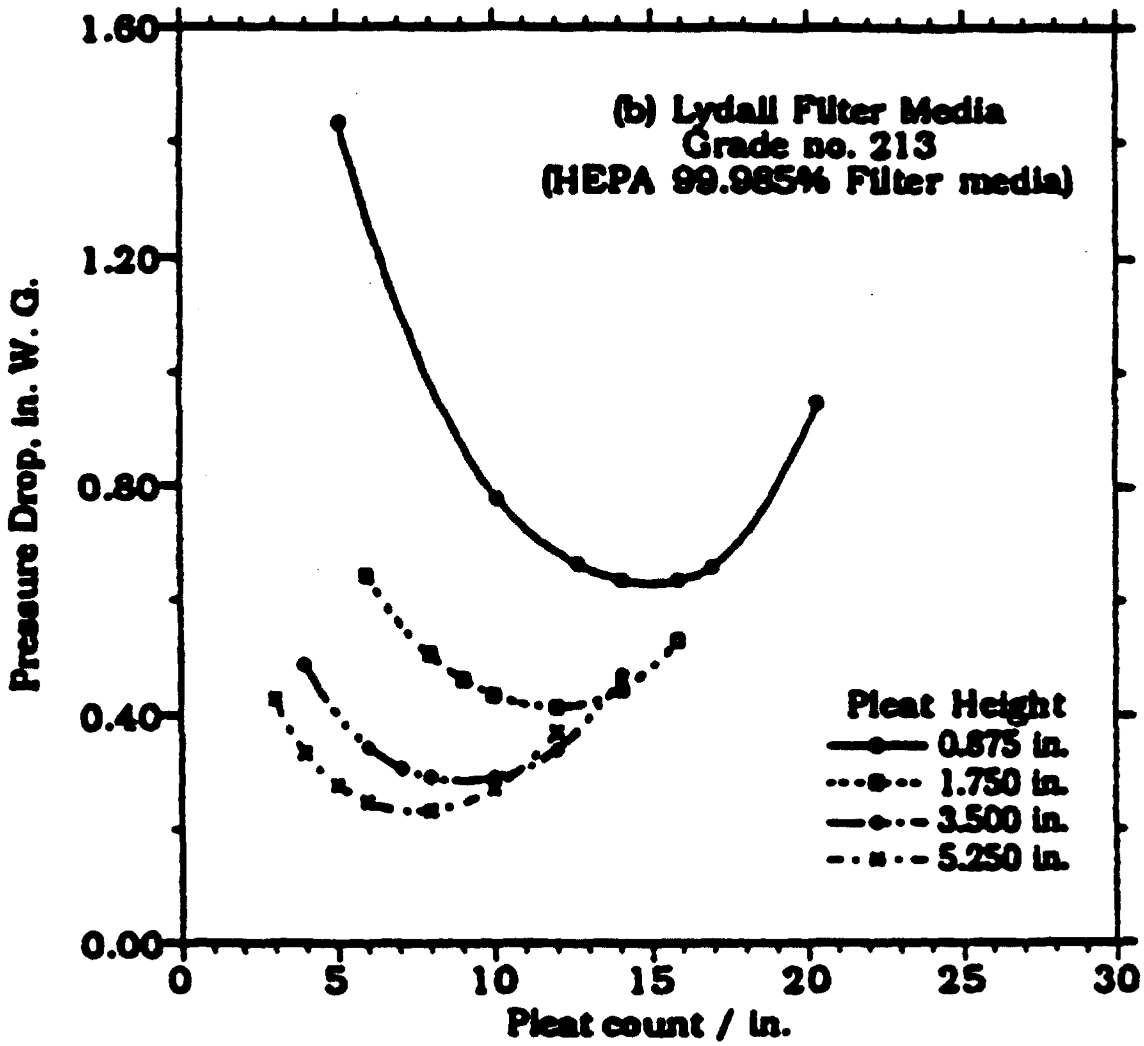

Figure 3. Computed pressure drop for HEPA media having various pleat heights as a function of pleat count/ in..

Chen et al derived the following equation for the filter pressure drop, ΔP , from their theoretical studies: (13)

$$\Delta P = \Delta p_m \{ 1 + 8 L^2 / [K (W-t)^3] \} \tag{3}$$

where

Δp_m	= Pressure drop across media
L	= Pleat height
K	= Constant for media, pressure drop per media face velocity
W	= Pleat space
t	= Media thickness

The validity of Equation 3 is demonstrated in Figure 4, where Chen et al have replotted the data from Figure 3 into Figure 4 using Equation 3. Since all of the data fit on a straight line, Equation 3 is validated.

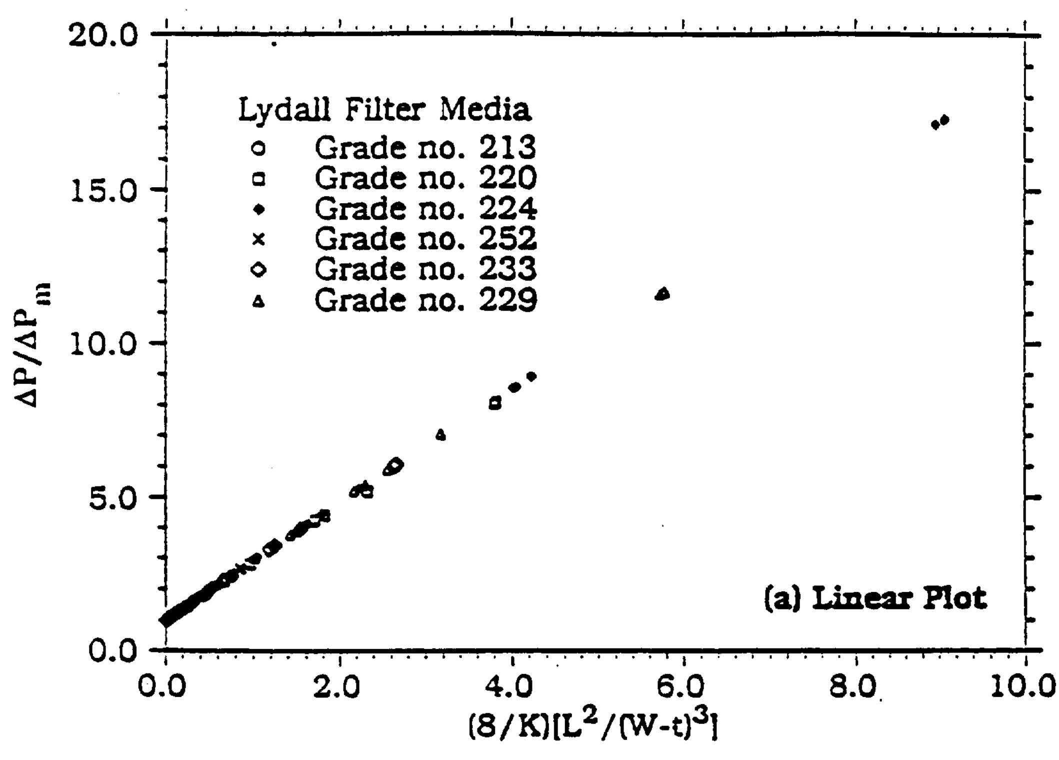

Figure 4. Normalized pressure drop replotted from the data in Figure 3 as a function of Equation 3 parameters.

III. Laboratory and Field Evaluation of HEPA Filters

Many studies have been conducted on the performance of HEPA filters under various controlled laboratory and uncontrolled field conditions since the last HEPA filter review in 1980. [1] Bergman et al have reviewed the available data on HEPA filter performance through 1994 in an attempt to determine the efficiency of HEPA filters during and after accidents. [14] A draft DOE Standard based on this study was prepared but never issued. [15] We have updated the previous review and summarized the results in Table 1 and 2. The objective of all of the studies is to determine the effect of potential challenges such as increased temperature, particulate loading, moisture, shock, high air flow, HEPA, chemical exposure, radiation, age, and seismic loads on the efficiency and pressure drop of HEPA filters.

Table 1 summarizes the pressure drop at which there is visible damage to the standard size V HEPA filter having a deep pleat configuration with aluminum separators. Other commercially available HEPA filters have lower threshold values for differential pressure. The degree of damage varies with each study from tears in the media to complete blow-out of the filter pack. Note, that some of the studies were conducted on filter media samples, not complete HEPA filters. In these cases, the reduction in threshold pressure drop was assumed to be directly proportional to the reduction in media strength. Most of the studies addressed exposure to a single type of challenge. However, in accidents, the HEPA filter is often subjected to several challenges. For example, during fires a HEPA filter may be subjected to high temperature, smoke, and high moisture. For multiple challenges, we may assume the threshold damage occurs the lowest pressure drop of the individual component.

Table 1 Threshold Values of Differential Pressure Required to Structurally Damage the Standard HEPA Filter

ΔP threshold, inches Avg.	Range	Parameter	Reference
66	(37-81)	Baseline (high air flow)	Gregory et al [16]
57	(38-72)	Baseline (high air flow)	Osaki et al [17]
63	(47-90)	Baseline (high air flow)	Ruedinger et al [18]
52	(29-70)	Explosion shock	Gregory et al [16]
38	(13-78)	Age (15-19 year old filters with Asbestos separators)	Johnson et al [19]
33[1]	(18-40)[1]	Age(50% loss in strength after 15 years)	Gilbert et al[20]
33[1]	(18-40)[1]	Radiation (5×10^7 rad)	Jones [21]
X[2]		HNO_3, HF exposure (variable)	Woodard et al [22]
		Temperature	
44[3]	(25-54)[3]	200°C (392°F), 1 hr.	Breschi et al [23]
33[4]	(19-41)[4]	300°C (572°F), 10 min.	Hamblin et al [24]
26[5]	(15-32)[5]	400°C (752°F), 1 hr.	Breschi et al [3] Hamblin et al (24)
13[6]	(8-16)[6]	500°C (932°F), 10 min.	Pratt et al [25]
	(8-20)	500°C (952°F), 10 min.	Pratt [26]
23	(10-36)	Clean filter, water spray	Ruedinger et al [27]
20	(16-25)	Loaded filter, 100% humidity	Ruedinger et al [27]
18	(7-36)	Clean filter, water spray	Ricketts et al [28]
16	(3.6-25)	Loaded filter, 99% RH	Ricketts et al [28]
40[7]	(22-49)[7]	Clean dry filter, prev. wet	Ricketts et al [28]

Footnotes

1. Values computed from a measured 50% reduction in media tensile strength and base line values from Gregory et al [25].
2. No available data relating differential pressure threshold and acid challenge. Observations of HEPA filter after acid challenge show the HEPA media collapses and may fall out of its housing by its own weight.
3. Values computed from a measured 33% reduction in media rupture pressure and baseline values from Gregory et al [25].
4. Values computed from a measured 50% reduction in media rupture pressure and baseline values from Gregory et al [25].
5. Values computed from a measured 60% reduction in media rupture pressure and baseline values from Gregory et al [25]
6. Values computed from measurement of 80% reduction in tensile strength and baseline filter values from Gregory et al [25].
7. Values computed from measurement of 40% reduction in tensile strength and baseline filter values from Gregory et al [25].

Table 2 Effect of Parameters on the Penetration of HEPA Filters

Parameter	Effect on Filter Penetration	Reference
Baseline	0.1%	Scripsick et al [29]
HF Corrosion		
1,500 ppm-hr	0.1% increase	Brassel et al [30]
Temperature		
increase from 25 to 200 C	decreases penetration from 0.01 to 0.001%	Osaki et al [17]
200°C	.03-0.01%	Pratt et al [25]
200°C for 48 hours	0.02%	Frankum et al[31]
240°C for 6 hours	0.01%	Osaki et al [17]
300°C	0.12-0.01%	Pratt et al [25]
350 C	0.4-0.03%	Pratt et al [25]
500°C	0.9-0.2%	Pratt et al [25
500°C for 10-45 min.	0.9-0.1%	Hackney [32]
538°C	1.2-0.5%	First [33]
Moisture		
Up to 100% RH	Negligible effect	Osaki et al [17]
Water spray loaded to 8 in.	Increase by 10 times	Osaki et al [17]
Filter clogging		
Solid particle loading	Decreases penetration	Bergman [34]
NaCl deposits to 1.9 in.	Decreases penetration from 0.003 to 0.000001%	Osaki et al [17]
Liquid DOP loaded to 4 in.	Penetration increases by factor of 10	Osaki et al [17]
Oil aerosols	Penetration increase is 1.3 Pi_P/_Pi increase	Payet et al [35]
Air Flow		
Increasing velocity from 0.5 cm/s to 20 cm/s	Penetration increases from 0.00003% to 0.5%	VanOsdell et al [36]
Increasing air flow by 10 times	Penetration of 0.1 μm particles increases by 100 times	Osaki et al [17]
Air Pulse		
1 psi pulse	Penetration of 0.46 _m latex particles is 0.1%	Gregory et al [16]
Shock tests on filters preloaded with .46 _m latex	Penetration is 0.9%	Gregory et al [16]
Seismic (0.2- 0.3 g)	negligible effect	Bergman et al [37]
Age	negligible effect up to 19 years old	Johnson et al [19]

Table 2 summarizes the DOP penetration obtained for the different exposures. It is noteworthy that the filter penetration does not increase very much even when subjected to severe exposures. For example, filters may be exposed to temperatures up to 500°C up to 45 minutes and still have less than 1% penetration.(25) HEPA filters also do not have higher aerosol penetration with increasing age up to the 19 years tested (19). The data in Table 2 suggests that HEPA filters are still effective in filtering particles after exposure to severe environmental challenges. However, this is a misleading conclusion and can lead to unsafe practices because the deterioration in filter strength in Table 1 is ignored. For example, the practice of using in-place penetration tests to determine HEPA filter replacement leads to the unsafe practice of having very old filters (over 30 years old) in some nuclear facilities. [39]

Based on the results of the many studies shown in Tables 1 and 2, Bergman et al have prepared a summary table that can be used in assessing potential HEPA filter damage from various environmental conditions. [14] Table 3 shows that HEPA filters subjected to high temperature, moisture, and age can suffer structural damage at pressure levels easily reached by the fans in most facilities. For example, fans with 15 inch water are widely used and can cause structural damage to HEPA filters under the indicated accident conditions. Many facilities having multiple stages of HEPA filters typically use fans with a capacity of more than 25 inches water. For these facilities, HEPA filter damage is highly probable under many accident conditions. It is unfortunate that the existing U.S. HEPA filter qualification standards do not incorporate these findings and only test new HEPA filters up to 10 inches water.

The results of the many studies have shown that the present HEPA filter design is subject to failure under accident conditions. Unfortunately, the existing qualification standards for HEPA filters in the U.S. have not incorporated the new experimental findings into the appropriate standards. One of the most serious problems that is still unresolved is the HEPA performance under fire conditions. Bergman et al have shown that three banks of HEPA filters were blown out of their housings as the result of a fire at the Rocky Flats Plant in 1980. [40] Figure 5 illustrates the severity of the destruction. Because face guards were not used on the filters, as required in HEPA filter specifications, the filter destruction is more severe than would be expected with face guards. Analysis of the filters indicated the filter sealant holding the filter pack in its housing had burned away at the top of the filter. The filter pack could then be blown out of its housing. Although face guards would have mitigated the destruction, the HEPA filters would have been seriously damaged.

Table 3 Threshold Values* of Differential Pressure Required to Structurally Damage the Standard HEPA Filter

Parameter	ΔP Threshold*, inches w.g.
Baseline (new filter, normal conditions)	37
Age (15 years or older)	13
Radiation (6 x 10^7 Rad)	18
Chemical (HNO_3, HF)	0-37
Temperature	
less than 200°C, (392°F)	37
200-300°C, (192-572°F)	
10 minutes	33
1 hour	30
10 hours	22
300-400°C, (572-752°F)	15
400-500°C, (752-932°F)	10
Moisture	
wet filter, (greater than 95% relative humidity)	10
dry filter, previously wet	22
Air pulse from explosion	29

* These values represent the most conservative values (except for moisture) taken from an analysis of experimental studies reviewed in this report and summarized in Table 2

Figure 5. Photograph showing the front side of the first stage HEPA filters in 1980 Rocky Flats fire.

IV Developments in HEPA Filter Construction

Reinforced Glass Fiber Media

Reudinger et al have developed a high strength HEPA filter to overcome the inherent weak structure of HEPA filters described in the last section. [41] The filter makes use of a HEPA filter media that is reinforced with glass scrim. The filter also uses a herringbone arrangement for the aluminum separators to improve the solidity of the filter pack under adverse conditions. Figure 6 shows the dramatic increase in filter strength of the high strength filter.

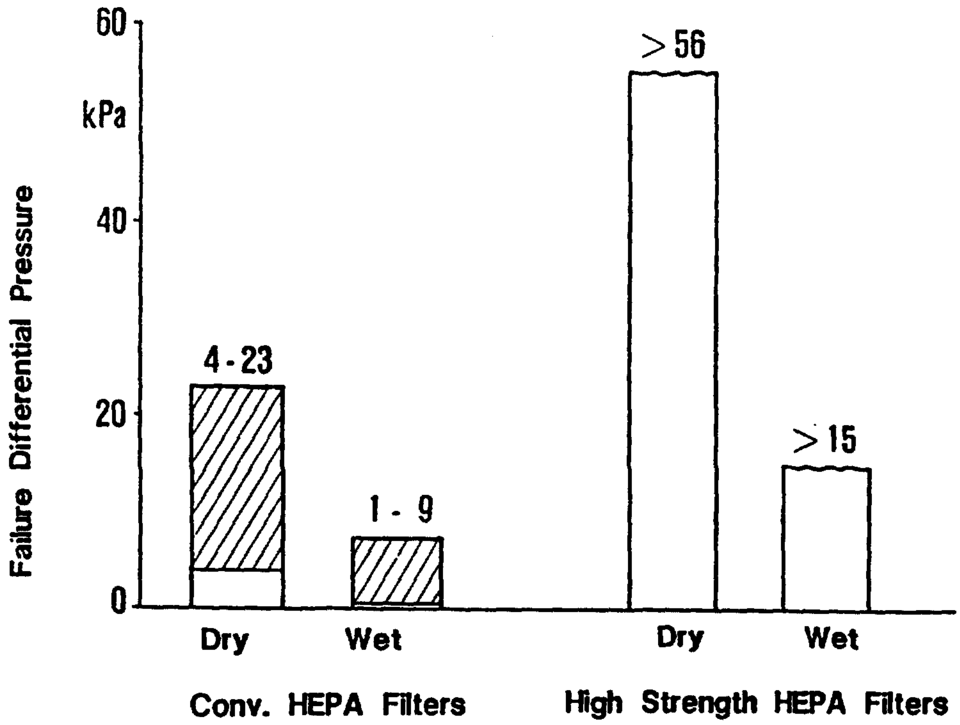

Figure 6. The high strength HEPA filter shows a dramatic increase in the differential pressure required to casue structural damage.

A program funded by the U. S. Department of Energy in the early 1990's at Lawrence Livermore Laboratories developed a high strength HEPA filter design. Nuclear grade glass filter medium supplemented and strengthened with a single monofilament scrim cloth was the major change from standard nuclear grade filters. The monofilament glass mesh consisted of 6.5 micrometer diameter filaments configured in a mesh size of 42 by 31 filaments to the inch. The scrim was on the downstream side of the glass media. Filters were constructed in accordance with ASME N-509 requirements (Mil-F-51068). Room Temperature Vulcanized Rubber (RTV-116) was used as the sealant. The filters exhibited increase strength and can withstand exposure to heated air and higher pressures than the standard nuclear grade HEPA filters.

Cylindrical Filters

Radial Flow filters were introduced into the nuclear industry in the late 1980's as an excellent means of limiting hazardous waste. Cylindrical filters, previously used primarily for military applications provide a means to reduce hazardous waste due to the filters ability to be crushed and easily stored in cylindrical drums. The filter consists of pleated media formed into a cylindrical shape, supported by two cylindrical screens or grids. The smaller cylinder forms the inlet to the filter and the larger cylinder the outlet with the pleated media between the cylinders. See Figure IV-1.

Cylindrical filters developed by Stewart and Pratt of the Harwell Laboratory in the U.K. also includes a unique circular lip seal that requires no clamping. See Figure IV- 2. This unique filter design is combined with a cylindrical housing to allow remote filter change out. Advantages include sealing without clamping, reliable remote handling, easily volume reduced, safe handling with no sharp edges, and the contaminant in contained inside the annulus of the filter, minimizing release and/or redispersal of collected particles.

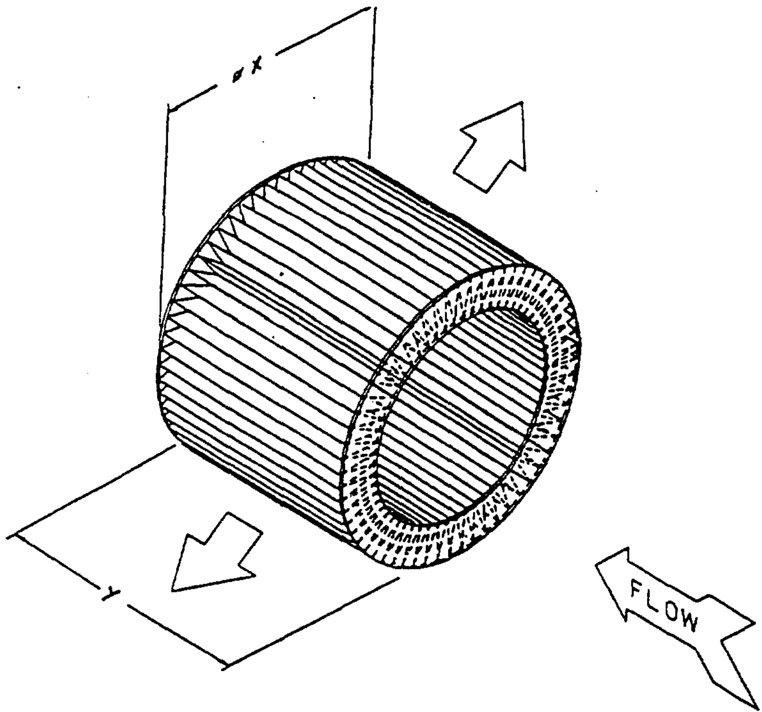

Figure IV-1

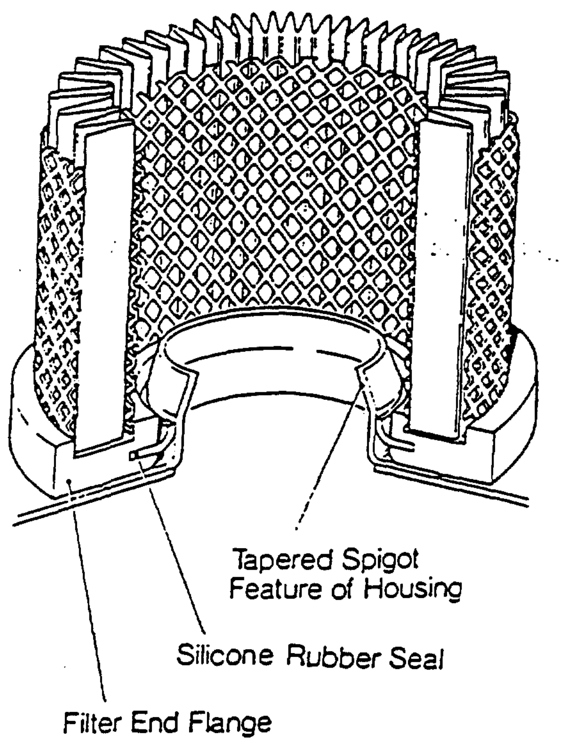

Figure IV-2

High Temperature Filters

"High Temperature" is a relative term. Standard nuclear grade filters are rated at 250° Fahrenheit (121° C). Components that limit temperature are the medium binders and the gasket. Filter ratings can be increased to 350° Fahrenheit (177°C) by using closed cell silicone gaskets.

In the 1950's the Naval Research Laboratory demonstrated a ceramic fiber high efficiency filter. The medium was produced from "Fiberfrax" fibers manufactured by the Carborundum Corporation. The ceramic fibers were heat-attenuated from silicon dioxide and aluminum oxide slag. The media was produced commercially by H&V and Hurlbut Paper companies. Flanders Filters produced a filter using a unique pressure pack of loose "Fiberfrax" fibers as a sealant, special high temperature separators and frame, capable of operating at 2000 degrees F. The unit performance was somewhat erratic due to a wide distribution of fibers and the presence of large amounts of "shot", short fiber, and contamination in the filter fiber bulk. As a result, the units were not widely accepted.

No significant development occurred in high temperature HEPA filtration until the late 1980's. Lawrence Livermore Laboratories under contract with the U. S. Department of Energy developed high efficiency metal filters. This filter utilizes a stainless steel fiber medium and is rated at 750° Fahrenheit (399° C). The filter has a higher resistance than conventional HEPA filters. For applications where high temperature HEPA filtration is required, such as incineration and waste reduction, filter resistance is not an issue. The cleanability of the metal filters offsets the initial high cost.

Chemical Resistant Filters

Chemical plants processing metals for nuclear energy applications employ nitric acid, sulfuric acid, ammonia, and Hydrogen Fluoride (HF) extensively. This highly corrosive atmosphere attacks the aluminum separators and binders. The HF also attacks the glass fibers of the medium. The ammonia combines with the nitric acid to form ammonium nitrate that plugs the filters. Measures were employed to avoid release of the nitric acid and ammonia in the same air stream. Prior to the identification of asbestos as a health risk, asbestos separators and asbestos fibers in the medium was employed to prolong the life of the filter.

Replacements for the asbestos containing media and separators were developed in the 1970's. A small percentage of high temperature nylon fibers, Kevlar or Nomex, mixed with the glass fibers was discovered to prolong the life of the medium. Aluminum separators were coated with a thermal set vinyl to resist the acids. This is the filter predominantly used for chemical corrosive air treatment today. The Metal mesh filters are also being used in certain applications where high temperature and corrosive atmospheres offset the increased filter cost.

Filter medium made of synthetic electrostatic charged micro-fiber nonwoven material was introduced in the 1980's in Federal Republic of Germany for high humidity and acid applications by Alken, Bella, Rudinger and Wilhelm. The media, called Microdon S consisted of three layers, a 0.2 mm covering layer of polypropylene fibers-spunbonded, a 0.6 mm layer of polycarbonate micro fibers, and a 0.5 carrier layer of polypropylene fibers-heat bonded. Filters manufactured with this medium exhibited particular resistance to hydrogen fluoride (HF) in nuclear fuel processing plants. .

High Capacity Filters

The search for higher capacity filters and low resistance filters has been ongoing for the past fifty years. Due to the stringent requirements for strength and flexibility, there has been little progress in the medium for nuclear grade filters. Currently ASME Code on Nuclear Air and Gas Treatment, AG-1, and formerly Mil Standards Mil-F-51068 and Mil-F-51079, establish the physical properties of nuclear medium. In addition, penetration is affected by media velocity. The limit for the medium velocity for nuclear grade media is 4 to 5 FPM. With the static or medium resistance set, the only area for improvement was the dynamic portion of the total filter resistance, which is configuration and entrance and exit losses. In other words, improvements to the mechanical design of the filter.

Several novel designs were developed in the 1970's and 1980's. All increased media areas to increase capacity. An optimized HEPA filter design was introduced in 1975 by two filter companies. The filter rated at 1500 CFM (2550 CMH) contains 300 square feet (27.87 square meters) of media. The separator was corrugated at a pitch that provides the least amount of entrance and exit losses while providing the maximum amount of medium that can be folded into a separator type filter. See Figure 1

Another method of increasing the area of media was the elimination of separators. A filter was developed whereby the media was corrugated and folded on itself. The corrugations formed the air slots thereby eliminating the separators. Problems with the ability of this filter to meet the qualification tests due to the inherent weakness of the filter pack made this filter unacceptable for most nuclear applications. Later versions of this filter use embossed media. The media is embossed elliptical or circular patterns that support the medium when the medium is folded upon it. This design utilizing shallow beds or filter panels _ to 2 inches deep are still in use today in the electronics industry. See Figure 2.

The cassette filter, initially developed in Europe, is a separatorless design utilizing either glass ribbons, beads of adhesive, or strings to keep the media folds separated. The fold depth is _ to 2 inches deep depending on the specific filter design. Panels are arranged in a v-shape to allow inclusion of 500 square feet (46.45 square meters) of medium within a 24 inch wide by 24 inch high by 11_ inch deep filter frame (203 mm x 203 mm x 292 mm). See Figure 3. This filter design lacks the strength of a separator type filter. This combined with the additional combustible material from the adhesives makes this filter difficult to qualify to nuclear standards. Several manufacturers have qualified this filter in the past but limited demand in the nuclear industry makes this configuration unattractive to manufacturers due to the high cost of manufacturing and qualification to nuclear codes and standards. The advantages of this higher capacity filter are smaller systems/less floor space, less capital investment in housing costs, lower replacement and maintenance time.

<u>Super High Efficiency Filters</u>

Major improvements in filter efficiency were achieved in the last 20 years. Filters identified as ULPA Ultra Low Penetration Air (ULPA) Filters attain efficiencies of 99.999995 in trapping 0.1 micrometer particles. These filters are used primarily in the electronics industry. Initially developed by Oshitari Laboratory, Inc. in Tokyo, filters are now supplied by every leading manufacturer. The filters are tested using laser particle counters. This type of filter is not used in nuclear applications. The media as currently formulated and manufactured is fragile and lacks sufficient strength to meet the current structural and environmental requirements of nuclear filters.

Gaskets/Filter Seal

Various materials have been employed for gasketing of nuclear filters. Materials ranged from glass fiber mat and cork to silicone. The most widely used material currently employed is closed cell neoprene in accordance with ASTM D1056 Grade 2C3 or 2C4.

A self-healing cured gel seal made of Polydimethylsiloxane was developed to provide a unique seal for applications where filter sealing surface flatness cannot be adequately maintained. The gelatinous gel seal is normally contained in a channel on the edge of the filter frame and is seated on a knife-edge frame on the filter rack. The resultant seal is self-healing and will not take a permanent set or shrink.

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Steel HEPA Filters

Bergman et al have developing a cleanable steel fiber HEPA filter. They fabricated a pleated cylindrical cartridge using commercially available steel fiber media that is made with 1 mm stainless steel fibers and sintered into a sheet form. Test results at the Department of Energy (DOE) Filter Test Station at Oak Ridge show the prototype filter cartridge has 99.99% efficiency for 0.3 μm dioctyl phthalate (DOP) aerosols and a pressure drop of 1.5 inches. Filter loading and cleaning tests using AC Fine dust showed the filter could be repeatedly cleaned using reverse air pulses.

V Filter Housing

Walk-in filter plenums designed in accordance with ASME N509 and ASME AG-1 Code continue to be the standard for the commercial nuclear power industry in the United States and Asia. The Caisson or Bag-In/Bag-out side access housings are used extensively in highly contaminated areas and low air volume applications where walk-in plenums are impractical.

New developments in housing design by the United Kingdom and France utilize the cylindrical filter for highly contaminated areas. Pratt and Steward of Harwell Laboratory in the U.K. presented a paper at the 20th Nuclear Air Cleaning Conference in 1988 detailing their U.K. development of a cylindrical bag-out housing for remote handling. The system uses a unique push through design for filter replacement. See Figure V-1.

SGN and COGEMA of France developed a filtration cask type design for highly contaminated areas. This design uses cylindrical filters with remote vertical removal. See Figure V-2

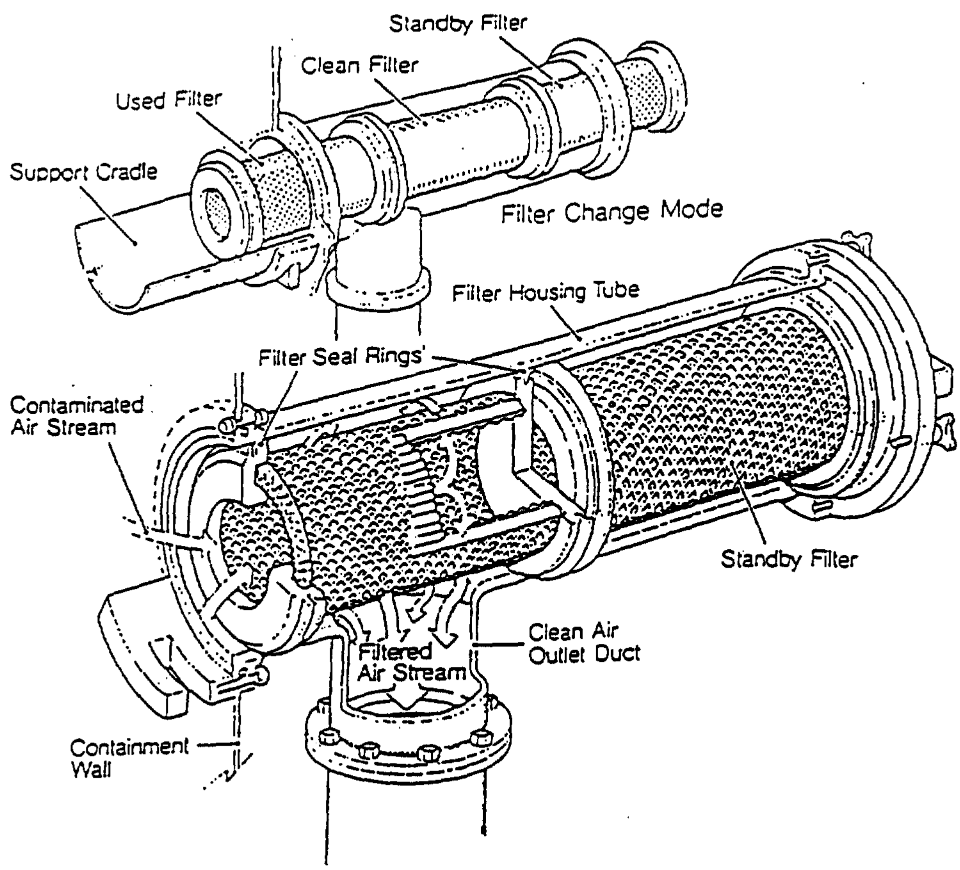
Standby Filter
Clean Filter
Used Filter
Support Cradle
Filter Change Mode
Filter Housing Tube
Filter Seal Rings'
Contaminated Air Stream
Standby Filter
Clean Air Outlet Duct
Filtered Air Stream
Containment Wall

Figure V-1

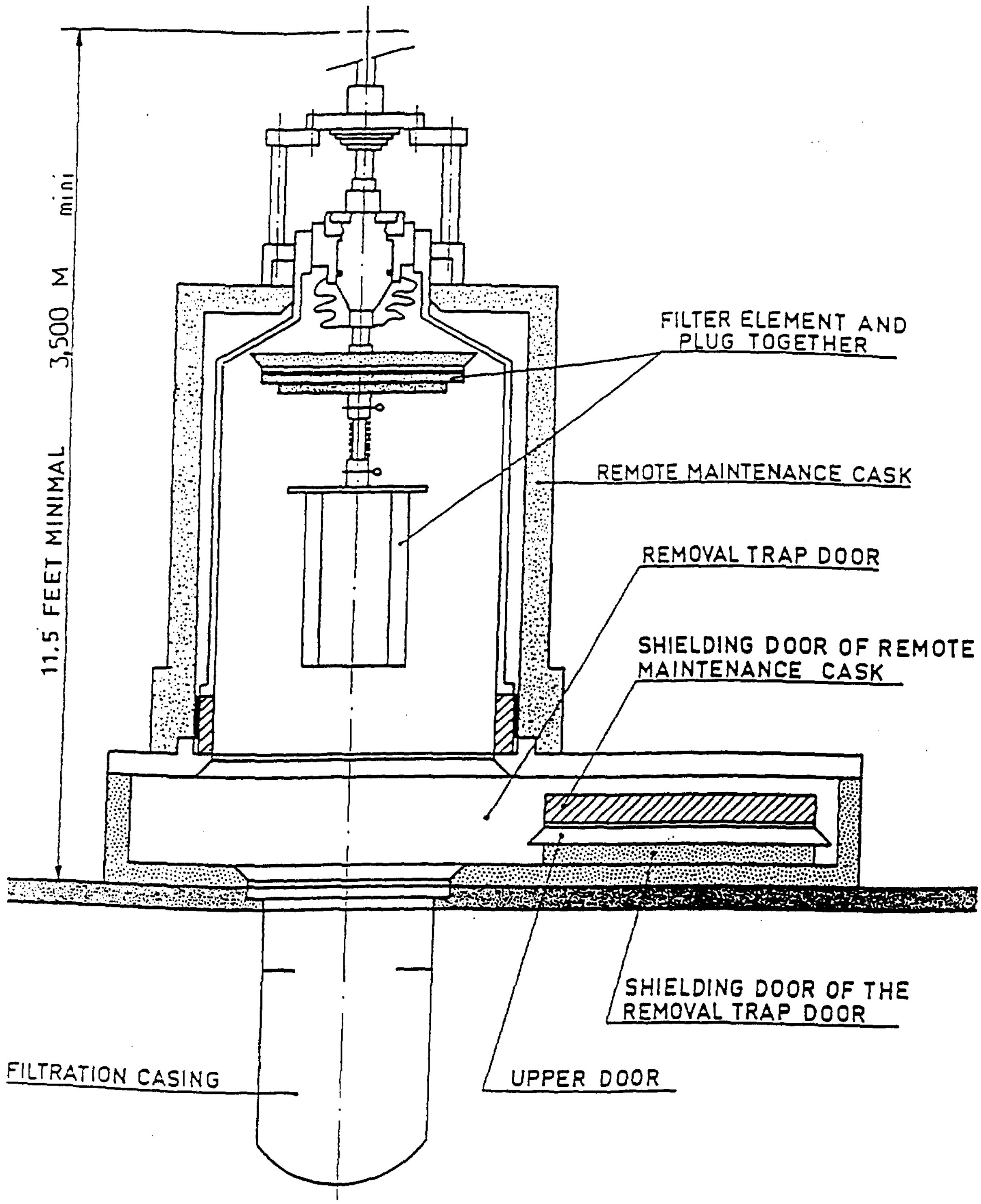
11.5 FEET MINIMAL 3,500 M mini
FILTER ELEMENT AND
PLUG TOGETHER
REMOTE MAINTENANCE CASK
REMOVAL TRAP DOOR
SHIELDING DOOR OF REMOTE
MAINTENANCE CASK
SHIELDING DOOR OF THE
REMOVAL TRAP DOOR
FILTRATION CASING
UPPER DOOR

Figure V-2

VI. Testing

Qualification Testing

With the military eliminating the Quality Products List (QPL) for HEPA filters, ASME Code AG-1 allows qualification by independent laboratories. The problem is that no laboratories besides Edgewood Arsenal has the equipment or inclination to qualify filters. This dilemma must be addressed immediately.

In addition, one must take a critical review of the qualification test protocol. Are there changes needed in the heated air test, moisture overpressure test, environmental cycle tests, or the rough handling test. Are the conditions accurate or should they be changed. Should additional tests be included? This is the challenge for the industry.

Certification Testing

The Q107 Scattering Light Photometer has been the standard test equipment used to evaluate penetration (efficiency) and resistance for nuclear grade filters for over 35 years.
With this method, a portion of the air passing through the Q107 is heated and passed over liquid Dioctlyphthalate (DOP) or other acceptable compounds (DOS, PAO, etc.) picking up vapor from the hot DOP, passes though a mixing chamber and into a test chamber. The resulting smoke-air mixture flows into the test chamber at a preset test flow challenging the filter being tested. The amount of smoke penetration through the filter is measured from a sample of the effluent air. A vacuum pump pulls the sample through a light scattering chamber where the amount of smoke is detected by a photoelectric cell and measured as a percent penetration.

Laser particle technology was introduced in the 1970's and continues to improve. Widely used in the electronics industry and an acceptable test method by the Nuclear Code on Air and Gas Treatment Systems, AG-1. Laser aerosol spectrometers (LAS) operate routinely at nominal particle diameters of 0.12 micrometer without resorting to aerosol dilution or changing sample rates. The test method, although much more accurate than the light scattering photometer, is not as cost effective for nuclear filters.

In-place Efficiency Testing

Light scattering photometers historically have been used for both the efficiency test and the leak test. In recent years, laser particle counters have also been used in the efficiency certification. With the development of portable laser counters, it is also possible to now measure in-place HEPA filter efficiencies. This is possible because portable particle size analyzers discriminate between different particle sizes whereas the current light scattering photometers do not.

Bergman et al have demonstrated the feasibility of an in-place efficiency test by conducting a series of comparison tests on different filter installations with a portable laser particle counter and a light scattering photometer. The in-place efficiency test was compared to the current in-place leak test for single HEPA filter installations and for HEPA filter plenums using both the shroud and the traversing probe methods. Test results show the in-place efficiency test is comparable to the in-place leak tests in terms of operating procedure and length of test. They have also conducted calibration tests on a Q-107 filter tester that demonstrate the in-place efficiency test is comparable to the official DOP efficiency test. Further development of the procedure is also required to reduce the test time before the in-place penetration test is practical.

VII. Codes and Standards

The most significant development regarding codes and standards was the issue of the ASME Code on Nuclear Air and Gas Treatment in 1986. The American National Standards Institute (ANSI) approved the latest edition, ASME AG-1-1997 on September 25, 1997. The Committee On Nuclear Air and Gas Treatment (CONAGT) was chartered in 1975 by ASME to develop, review, maintain and coordinate codes and standards for the design, fabrication, installation, testing and inspection of equipment for nuclear power plant air and gas treatment systems. The first edition of ASME AG-1 was issued in 1986. This code extends the scope of equipment covered by ASME N509 to refrigeration and conditioning equipment. In the past the focus of the code has been strictly toward commercial nuclear power. This focus has changed in recent years to include the needs of government laboratories, fuel processing and reprocessing facilities.

With the issuance of Section FC of the ASME Code AG-1 in 1997, Military Standard Mil-F-51068 covering the design and testing of HEPA filters has been designated obsolete and superseded by ASME Code AG-1.

VIII. Future Needs

Although there has been major improvements in particulate filtration over the past 18 years, many have not been adopted by the nuclear industry. We all need to ask why? The needs of the nuclear industry have changed and are better defined. We must look at our codes and standards and ensure that they reflect the best available technology and the most cost-effective technology.

Challenges for the industry for the next decade are:

1. Incineratable /Disposable / Cleanable Filters

   Low-level waste disposal costs continue to rise. Fire resistant filters that are Incinerable is an oxymoron. Perhaps a recyclable or cleanable filter is the answer.

2. Prefiltration

Probably one of most ignored areas for improvement. Good prefiltration extends the life of high efficiency filters. Perhaps a development whereby the prefilter is used not only to extend the life of the HEPA but also to provide protection from pressure surges, and other environmental factors when used in combination with a HEPA Filter.

3. In-Place Efficiency Testing

Improved field testing methods and equipment. Standards must be adopted for consistent testing and results.

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