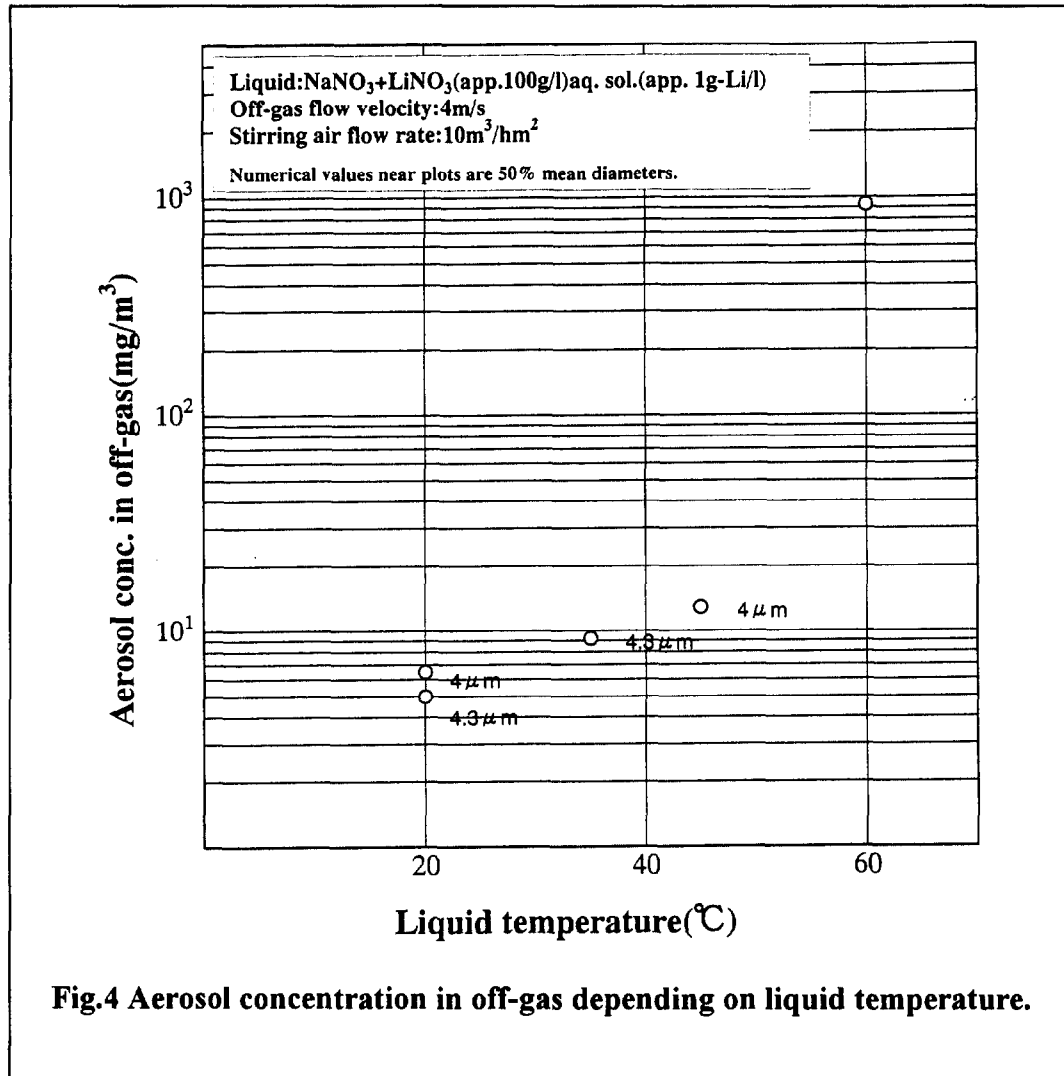


Significant aerosol increase is observed at 60°C in particular. More particles of smaller size are observed for the higher temperature.

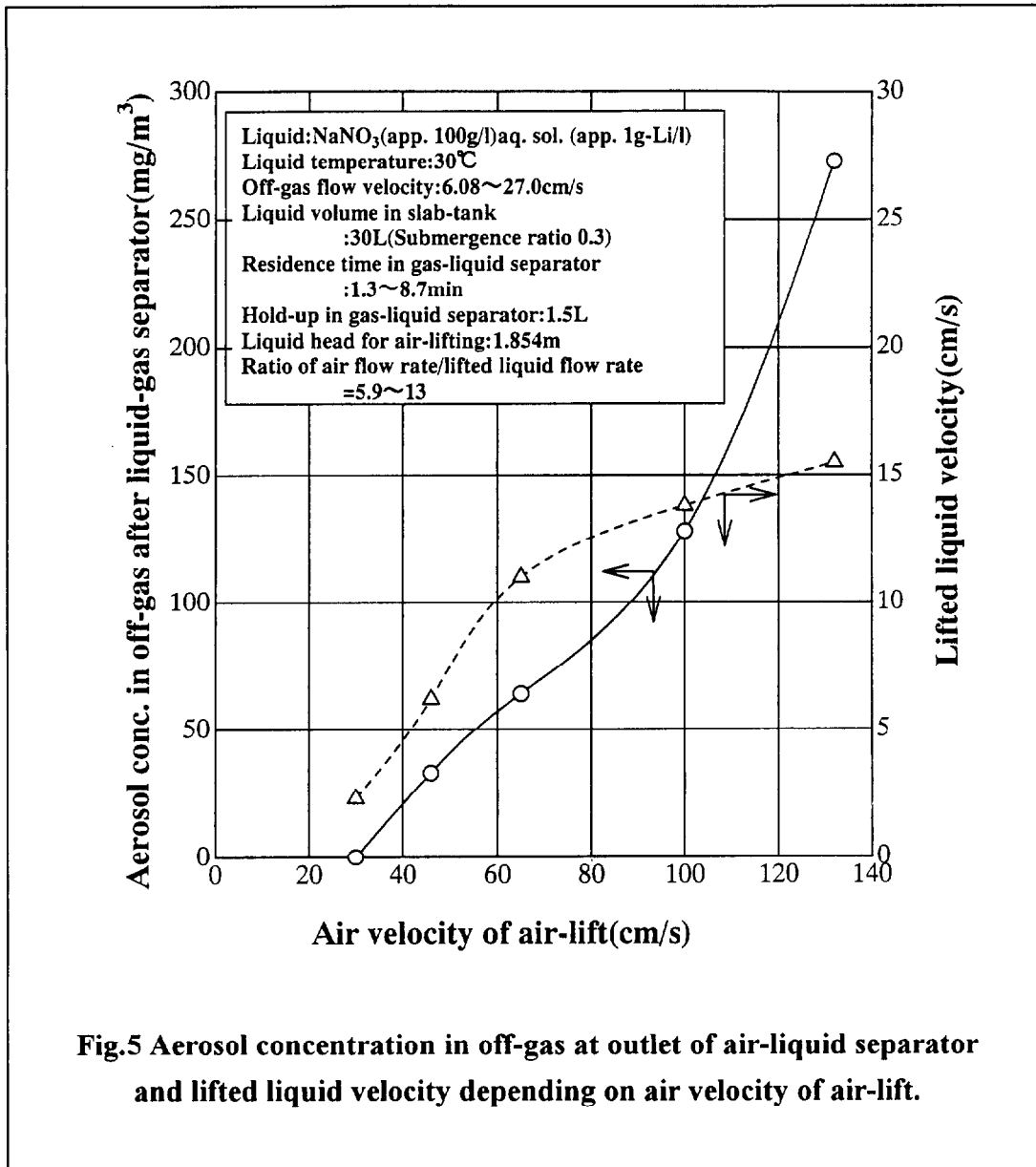


Air-lift Operation

Characteristics of air-lift depends on submergence ratio. Submergence ratio is defined as the ratio of depth of air-lift submergence beneath free surface to total head of lifting liquid. Air-lift was operated by adjusting submergence ratio at 0.3 by keeping app. 30L solution volume in slab-tank. Solution was recycled through air-liquid separator and pot to slab-tank. Diameter of air-lifting pipe is 12.7 mm. Aerosol sampling was carried out for 5 hours on vent pipe from air-liquid separator.

Aerosol concentration in off-gas from air-liquid separator are related to linear velocity of air in air-lifting pipe, as shown in Fig.5. Lifted liquid velocity is also shown in the figure. Aerosol concentrations are roughly proportional to air velocity. And it is observed that aerosol concentrations are in the range from a few to several hundreds mg/m^3 in this experimental range. Air-liquid separator

actually has no function to remove aerosol from off-gas. Demister should be applied to reduce aerosol migration to the downstream of off-gas from air-liquid separator.



Evaporation

Evaporation of solution in slab-tank was carried out at the evaporation rate in the range from 1.4 to 7 L/h. Standard evaporation rate is assumed to be 10% liquid volume in one hour, this rate corresponds to 3 L/h in this experiment. Evaporation rate was controlled by heater output and measured by condensate level increase in pot. Inner pressure of slab-tank was adjusted in the range of app. -80 to -200 mmH₂O by exhaustive blower operation. Off-gas flow velocity was adjusted at 4 m/s at off-gas outlet of condenser by controlling carrier air which sweeps the volume above free surface in

slab-tank. Aerosol sample was collected at the off-gas outlet of condenser for one hour.

Aerosol concentration and migration rate to outlet of condenser are related to evaporation rate, as shown in Fig.6. Dependence of aerosol migration rate on evaporation rate is not apparently clear in this experiment. Aerosol concentrations are observed in the range from 2 to 7 mg/m³ in off-gas. Hourly migration ratios are calculated in the range from 6.2x10⁻⁴ to 1.7x10⁻³. Hourly migration ratios are defined by the ratio of migration rate to outlet of condenser divided by total amount of solution in slab-tank.

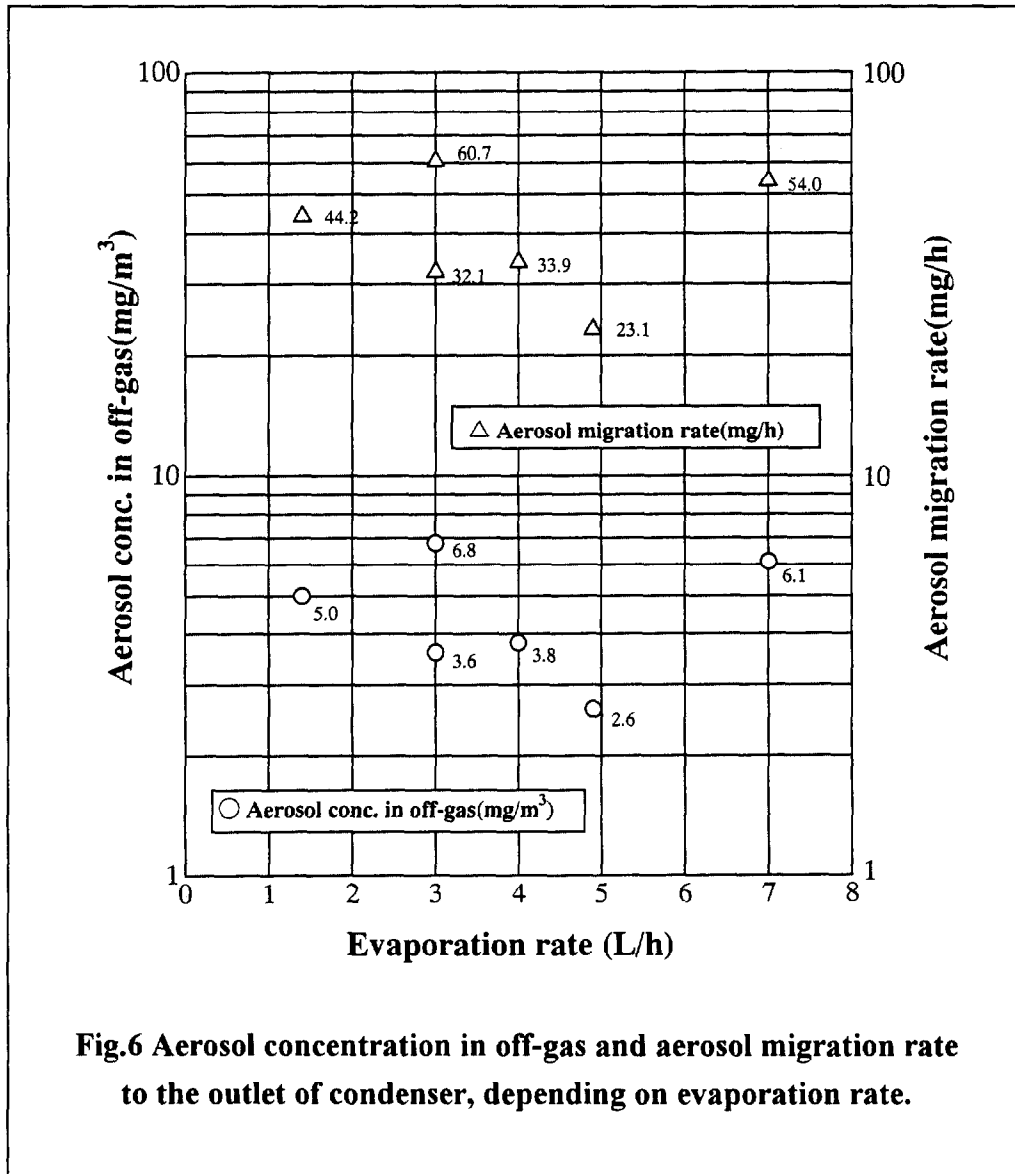


Fig.6 Aerosol concentration in off-gas and aerosol migration rate to the outlet of condenser, depending on evaporation rate.

IV. Conclusion

Aerosols in off-gas are measured at outlet of vessel under various operation condition using

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simulated nitrate solutions to understand the behavior of non-volatile radioactive elements under normal operation of reprocessing. Experimental results show the following conclusions.

- (1) Aerosol concentrations in off-gas at outlet of vessel are observed in the range from a few to 20 mg/m³ in the range of off-gas flow rate 2 to 10 m/s, stirring air flow rate up to 50 m³/hm², liquid temperature 20 to 45 °C. Aerosol concentration of less than 10 mg/m³ is observed at stirring air rate less than 30 m³/hm² for 350 g/L NaNO₃+LiNO₃-3M nitric acid solution.
- (2) Decrease of liquid surface tension by adding trace amount of TBP increases aerosol concentration in off-gas by 2 to 5 times that of nitrate solution without organic additives.
- (3) Aerosol concentrations in off-gas from air-liquid separator are observed in the range from a few to several hundreds mg/m³. Aerosol removal should be applied to reduce aerosol migration to the downstream of off-gas from air-liquid separator.
- (4) Aerosol concentrations in off-gas from condenser of vessel under evaporation operation are observed in the range less than 10 mg/m³.

Acknowledgements

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DISCUSSION

DORMAN: One would expect fairly rapid evaporation of some of the aerosols so size would depend markedly on position of sampling. Did you carry out size measurements at more than one point?

FUJINE: Yes, we measured the aerosol sizes at different points, namely, different distances less than 2 m from the vessel in which aerosols are generated. Average sizes of aerosols observed were not different markedly. Regarding evaporation, we made measurements on the size distribution of aerosols in humidified and non-humidified carrier air. Aerosols in humidified air consist of smaller sizes than those in non-humidified air. However, the difference is not big, approximately 10%. Sampling point was just at the outlet of the vessel. I think the non-humidified air was partially humidified to some extent in our experiment.

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EXTENDED-LIFE NUCLEAR AIR CLEANING FILTERS VIA DYNAMIC EXCLUSION PREFILTERS

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Abstract

The primary objective of this feasibility investigation was to ascertain whether a dynamic, self-cleaning particulate exclusion precleaner, previously designed for relatively large dust removal (2 to 100+ μm diameter particles) from military helicopter turbine inlets, could be extended to **submicron** filtration capabilities. If successful, the improved device could then be utilized as a prefilter for many types of HEPA filtration systems, significantly increasing their service life. In applications such as nuclear air cleaning, its use would reduce the amount of nuclear particulate matter that would otherwise be entrapped in the HEPA filter cartridge/panel, causing fouling and increased back pressure, as well as requiring subsequent disposal of the contaminated media at considerable expense.

A unique (patent-pending) mechanical separation device has recently been developed to extract particulate matter from fluid process streams based on a proprietary concept called **Boundary Layer Momentum Transfer (BLMT)**. The device creates multiple boundary layers that actively exclude particles from entering the perimeter of the device, while allowing air to traverse the boundaries relatively unimpeded. A modified two-dimensional (2-D) computerized flow simulation model was used to assist in the prototype design. Empirical results are presented from particle breakthrough and ΔP experiments obtained from a reduced-scale prototype filter. Particles larger than 0.23 μm were actively excluded by the prototype, but at a higher pressure drop than anticipated.

Experimental data collected indicates that the filter housing and the inlet flow configuration may contribute significantly to improvements in device particle separation capabilities. Furthermore, preliminary experiments have shown that other downstream pressure drop considerations (besides those just across the spinning filtration disks) must be included to accurately portray the ΔP across the device. Further detailed quantitative investigations on a larger scale (1,000 CFM) prototype are warranted.

Introduction

High efficiency particulate air (HEPA) cleaning systems perform an important function in nuclear facilities - removal of very fine airborne nuclear particulate matter from the installation. Since nuclear HEPA systems have been proven extremely safe over the years, their extensive use in all major nuclear installations will continue to provide adequate safety margins, but at a high cost of disposal of contaminated filter media. The market for nuclear HEPA systems has been estimated at over a million units annually just in the U.S.¹ Assuming a cost of contaminated HEPA cartridge/panel disposal of

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many thousands of dollars per unit, millions of taxpayer dollars could be saved each year by simply extending the service life of these conventional HEPA filters. Environmental benefit would result from reductions in the amount of nuclear contaminated media targeted for high- and low-level radwaste sites.

The use of a medialess (dynamic) *submicron prefilter* would be an expedient solution to this problem. Until recently, an effective medialess prefilter (i.e., such as a high efficiency cyclone or vortex separator) did not exist that could discriminate submicron particle matter. However, a recent development in *supermicron* medialess particulate separators, developed by **Micro Composite Materials Corporation (MCMC)**, was believed to be extendible to the submicron regime. The patent-pending device is currently being developed for the Army to mitigate erosion damage due to sand ingestion in helicopter turbine engines. The mechanical separation/extraction of particulate matter from air or process gas streams, which requires no barrier filter media, is based on a proprietary concept called **Boundary Layer Momentum Transfer (BLMT)**. Boundary layers, generated on multiple closely-spaced rotating disks, actively "*exclude*" particles from entering the 360° perimeter of the filter. Conceivably, a BLMT device designed to have submicron discrimination could be effectively used as a nuclear HEPA prefilter. If operated upstream of a conventional HEPA panel, submicron contaminated particulate matter could be extracted from the air stream, collected and disposed or reprocessed without contaminating the HEPA media. The downstream HEPA panel(s) would still provide the added margins of safety that the nuclear industry demands, but would last much longer due to reduced particulate loading from the BLMT prefilter upstream. The degree to which service life could be extended would be dependent upon the extent of BLMT submicron discrimination. Separation of smaller submicron sizes (down to 0.3 μm) with the BLMT prefilter would lead to longer HEPA service life. Conversely, BLMT discrimination of only larger particle sizes (micron or larger) would lead to shorter downstream HEPA lifetime enhancements.

Theoretical Development

The basic concept of BLMT filtration is to transfer inertia from the boundary layer of a rotating disk to entrained particulate matter; centrifugal force is used to expel particles. This is accomplished by spinning the fluid between each disk pair in solid body rotation: the boundary layers that extend from the sides of each rotating disk must thicken enough to touch or overlap. If boundary layer overlap does not occur, either because the disks do not rotate fast enough or because the spacing between disks is too great, the device does not function as a filter.

There are three different means of by which particles are addressed by the BLMT device:

- Particles that are too small to be excluded follow a spiral path through the device and eventually pass through to the exit,
- Particles that are small enough to enter the device but large enough to keep them from passing through to the exit spiral into orbit around the device somewhere between the disks (these particles are eventually excluded from airflow based on secondary effects), and
- Particles that are large enough to be excluded from flow prior to entering the BLMT device.

This paper presents the theory associated with particles that are large enough to be excluded from flow prior to entering the BLMT device. Radial airflow velocity into the BLMT device is small compared to the tangential airflow velocity that circulates outside the rotating disk assembly. Other airflow

characteristics in the radial and tangential directions differ greatly, including Reynold's number and pressure drop.

Theoretical Particle Size Exclusion

The particle size discrimination ability of the BLMT filter device is derived by equating the inertial force developed by the particle to the drag force imposed on the particle. The inertial force developed by the particle is the direct result of being captured in a disk boundary layer. The drag force on a particle is due to the upstream airflow pressure or downstream suction.

Particle Centrifugal Force Development

The basic assumption made in particle centrifugal force development is that a boundary layer rotates with each surface of a disk when it is rotated. The strength, depth, and profile of the boundary layer is related to the rotational velocity of the disk and the physical properties of the fluid surrounding it. Under appropriate conditions, a particle will rotate with the boundary layer at the same speed as the disk. With this assumption, the beginning step in theoretical development is to make use of Newton's second law, where the force, **F**, on a particle is:

$$\mathbf{F} = \mathbf{ma} \qquad \text{Equation 1}$$

Where: **m** is the mass of the particle, and
a is the acceleration of the particle.

From this starting point, a number of substitutions are made to relate acceleration to rotational speed and the relative position of the particle on the disk, and mass of the particle based on density and assumed spherical volume. The result is a solution for the centrifugal force, **F_C**, in terms of known particle and disk parameters:

$$\mathbf{F}_C = \frac{4\pi\rho_p \mathbf{R}_p^3 \omega^2 \mathbf{R}_o}{3} \qquad \text{Equation 2}$$

Where: ρ_p is the particle density,
 \mathbf{R}_p is the particle radius,
 \mathbf{R}_o is the outside radius at the perimeter of the disk.
 ω is the angular velocity of the particle, and

Equation 2 describes the centrifugal force acting to eject a particle as it attempts to enter the flow field outside the disk. The centrifugal force acting on a particle at this point is:

- Directly proportional to the particle location, or radius (relative to the center of the disk pack), and the particle density,
- Directly proportional to the square of the angular velocity of the disks, and
- Directly proportional to the cube of the particle radius.

Particle Drag Force Development

Drag forces serve to counteract the centrifugal forces due to either downstream suction at the filter exit or pressure at the inlet. In conditions where flows permit low Reynolds' Numbers, the drag force, F_D , on a spherical particle can be approximated by Stoke's Law:

$$F_D = 6\pi R_p V_g \mu_g \tag{Equation 3}$$

Where: R_p is the particle radius,
 V_g is the gas velocity, and
 μ_g is the gas dynamic viscosity.

Substituting known relationships involving gas/fluid mass flow rate, density, cross sectional area, and velocity, the equation can be rearranged to provide a closed-form solution for particle drag force in terms of known gas properties, BLMT filter device attributes, and particle geometry:

$$F_D = \frac{3\mu_g R_p \dot{M}}{R_o d n \rho_g} \tag{Equation 4}$$

Where: \dot{M} is the gas mass flow rate,
 R_o is the outside radius of the BLMT device disk,
 ρ_g is the gas (e.g., air, process flow, or otherwise filtered medium) density,
 d is the distance between disks, and
 n is the number of disks

Equation 4 describes the drag force acting to push a particle in as it enters the perimeter flow field. The drag force acting on a particle in the flow field is:

- Directly proportional to the particle size and mass flow rate,
- Inversely proportional to the radius of the disks, inter-disk spacing, and the number of disks, and
- Directly proportional to the gas kinematic viscosity ($\nu = \mu / \rho$).

When Drag Force Equals Centrifugal Force

Equating the centrifugal force expression, Equation 2, to that for the drag force, Equation 4, results in an expression to be used for identification of particle size cutoff.

$$\frac{\rho_p 4\pi R_p^3 \omega^2 R_o}{3} = \frac{3\mu_g R_p \dot{M}}{R_o d n \rho_g} \tag{Equation 5}$$

Rearranging and substituting particle diameter, D_p , for $2 \cdot R_p$, results in:

$$D_p = \frac{3}{R_o \omega} \sqrt{\frac{\nu_g \dot{M}}{d n \pi \rho_p}} \tag{Equation 6}$$

The analytical solution for particle size exclusion, Equation 6, varies according to two different sets of parameters: BLMT device parameters and airflow parameters. The device parameters include disk outer radius, angular velocity, disk spacing, and number of disk spaces. The airflow parameters include mass flow rate, gas dynamic viscosity, and particle density.

For filter parameters, the critical particle diameter is:

- Inversely proportional to disk outer radius and angular velocity, and
- Inversely proportional to the square root of the disk spacing and number of disk spaces.

For airflow parameters, the critical particle diameter is:

- Proportional to the square root of mass flow rate and dynamic viscosity, and
- Inversely proportional to the square root of the particle density.

The above equations define, for a given set of BLMT device and airflow parameters, a critical particle diameter (and anything larger) that will “orbit” outside the BLMT device. The following figure schematically illustrates the conceptual BLMT device, showing airflow, particulate matter in orbit, and critical BLMT components.

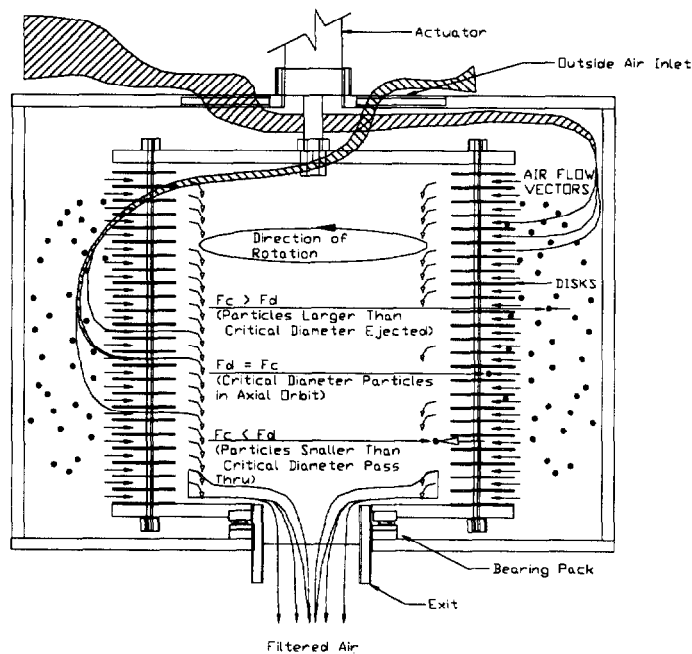


Figure 1. Schematic Representation of the BLMT Filter

Theoretical Pressure Drop

The pressure differential developed in the filter is due to several different factors, primarily including:

- Decreasing flow area,
- Centrifugal forces acting on the rotating gas, and
- Frictional drag along the disk surfaces.

Pressure Loss Due to Decreasing Flow Area

According to Bernoulli's Law, pressure loss is defined as:

$$\Delta P = \frac{\rho_g}{2} (V_o^2 - V_i^2) \quad \text{Equation 7}$$

Where: Subscripts **i** and **o** designate the position at the inside and outside radius, respectively, and all other variables have been previously defined.

Substituting relationships for gas velocity as a function of available flow area and mass flow rate yields:

$$\Delta P_A = \frac{\rho_g}{2} \left(\frac{\dot{M}}{2\pi\rho_g dn} \right)^2 \left(\frac{1}{R_o^2} - \frac{1}{R_i^2} \right) \quad \text{Equation 8}$$

Due to the inverse relationship to the square of the inner and outer radii, this component of the total pressure loss is small, and rapidly decreases in importance as the outside radius increases in size.

Pressure Loss Due to Centrifugal Forces on the Rotating Gas

The pressure loss for flow from the disk outside radius to the disk inside radius is inversely proportional to the differences between their respective flow areas. Starting again with Bernoulli's Law and substituting the relationship of acceleration to rotational speed and the relative position of the particle on the disk yields:

$$\Delta P_B = \frac{\rho_g \omega^2}{2} (R_o^2 - R_i^2) \quad \text{Equation 9}$$

Due to the direct relationship to the square of the inner and outer radii, this component of the total pressure loss dominates the total pressure loss expression, and will increase in importance as the outside radius increases in size.

Pressure Loss Due to Frictional Drag Along the Disk Surfaces

The pressure loss due to frictional drag, **D**, at the boundary layer surface area, **A**, can be expressed as:

$$\Delta P_C = \frac{D}{A} = \frac{C_f \rho_g V_o^2}{2A} \quad \text{Equation 10}$$

Where: **C_f** is the coefficient of friction.

The effect of friction has little or no meaning at these flow rates. This term is considered to be negligible.

Total Pressure Loss

The total pressure loss through the BLMT filter is expressed through the combination of Equations 8 and 9.

$$\Delta P = \frac{\rho_g}{2} \left(\left(\frac{\dot{M}}{2\pi\rho_g dn} \right)^2 \left(\frac{1}{R_o^2} - \frac{1}{R_i^2} \right) + \omega^2 (R_o^2 - R_i^2) \right) \quad \text{Equation 11}$$

BLMT Gas Velocity

The equation defining the air velocity, V , entering the perimeter of the BLMT device is:

$$V = \frac{\dot{M}}{2\pi\rho_g R_o dn} \quad \text{Equation 12}$$

Relationship Between Reynolds Numbers for BLMT Tangential and Radial Flows

To evaluate the ratios of the Reynolds Numbers of flow between the individual disks and circling the BLMT disk pack, the relationship with previously developed equations defined. The Reynolds Number for tangential flow circling the BLMT device is:

$$Re_\omega = \frac{\rho_g R_o \omega h}{\mu_g} \quad \text{Equation 13}$$

The Reynolds Number for radial flow between the individual disks is:

$$Re_h = \frac{\rho_g V_g h}{\mu_g} \quad \text{Equation 14}$$

Using Equation 6, substituting Equation 12, and rearranging terms it can be seen that the following is true:

$$D_p^2 \geq \left(\frac{18}{R_o \omega^2} \right) \left(\frac{\mu_g V_g}{\rho_p} \right) \left(\frac{\rho}{\rho_g} \right) \left(\frac{\mu}{\mu_g} \right) \left(\frac{h}{h} \right) = \left(\frac{18\mu_g}{\rho_p \omega} \right) \left(\frac{\rho_g V_g h}{\mu_g} \right) \left(\frac{\mu_g}{\rho_g R_o \omega h} \right)$$

So the relationship linking particle diameter (to be excluded from flow) to the ratio of radial to tangential BLMT Reynolds Numbers is:

$$D_p^2 \geq \left(\frac{18\mu_g}{\rho_p \omega} \right) \left(\frac{Re_h}{Re_\omega} \right) \quad \text{Equation 15}$$

Future BLMT research involves the scale-up from small-scale and prototype models of the BLMT filter. This relationship will be important in the scale-up to larger models.

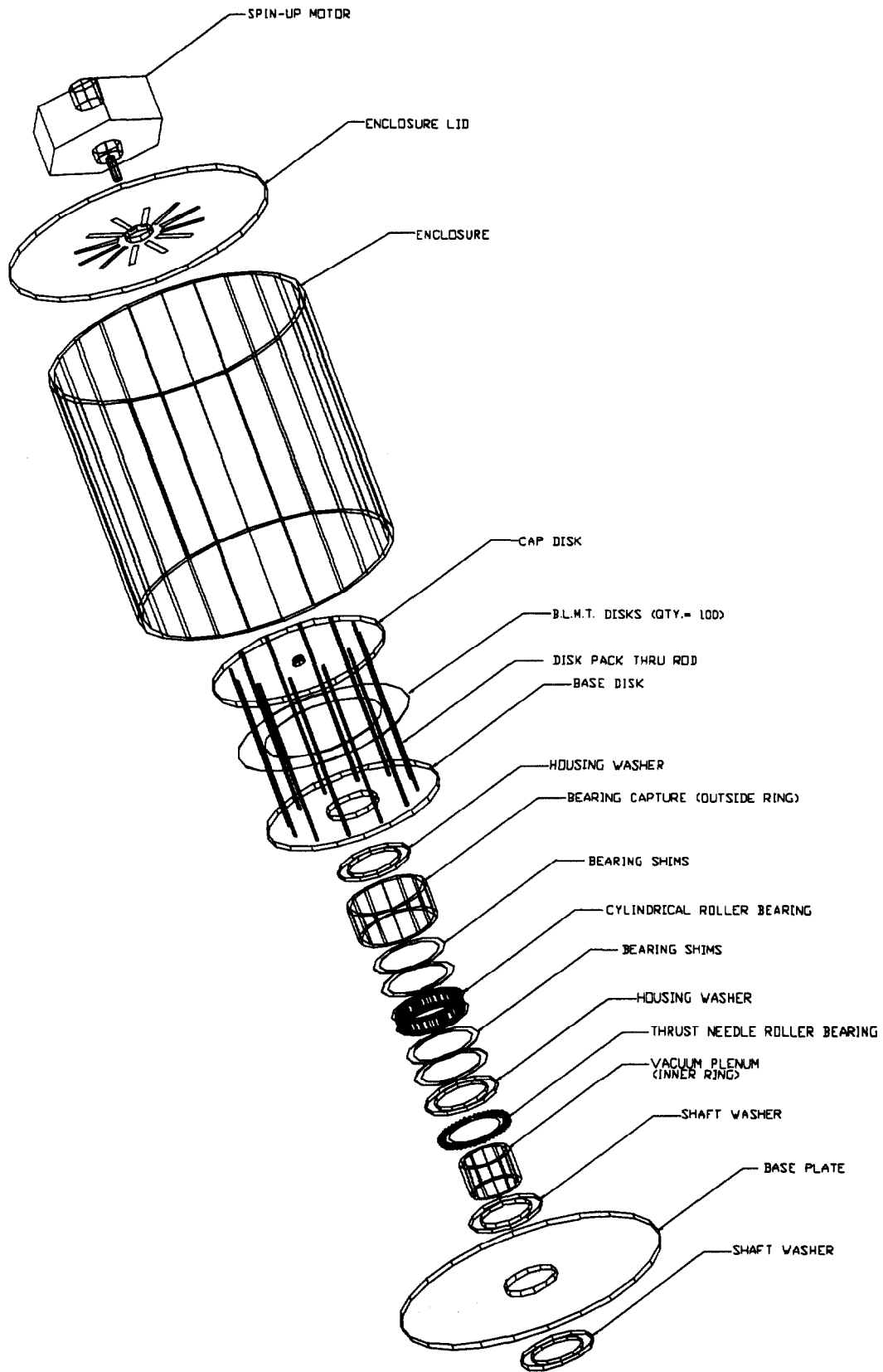


Figure 2 Exploded View of the BLMT Filter

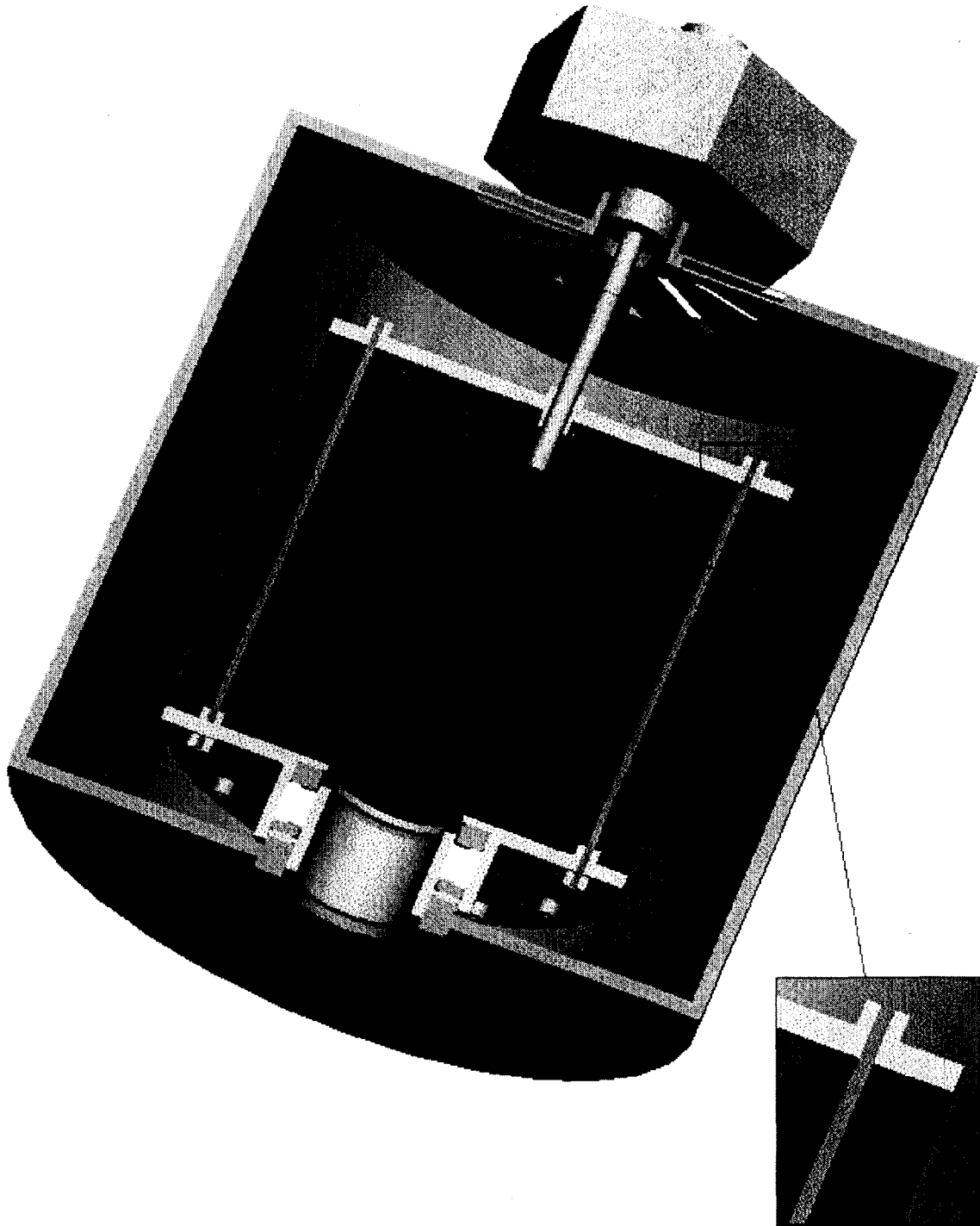


Figure 3 Cut-Away CAD Rendering of the BLMT Filter

Results of BLMT Testing

Bench testing was performed in accordance with our DOE SBIR Phase I program. Figures 1, 2, and 3 illustrate the general arrangement of the BLMT filter. Powdered aluminum oxide, Al_2O_3 , was added to the air intake of the reduced-scale BLMT filter to test filtration efficiency. Results of the testing exceeded expectations, as no particulate was observed to pass through the BLMT device. The chosen particulate is pure white in color and is made-up of particle diameters ranging from 0.1 micron to 10 micron, with a median value of 0.46 micron. Density is $3,965 \text{ kg/m}^3$. Figure 4 illustrates the particle size distribution provided by the supplier.

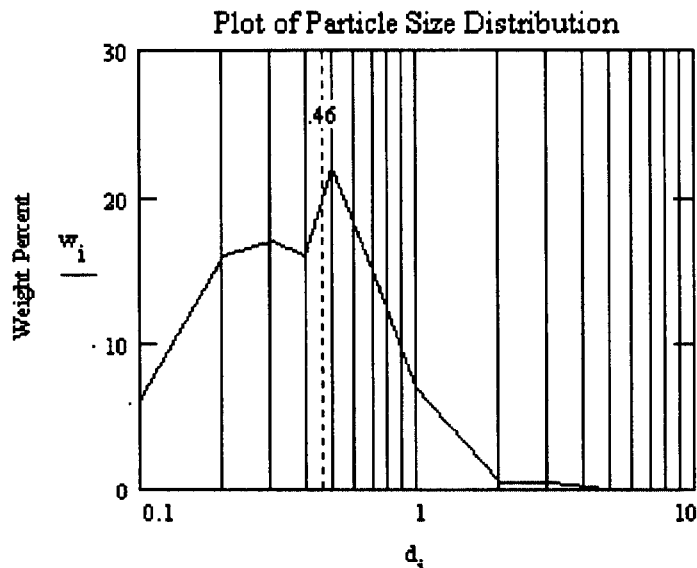


Figure 4 Al_2O_3 Particle Size Distribution

The initial test parameters were as follows:

- Disk pack rotating speed: 1500 rpm
- Flow rate: approximately 12 cfm
- Particulate: approximately 60 cc's of aluminum oxide

The test results were both impressive and successful. With extremely high particulate loading inside a 12-inch diameter, 12-inch high filter housing, none of the particulate was observed to pass into the exhaust chamber. The pressure drop across the prototype filter was higher than expected, at approximately 5-1/2 inches of water. To provide some perspective, the military defines "zero visibility" for larger dust sizes as 0.025 gram/ft^3 . During this test run, particulate loading was approximately 0.0043 gram/cm^3 , a factor of 4800X higher than zero visibility conditions (assuming all particles remain suspended).

In an attempt to force "breakthrough" on the filter, the gas flow rate was increased. This parameter variation increases drag on particles as they circulate the BLMT device. At a flow rate of approximately 60 cfm there was no observed particulate loss into the exhaust chamber. In another attempt to overload the filter, the flow rate was increased to the maximum capacity of the laboratory blower (approximately 90 cfm) and an additional 60 cc's of aluminum oxide were added to the filter

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intake. Although the circulation inside the filter (but outside the BLMT device) was essentially “blinded” with particulate matter, still no breakthrough was observed.

The next step taken was to reduce the rotating speed of the disk pack. This parameter variation decreased the centrifugal force (resistance) imparted to particles attempting to enter the BLMT device. With all other parameters maintained, the speed was reduced to 1000 rpm. Once again, no breakthrough was observed. Testing was concluded at this point as the exhaust blower used to develop the flow through the filter shut down on thermal overload.

The filter housing was a clear acrylic tube, allowing observation during the test. Several different vortex patterns developed during the test, seemingly dependent upon a combination of flow rate, particulate loading, and disk pack rotating speed. It was observed that the vortex action within the housing may have contributed to the efficiency of the filter by keeping particulate matter away from the periphery of the BLMT device. This is a “second order” effect that deserves additional study, most likely in combination with tasks associated with housing design and particulate collection. Taking advantage of naturally occurring particulate behavior in addition to the intended action will yield a more efficient filter.

Upon disassembly of the prototype filter and test setup, a light coating of extremely fine powder was found on the inside of the ductwork exiting the prototype filter. The filter had experienced breakthrough of the aluminum oxide material, but the small size and volume of the breakthrough made visual identification during the test impossible. A sample of the material was collected for measurement under a scanning electron microscope (SEM). The material sample was prepared for inspection by sputtering with a conductive material and placing it in an appropriate inspection crucible. The SEM inspection revealed the material that achieved breakthrough was sized below the 0.3 μm cutoff normally associated with HEPA filtration requirements. A photograph of the SEM results is presented in Figure 5. The magnification of the SEM was $0.91 \times 15,000 = 13,650X$. The average maximum particle size in the SEM viewfinder was determined to be approximately 0.32 μm . Therefore the average maximum particle size is: $0.32/13,650 \approx 2.3 \times 10^{-5} \text{ cm} \approx 2.3 \times 10^{-7} \text{ m} \approx 0.23 \mu\text{m}$.

Based on the known test parameters (summarized in Table 1, below) and making use of the equations previously developed, the anticipated filter performance can be calculated.

Type of Parameter	Parameter	Parameter Value
Design Parameters	Flow Rate (\dot{M})	90 cfm = 0.0467 kg/sec
	Kinematic Gas Viscosity (ν_g)	$1.636 \times 10^{-5} \text{ m}^2/\text{sec}$
	Gas Density (ρ_g)	1.1 kg/m^3
	Particle Density (ρ_p)	$3.96 \times 10^3 \text{ kg/m}^3$
BLMT Filter Parameters	Number of Disks	100
	Number of Disk Spaces (n)	99
	Disk Spacing (d)	0.001 m
	Disk Outside Radius (R_o)	4 in = 0.1016 m
	Disk Inside Radius (R_i)	2.75 in = 0.0699 m
	Angular Velocity (ω)	1,000 rpm = 104.7 rad/sec

Table 1 Summary of Design and Filter Parameters



Substituting into Equation 6, the expected critical diameter for the filter and design parameters is:

$$D_p = \frac{3}{R_o \omega} \sqrt{\frac{v_g \dot{M}}{dn \pi \rho_p}}$$

$$D_p = \frac{3}{(0.1016)(104.7)} \sqrt{\frac{(1.636 \times 10^{-5})(0.0467)}{(0.001)(99)\pi(3.965 \times 10^3)}} \approx 7 \mu\text{m}$$

The anticipated pressure differential across this filter is determined by substituting into Equation 11:

$$\Delta P = \frac{\rho_g}{2} \left(\left(\frac{\dot{M}}{2\pi \rho_g dn} \right)^2 \left(\frac{1}{R_o^2} - \frac{1}{R_i^2} \right) + \omega^2 (R_o^2 - R_i^2) \right)$$

$$\Delta P = \frac{1.1}{2(6895)(14.7)} \cdot \left(\left(\left(\frac{0.0467}{2\pi(1.1)(0.001)(99)} \right)^2 \left(\frac{1}{(0.1016)^2} - \frac{1}{(0.0699)^2} \right) \right) + \left((104.7)^2 ((0.1016)^2 - (0.0699)^2) \right) \right) \cdot 100 \approx 0.032\%$$

The airflow velocity entering each individual disk space is based on Equation 12:

$$V = \frac{\dot{M}}{2\pi \rho_g R_o dn}$$

$$V = \frac{0.0467}{2\pi(1.1)(0.1016)(0.001)(99)} = 0.67 \text{ m/sec}$$

The following table summarizes the differences between the analytical (expected) and empirical (actual) results.

Result Description	Expected Results	Actual Results
Critical Diameter	7 μm	0.23 μm
Differential Pressure	0.032% (0.0089 in. of H ₂ O)	approx. 5-1/2 in. of H ₂ O
Airflow Velocity Between Disks	0.67 m/sec	not measured

Table 2 Summary of Expected and Actual Test Results

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The difference between the expected and actual critical diameter was substantial, and likely due to the following:

- The boundary layers effect airborne particles before they enter the BLMT device.
- Vortices and airflow patterns within the housing contribute to inertial effects that prevent particle passage into the BLMT device (i.e., the device housing acts similar to a cyclone in that particle density is suspected to be highest closest to the inside wall and falls off rapidly as it approaches the BLMT device).
- The analytical models predict that there is a third size range of particle, those that enter, but do not exit the BLMT device. They settle into and orbit within the device, and particle interaction and other second-order effects eventually eject the particle.

The difference between the expected and actual pressure differential is also substantial, and is probably due to one or more of the following:

- Reduced exit port size (cross-sectional area) in relation to the disk pack inside radius. The diameter of the suction line from the filter assembly was approximately 2 inches. The inner diameter of the disk pack was 5.5 inches. This transition alone, at 90 cfm, generates a pressure differential of as much as 1.7 inches of H₂O.
- Inefficient placement of pitot tubes for pressure differential measurement.
- Measurement of pressure differential attributable to the BLMT device combined with that for other system components.
- Vortices and airflow patterns within the housing contribute to inertial effects that increase the pressure differential.

Conclusion

The empirical data collected to date establish that it is feasible to extend the BLMT filtration concept to the submicron size range for prefilter applications. Significantly more data, however, must be gathered in subsequent experiments for accurate quantification. The SEM microphotographs of the breakthrough particles (the particulate matter that passed through the filter when operational parameters were minimized) definitively show that, at the filter parameters reported, sub-HEPA particle sizes (i.e., less than 0.3 μm) were not excluded, but at conditions (purely from theoretical considerations) that would normally reject particles 7 μm and larger. In other words, there is a discrepancy between the particle size empirically rejected (0.23 μm) and that theoretically predicted to be excluded (7 μm).

A hypothesis has been suggested to explain this “better than predicted” particle exclusion phenomena (still to be definitively ascertained). Note that the equations used to describe the particle size rejection and ΔP across the filter do not take into account any contribution due to the housing size, shape or configuration. Logically, both the housing geometry/flow conditions (e.g., involute design) and the input flow characteristics (i.e., tangential rather than normal) will influence the BLMT filtration efficiency, as well as the pressure drop. The magnitude to which the housing affects the separation efficiency will be the subject of further R&D over the next several years.

This feasibility investigation has demonstrated the merit in proceeding with a full-scale prototype BLMT prefilter, in which far more sophisticated submicron particle generation and detection equipment can be used to accurately quantify the prefilter. Since only approximately 90 CFM flow rate

through the device was measured to demonstrate feasibility, nearly 11 times this flow rate (or 1,000 CFM) will be required for demonstration of the full-scale BLMT device in the next phase of experimentation. From a scale-up perspective, the least risky alternative for full-scale demonstration of the prefilter is simply to have multiple (10 to 11) reduced-scale units operate in parallel. However, the scale-up criteria suggested by the Reynold's numbers analysis offers another alternative - use of larger disks (both outside and inside diameters) and more of them. This would result in a larger prototype design with perhaps three or four parallel units operating simultaneously to achieve the desired submicron cut-off size and flow rate.

Acknowledgments

MCMC would like to acknowledge the support of the Department of Energy (DOE) for this research effort under grant number DE-FG02-95ER82026. Indirect research and development support for this technology was previously received from the Department of Defense (DoD) under contract number DAAJ02-93-C-0015, as well as from the Environmental Protection Agency (EPA) under contract number 68D50106. Complimentary research support for development of the BLMT is currently being received from DoD under contract number DAAJ02-95-C-0009.

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DISCUSSION

ENGELMANN: It is very difficult when one collects particles in chains at the end of a system to know just what size particle one is dealing with, whether the chain agglomerated afterwards or during the process, or was created that way. Do you have any plans to determine this with a moving filter paper or something else at the end of the system?

WRIGHT: For phase two we are acquiring \$100,000 worth of test equipment. We will have a standard DOP generator ahead of the filter. We have not been set up to do filter work, and that is why we were using indirect methods. When we ran this particular experiment we were expecting a large plume of material to come through, and had a flow visualization chamber ahead of the fan, but we never saw anything. We increased flow to push material through and we added another 60cc of material. At the end of the test we had 120cc in the unit. This corresponded to 0.029g/m^3 , which is a fairly heavy loading. At the end of this test, we increased the STET rate of the unit to about 100CFM. When you increase flow rate and reduce spin rate particles should go through. Since we did not have a filter downstream, we had a fairly clean system to start off with. We had noticed there was a small amount of dusting and dust was what we ended up taking over to the SEM. I admit this was a very crude method but it was just to show feasibility. In phase two we will be able to do a lot more to quantify it.

WEBER: Did you have a chance to examine the condition of the disks at the end of the tests and the gap between the disks?

WRIGHT: The gap does not change. We have a dozen bolts running through them with spacers. The disk thickness was 30mils. We saw no effects due to erosion, but the test was not long enough to establish any kind of erosion pattern, we would not expect to see erosion except over a very long period of time.

WEBER: Any residual particles?

WRIGHT: We were trying to push particles through but we had quite a bit of material that stuck to the inside part of the chamber. All we were able to do was get some extremely light dusting at the very end that we ran through the SEM. We did a number of samples and the average particle size that had gone through was around $0.2\text{-}0.3\mu\text{m}$. Other than that we did not have enough to measure.

DAUBER: Given that the particle size that you found was more than an order of magnitude smaller than you had predicted, is it possible to bring it down another order of magnitude by some refinement so as not to have a prefilter, but a HEPA filter?

WRIGHT: We would like to get to that point. Some of our early modeling showed that if we had tangential inflow rather than coming in radially, or perpendicularly, to our inflow, that we would get about an order of magnitude increase in terms of our separation efficiency. What we are trying to do is achieve solid body rotation between the disks. As long as our disk spacing is such that we can make sure that there is no core flow going through there, then this thing will continue to act as a filter. Yes, we are trying to look at this. We can envision a truncated cone housing design so that we have a natural pressure distribution that forces the particles to the outside so that you could extract them from the lower portion. You have a large particle concentration toward the outer edge of the filter housing and therefore you are

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only literally filtering a fairly clean core of air inside. That gives us hope that we will be able to get further down in terms of particle size and also increase our flow rate, to get into a more industrial size.

DAUBER: Then all you have to do is add another concentric ring.

WRIGHT: Exactly. There is a lot of additional work that needs to go on and we need to look at what else we can incorporate. We have quite a bit of surface area and we could add catalysts or other things on to the surface of the plates themselves. It is a fairly simple design. We have to protect the motor (which could be hermetically sealed) and the bearing, they are our critical parts.

CLOSING COMMENTS OF SESSION CHAIRMAN

Yesterday, Dr. First referred to a meeting (1985) in Aix-en-Provence where he made a plea for operators to be certified to conduct in-place tests. As Convenor until 2 years ago of a European Committee on a new method for testing HEPA filters I also said then that once a laboratory/factory test had been decided upon, the next step was to attend to in-place tests. I think that one can make fairly definite decisions on the types of equipment to be used for in-place tests but it is less easy to decide on how the equipment can be used for in-place testing because of different designs of ducts, available injection and sampling points, mixing devices, and so on. I believe that results of many in-place tests are greatly in error. There is likely to be considerable scope for operators to use experience and common sense in test layout. In other words, operators should be trained and themselves tested before being let loose on in-place tests. I do not suggest that laboratory tests should be abandoned but there is no doubt that the really important test is that after installation and during use. If a successful session is measured by the number of questions asked, I think we have done very well.

SESSION 12

CODES & STANDARDS FOR FILTERS AND ADSORBERS

Thursday July 18, 1996

Co-Chairmen: J.J. Hayes, Jr.
R.D. Porco

THE FIRST TWENTY YEARS OF THE ASME COMMITTEE ON
NUCLEAR AIR AND GAS TREATMENT- A RETROSPECTIVE
BY A FOUNDING MEMBER

J. Jacox

PERFORMANCE TESTING OF HEPA FILTERS: PROGRESS
TOWARDS A EUROPEAN STANDARD PROCEDURE

J. Dymant

THE CASE FOR IMPROVED HEPA-FILTER MECHANICAL
PERFORMANCE STANDARDS REVISITED

C.I. Ricketts and P.R. Smith

**PANEL SESSION: CHANGES TO ASME
CODE AG-1, SECTION FC, HEPA FILTERS**

Co-Chairmen: J.J. Hayes, Jr.
R.D. Porco

Panel Members: J. Slawski
R. Rown
B. Franklin
S. Klocke

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THE FIRST TWENTY YEARS OF THE ASME COMMITTEE ON NUCLEAR AIR AND GAS TREATMENT - A RETROSPECTIVE BY A FOUNDING MEMBER

Jack Jacox
Jacox Associates
Columbus, Ohio

Abstract

Since the 1996 Winter Meeting of CONAGT was the twentieth anniversary of CONAGT a review of the Committee and its members seems in order.

This Paper will cover the background and formation of CONAGT as well as the history to date.

This history will include not only the basic accomplishments but some of the less successfully met goals and a look at some of the personalities involved in the Committee work. General future plans will be included.

The intent of the Paper is less a formal history than a personal recollection of the Committee and those who worked so hard to create the best possible Codes and Standards for the industry to use.

Introduction

The Committee On Nuclear Air and Gas Treatment (CONAGT) grew from a basic industry need. In the 1960s there was an unprecedented growth in building nuclear power plants. Since these were unique in history, there was no historical base of industry or governmental standards to use to build them. The only technical information was from the military programs that initiated the nuclear age. These were of considerable assistance but far from what was required for an industry that had to meet the twin needs of safety and profitability, while growing many fold. To meet this need in the area of gas treatment a group of technical experts met under the auspices of the American National Standards Institute (ANSI) Nuclear Technical Advisory Board (NTAB). The American Society of Mechanical Engineers was the direct sponsor of the effort. This group met in the early 1970s and produced the first editions of N509 "Nuclear Power Plant Air-Cleaning Units and Components" ¹ and N510 "Testing of Nuclear Air Treatment Systems" ². These two documents in their latest editions are still the most widely used Nuclear Air treatment System (NATS) standards in use. I was fortunate to have participated as a guest at some of these meetings.

Discussion

As productive as this first effort was there was one defect. The writing group was an ad hoc group that dissolved upon completion of the Standards. The need for revision and expansion of these milestone Standards had been recognized even before they were published. ASME was chosen to be the sponsoring society for an ongoing Code committee to be responsible for NATS equipment Codes and Standards. This effort was, at the time, to include noble gas delay carbon beds and hydrogen

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recombiners. The first meeting of the ASME "Committee on Nuclear Air and Gas Treatment" (CONAGT) was held at ASME Headquarters in New York on 26 February 1976. This meeting was organizational in nature and set the initial structure and membership for a permanent ASME Code Committee. The attendees at this meeting were largely those who had been on the ad hoc NTAB committee but a few of us were new comers. While a relatively brief meeting it was the critical first step in creation of what is now a maturing Code Committee recognized internationally. Minutes of this first meeting are reproduced as Appendix A along with our first organization chart.

Our second meeting was held on 6 May of 1976 where we continued to work on more detailed organizational matters. I find it interesting that organizational considerations have continued to be on the Committee's agenda throughout its life. Continued shifting of Subcommittee and Subgroup structure appears to be a life long effort. In the early 1980's we had a major restructuring of all our Subcommittees after special Executive Committee meetings and long Main Committee discussion. As we expand to include DOE facility needs our organizational structure is still evolving. This ability to adapt to both changing industry needs and our recognition of existing weakness in our internal organization for which we provide solutions is one of our greatest strengths.

It is very important to note that the initial mandate of CONAGT was limited to nuclear power plants, more specifically in practice, United States designed light water reactors. The presence of an NRC representative and the membership of the Committee at all levels reflects this as, much as it reinforces it. In retrospect it is perhaps well that we started with a limited scope so as not to be overwhelmed by our mission. However, this limitation has become a weakness we are just now starting to overcome. In our first two decades CONAGT had become too focused on USNRC Regulatory Guides 1.52 "Design, Testing and Maintenance Criteria for Atmospheric Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power plants" ³ and 1.140 "Design, Testing and Maintenance Criteria for Normal Ventilation Exhaust System Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power plants" ⁴. In recent years we have found that there is far more to Nuclear Air Treatment Systems than these two Regulatory Guides.

As a newcomer to Code and Standard writing I had a great deal to learn. Not the least of which was the time required to bring a consensus document to publication. I vividly recall talking to Jim Fish, our first Chairman, just after the decision was made to revise N510. I told him I saw no reason it should take more than six months. Five years later when the revision was published I had become much more knowledgeable about the process. Jim was kind enough not to remind me of my earlier comment.

Another early learning experience was when we were working on the Housing and Frame Leak Tests in N510. The Pressure Decay calculations seemed very simple and straight forward. They are, but the sensitivity of the calculated Leak rate to temperature was not recognized by most of us. Paul Estriech spent nearly a year educating the rest of the Subcommittee on this critical point. We held probably four meetings devoted to trying to avoid the limitations this sensitivity creates to a Leak Test. Unfortunately as the saying goes, "You can't fool Mother Nature" so we had to admit to the limitations and revise the testing limits and acceptance criteria. There has been continued refinement of Pressure Decay Leak Testing Procedures and Calculations through out the revisions of N510. The Code and Standards are better for this exercise and many of us who participated are wiser for it.

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Throughout our work we have had major success and as well as some failures, as is true in all endeavors. There are two efforts that did not result in success I would like to mention as they are of considerable personal interest to me.

In our original planning Boiling Water Reactor Off Gas Systems were included in our scope. Specifically the hydrogen/oxygen recombiners as "Safety" systems and the carbon delay beds as "Non-safety". A Subcommittee was formed to write the equipment and testing standards. Subgroups for Equipment and Testing worked for years on these tasks. Work went slowly since these groups of experts were starting from zero. There was nothing in existence to build on as N509 and N510 provided in NATS area. More importantly one of the Subcommittee members who was also a member of the Gas Processing Equipment Subgroup, and later the Subcommittee Chairman and Main Committee member, had a different agenda than we had thought. This individual had a specific goal. That was to see that there would not be any new requirements published for BWR Off Gas Systems. He worked for a major nuclear utility with two large BWR plants. By using the CONAGT rules he was able to block the efforts of the Subcommittee for enough years that the effort was dropped. I guess this individual's political expertise was proven valuable to him since he became a very young vice president of the utility.

Fortunately this original goal has recently been put back on track and work on a variety of gas processing systems is again well underway. This time the Subcommittee is under a strong leader and there is no obstacle to completion of the work.

One of the initial goals of the Testing Subcommittee (of which I was chairman for over a decade) was to publish a standard for Personnel Qualification. Dr. Melvin First was the Subgroup Chairman. We worked for years to develop technical requirements to compliment and expand on the existing time based experience requirements in ANSI N45.2.6 "Qualifications of Inspection, Examination, and Testing Personnel for Nuclear Power Plants" ⁵ and ANS 3.1 "Selection, Qualification and Training of Personnel for Nuclear Power Plants" ⁶. These documents specify periods of time necessary to be qualified at various levels for testing but do not specify what the technical experience must be during these periods. This has allowed some organizations to qualify personnel who know all the bureaucratic requirements but none of the technical requirements. The Testing Subcommittee, with the Main Committee's initial endorsement, wrote a draft of a Personnel Qualification Standard to provide technical guidance for the specific types of education and experience required to test NATS. After the draft was developed by the Subcommittee it was submitted to the Main Committee. Many of the utility members objected to any additional training requirements at all. Over a period of a year or more the Subcommittee met with many utility representatives at two special meetings hosted by the utilities. We wrote and rewrote the draft in accordance with the utilities requests until it became obvious that no additional training requirements would ever be accepted. The final draft of this standard was published for the record as "Proposed Appendix to ANSI/ASME N510-1986" ⁷ in the Proceedings of the 20th Air Cleaning Conference in 1988. I still believe it is a very valuable document and should be used for guidance in planning a training and certification program for testing to N 510. At least on DOE facility has done so, that I know of.

I could say that CONAGT's greatest accomplishment is that after twenty years we are alive and still growing. Certainly this is a major achievement, but that we have established the ASME "Code AG-1, Code On Nuclear Air and Gas Treatment" ⁸ is indeed our major accomplishment. There are too many success stories to try to relate them all. In fact there are so many I am not qualified to do so. I will

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mention a few that I find significant. Not all are official CONAGT activities. Some are simply the result of the extraordinary efforts of CONAGT's members.

In the early 80s many CONAGT members recognized that there were serious deficiencies in the radioiodine testing of carbon used in nuclear power plants. All currently operating power plants then and now require, through their license, testing of the carbon used in the plant NATS. This testing is required for new carbon and periodically for in service carbon. The results from the commercial testing laboratories appeared to vary much more than made sense to the experts in the field. At that time these tests were performed to an old government standard that had not been subject to consensus peer review. The testing Subcommittee arranged for a series of round robin tests with all the laboratories performing this testing in the U.S. and a number of international facilities. Again Dr. First again took the lead in this special effort. Used carbon was provided by the NRC. When the results were received and analyzed they were found to vary up to three orders of magnitude for the same sample and set of test parameters. Clearly a serious problem existed. The NRC used the CONAGT results as the basis for a major program to improve the accuracy of required radioiodine efficiency testing. A number of meetings of technical experts were hosted by the NRC to determine why the results varied so much and how to improve the situation. The Idaho National Engineering Laboratory was contracted to hold additional round robin tests and suggest how to improve the test protocol and instrumentation. The results of this multi year effort include ASTM a new radioiodine test standard D3803-89 "Standard Test Method for Nuclear-Grade Activated Carbon" ⁹, an excellent INEL report on the technical background of this test (INEL EGG-CS-7653, "Final Technical Evaluation Report for the Nuclear Regulatory Commission/Idaho National Engineering Laboratory Activated Carbon Testing Program" ¹⁰) and NRC recommended laboratories. Given the sensitivity of this type of test, research and improvements still continue but the CONAGT testing Subcommittee round robin is the basis for today's vastly improved radioiodine efficiency test results.

For many years those of us who have enjoyed and benefited from these Air Cleaning Conferences had discussed an industry organization on Nuclear Air Treatment Technology. In the late 1980s a group of us from CONAGT took the step of incorporating a non-profit organization to bring this idea to reality. The "International Society of Nuclear Air Treatment Technologies" (ISNATT) was formed. As you see at this Conference ISNATT is a cosponsor of the Conference, has a commercial exhibit and Professional Development courses. While not an official development of CONAGT it certainly exists due to the efforts of CONAGT members and their dedication.

Based on technical inquiries about N509 and N510, CONAGT decided to hold two public meetings to learn what the users of these documents thought of them, learn where there were weaknesses and how to improve them. These were exceptionally valuable exercises. From them grew the idea of "short courses" where CONAGT members could both teach the attendees about the CONAGT documents and obtain user input to improve them. A number of these Professional Development courses have been held under the auspices of ASME and are now offered by ISNATT. The scope of the courses and seminars has broadened from N509 and N510 to include AG-1 and DOE facility cleanup subject matter.

These accomplishments are not the only ones CONAGT has provided the industry but are significant to me in that they are beyond the scope of simply writing codes and Standards.

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Summary

AG-1 is CONAGT's major achievement. It has greatly extended the scope of equipment covered by N509, it has significantly improved the depth of coverage of the equipment included and is in the process of a major expansion to include DOE facility needs. During our twenty years of existence there has been nearly 100% turnover of Committee personnel but CONAGT remains as strong or stronger as ever. The structure and composition of the various levels of committees continues to evolve to meet ever changing industry needs and technological advances.

CONAGT will provide support Nuclear Air Treatment and Gas Processing Systems for the worlds nuclear industry for the next millennia as well as it has for the one now ending.

In closing I want to say what an honor and delight it has been to work on this Committee and to be associated with such excellent people for the past twenty years.

Dedication

I would like to dedicate this paper to the memory of three founding members who contributed so greatly to our success; Jim Fish, Cliff Burchsted and Paul Estriech

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7. USDOE, CONAGT, "Proposed Appendix to ANSI/ASME N510-1986", 20th Conference, CONF880822, 1989
8. ASME, CONAGT, AG-1, "Code On Nuclear Air and Gas Treatment", 1994
9. ASTM D3803-89 "Standard Test Method for Nuclear-Grade Activated Carbon", 1989, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959
10. EGG-CS-7653, "Final Technical Evaluation Report for the Nuclear Regulatory Commission/Idaho National Engineering Laboratory Activated Carbon Testing Program", April 1987,

APPENDIX A

Attached are a reproduction of the minutes of the meeting that created CONAGT along with our first draft organization chart. My thanks to ASME and Mr. William Miller for permission to reproduce this document.

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SARGENT & LUNDY
ENGINEERS
CHICAGO

Subject:
Notes of Meeting of
ASHE Ad Hoc Task Group
On Organization of the Committee
on Air and Gas Treatment Equipment
Held in New York at United Engineering Center
On February 26, 1976

THOSE PRESENT:

G. Beasley	)	Tennessee Valley Authority
C. Burchsted	)	Oak Ridge National Laboratory
P. Estrieck	)	EBASCO
J. Fish	)	American Air Filter
J. Jacobson	)	Nuclear Consulting Services
A. Silverman	)	United Engineers
H. Smith	)	Duke Power
C. Thompon	)	Bechtel-Gaithersburg
W. Woollacott	)	ASME STAFF
W. Miller	)	Sargent & Lundy

Purpose

This was an organizational meeting for creation of a new ASME committee to oversee preparation of codes for air and gas treatment equipment. The stated meeting objectives were as follows:

1. Review previous scope of ANSI N-45.8.
2. Prepare scope for new committee.
3. Prepare outline of activities.
4. Review potential membership.
5. Develop working organization.

Background

ASME is reorganizing the former ANSI N-45 effort into ASME Committees under the "Accredited Organization Method" for preparing American

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National Standards. One of the parts of this reorganization is to convert the N-45.8 effort* into the ASME Committee on Nuclear Gas Treatment Equipment.

Meeting Report

As a prelude to the meeting, Mr. W. Woollacott explained that ASME now has approved procedures to develop standards that will be recognized by ANSI. The new committee on Air and Gas Treatment Equipment (AGTE) must prepare and submit a scope statement to ANSI for distribution to public and other societies to identify any potential scope infringements. Representatives of ASHRAE, IEEE, ANS and NRC will be invited to join the committee.

The new standards should be written like codes ("shalls" not "shoulds") and be unified into a single book with many chapters, as opposed to "white paper" issue. The addenda issue basis should be used. Only mandatory requirements should be contained in body of the standard with non-mandatory sections referenced as appendicies.

A long discussion ensued on the scope of this endeavor. It was generally agreed that the standard should cover only equipment for nuclear power generating stations. As to what constitutes air and gas treatment equipment, the task group decided to include offgas equipment, post LOCA hydrogen mixing fans and blowers, recombiners, and the full contingent of HVAC equipment. While the primary concern of the Standard should be safety related equipment, the overall objective should be to define and possibly upgrade the quality and reliability of all equipment associated with the power generation objective.

The task group unanimously approved the following scope and title for the committee:

Title: Committee on Air and Gas Treatment Equipment

Scope: TO DEVELOP, REVIEW, MAINTAIN AND COORDINATE CODES AND STANDARDS FOR DESIGN, FABRICATION, INSTALLATION, TESTING, AND INSPECTION OF EQUIPMENT FOR GAS TREATMENT FOR NUCLEAR POWER PLANTS. AS USED HEREIN "GAS TREATMENT" INCLUDES BOTH HVAC AND GAS PROCESSING

* Prepared ANSI 510-1975, Standard for Testing of Nuclear Air Cleaning Systems

ANSI 509-T, Standard for Nuclear Power Plant Air Cleaning Units and Components

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SARGENT & LUNDY
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- a) HVAC - the moving and conditioning of air which is supplied, exhausted, or recirculated into or from enclosed spaces to maintain prescribed ambient conditions. Conditions include pressure, temperature, humidity, and contaminant.
- b) Gas Processing - transport of gas and separation, isolation, and disposal of its constituents by physical, mechanical, chemical, delay, electrical and thermodynamic means.

The task group attempted to develop a list which may not be all inclusive of equipment standards as follows:

Conveying & Transport

Fans
Dampers
Ducts (incl. Hangers & Supports)
Compressors
Blowers
Pumps
Vessels
Pipes
Housings

Processing

Recombiners
Heaters
Coils
Filters
Humidifiers
Moisture Separator
Adsorber
Refrigeration Units

Mr. W. Woollacott explained that tentatively the committee should consist of approximately 30 members. Representatives of utilities, constructors, A/E's, manufacturers, societies, regulatory agencies should be included. No more than 33% of total committee membership may be from any single group. The tentative committee membership was read and commented on. Mr. Woollacott will forward solicitations for committee membership in the near future.

The first committee meeting will be held on April 22, 1976, at ASME Headquarters in New York. Members of task group were asked to forward their ideas on organization of working groups to Mr. Woollacott by March 15, 1976. An executive committee, which performs administrative and staff functions must be elected at the first meeting. Future committee meetings would be held quarterly.

The Ad Hoc Task Group was unanimously disbanded, its function fulfilled.

Side Notes

1. ORNL NSIC-65 will be published and available in May 1976.

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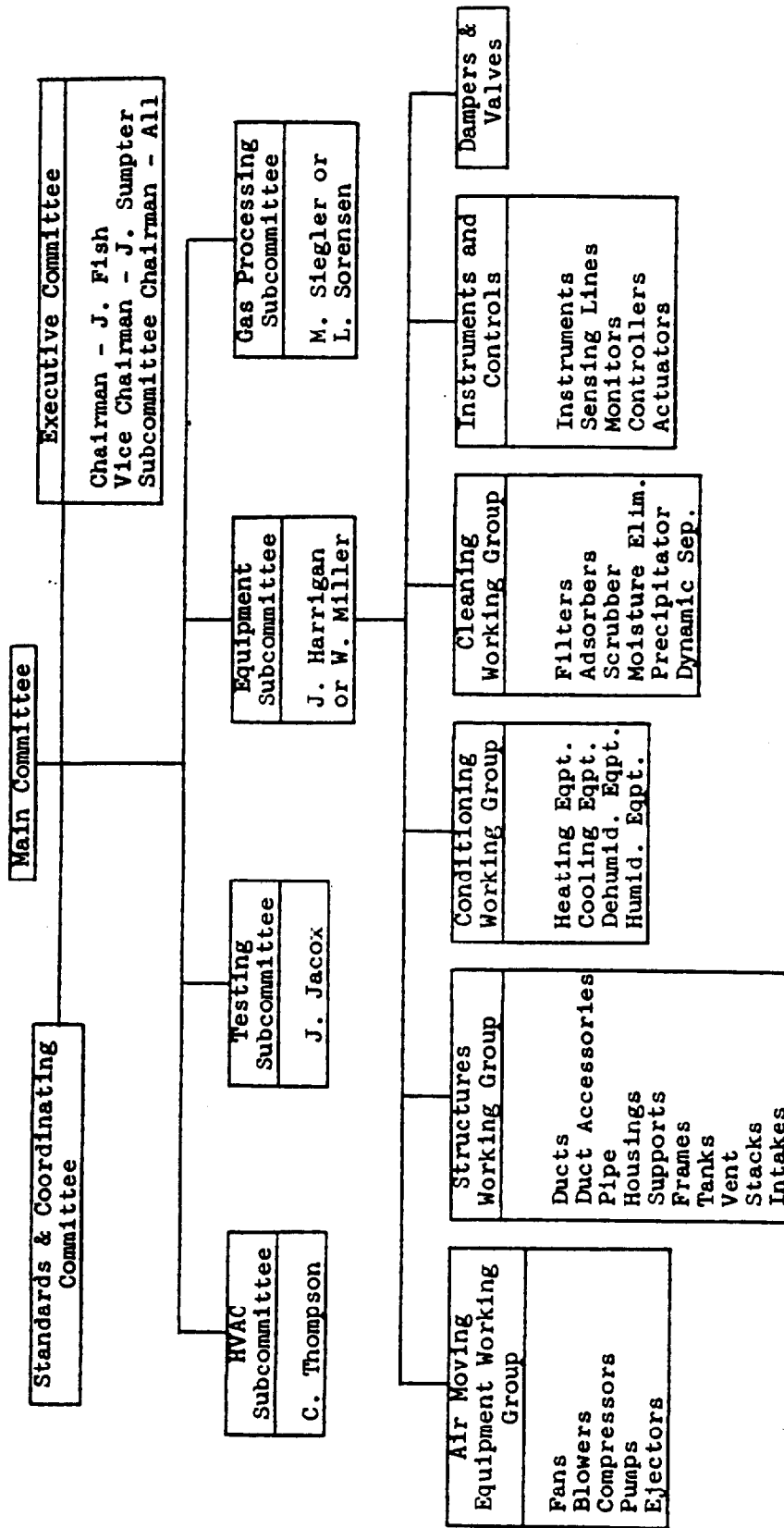
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2. Regulatory Guide 1.52 Rev. 1 will be subject of a closed ACRS meeting on March 2, 1976. Formal issue expected shortly thereafter.
3. ERDA has budgeted \$35,000,000 to initiate a waste handling and disposal management program at Oak Ridge, Tennessee. Initially ten people will be involved to study and acquire 10 sites suitable for disposing of radioactive waste.
4. Mr. C. Zitek (CECo), executive director of ANSI N-18 wanted to have ANSI N-509 balloted. This is being resisted.

W. H. Miller, Jr.

AIR AND GAS TREATMENT COMMITTEE PLAN OF ORGANIZATION*



*Names of Subcommittee Chairmen are ASME nominations and are subject to the respective member's management approval.

PERFORMANCE TESTING OF HEPA FILTERS:
PROGRESS TOWARDS A EUROPEAN STANDARD PROCEDURE

J Dymant (AWE plc, UK)

SUMMARY

Proposals for a future European testing procedure for "High Efficiency Particulate Air Filters (HEPA and ULPA)" are being developed by CEN (Comité Européen de Normalisation). The new standard will be given the status of national standard in participating countries, conflicting national standards being withdrawn.

The standard will comprise 5 parts covering the grouping and classification of HEPA and ULPA filters according to their efficiency, fundamental principles of testing, marking etc (in part 1). Part 2 will cover aerosol production, measurement principles, counting equipment and statistics. Parts 3-5 will cover testing flat sheet media, leak testing of filter elements and the efficiency testing of filter elements respectively.

The efficiency test methods allow the use of either homogeneous monodisperse or polydisperse aerosols for the determination of particulate filtration efficiencies as a function of particle size. The particle size at which maximum penetration occurs is first determined in flat sheet media tests; tests on filter elements (constructed using the same filter medium) may be carried out using either a homogeneous monodisperse aerosol of the size at which maximum penetration occurs (MPPS) or a polydisperse aerosol whose median size is close to the MPPS. Tests with monodisperse aerosols may be conducted using condensation nucleus counting equipment; tests using polydisperse test aerosols require the use of optical sizing particle counters.

When determining the efficiency of filter elements the downstream aerosol concentrations may be determined from air samples obtained using either an overall method (single point sampling after mixing) or a scan method. The scan method also allows "local" efficiency values to be determined.

INTRODUCTION

The standardization body involved is the Comité Européen de Normalisation, (CEN) which has its headquarters in Brussels.

Technical committees of CEN comprise delegations from European national

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standardization bodies(Figure 1) including British Standards Institute (BSI) for the UK, AFNOR (France) and DIN (Germany). Technical committees usually appoint working groups from individual experts nominated by the national bodies. The drafting process consists of a number of stages after production of the initial draft. Separate opportunities are given for changes to be proposed by individual experts, by national standardization bodies and by the general public in all participating countries before the final voting process.

REQUIREMENT FOR NEW STANDARD

Requirements for a future European test standard were initially compared with/against the characteristics of existing standard methods, both the national standards eg BS 3928, AFNOR X44011, DIN 24184 etc, as well as relevant trade association standards such as Eurovent 4/5.

Filtration performance testing requirements continue to advance as the technology of micro miniature electronic devices advances; by and large the nuclear industry filtration efficiency requirements are not subject to the same upward pressure; the availability of the improved performance potential of ULPA filters could in some circumstances be beneficial.

It was concluded that the existing standard methods did not provide an adequate technical basis to meet these requirements. Deficiencies in existing procedures were in the following areas:-

- (a) the need to adopt a generally acceptable continuous classification system for HEPA and ULPA filters.
- (b) the need for a test method capable of covering the whole range of efficiency from 85% to 99.999999%, a range of DF over 10E07.
- (c) the requirement to test at the MPPS (particle size for maximum penetration).
- (d) the need to express test results in terms of particle numbers rather than particulate mass.
- (e) the need to include leakage measurements in the testing arrangements and to relate them to the overall efficiency and classification of the filters.
- (f) the need to include particle size efficiency measurements within the overall procedure.
- (g) the need to establish correlation between results from test-rigs operated by

different organizations.

TECHNICAL BASIS FOR THE NEW TEST PROCEDURES

The technical basis for the new procedures are rooted firmly in existing advanced particle generation and measurement technology. It allows the use of laser optical particle counters (OPC), continuous condensation nuclei counters (CNC), differential mobility particle analysers (DMA) and computer controlled scanning and data processing.

Descriptions of the new procedures have evolved gradually over the last 3 years and have appeared as 5 separate parts; these reflect the fact that the complete standard comprises a number of procedures with options depending the classification of the unit and the purpose for which the test procedure is being carried out.

The requirements to be met and the procedures to be employed are prescriptive but the equipment to be used is not, provided it has the appropriate measurement capabilities, accuracy and consistency.

One main aim of the procedure is to be able to provide sufficient filtration efficiency data on a HEPA or ULPA filter to enable its suitability and adequacy for a particular purpose or purposes to be ascertained. Thus the procedures include a "single-point" efficiency test which may be used as a production control test for filters to be used in gas cleanup applications. Where filters for use in ultraclean-rooms are to be tested the procedures include scanning at specified traverse rate, and particle size sensitivity. For all cases the procedures include a specified method for determining the MPPS (Maximum Penetrating Particle Size) for the filter medium being used at the face velocity used in the filter.

CONTENTS OF THE DOCUMENTATION (denoted prEN 1822)

The documentation has been developed in 5 parts:-

Part 1: Requirements, Testing and Marking.

This includes extensive definitions, establishes groups and classes of HEPA and ULPA filters according to their performance as measured by the procedures in this standard. It sets out testing options available and the steps to be followed according to the filter class and the purpose for which the testing is to be conducted. It also specifies the data to be recorded in test certificates and the information to be marked on the filter itself. It specifies that the test aerosol will be a liquid with a vapour pressure $< 20 \mu\text{Pa}$ at 20°C with an index of refraction between 1.45 and 1.60 at 630 nm.

Part 2: Aerosol Production, Measuring Equipment and Statistics.

The aerosol material is not specified but physical data of DEHS (diethylhexylsebacate), DOP (dioctylphthalate) and paraffin oil (low viscosity) are tabulated. Principles of the methods for producing monodisperse aerosols (Sinclair LaMer and Rapaport & Weinstock) by heterogeneous condensation are outlined. The principle of homogeneous condensation is also described together with the use of a differential mobility analyser as a classifier with the capability of extracting a monodisperse component from a polydisperse aerosol. The use of nebulisers for polydisperse aerosol production is described. The requirements for electrical neutralisation of aerosols is covered. Other necessary parameters for aerosol generators are defined.

Essential performance parameters for measuring instrumentation such as optical particle sizers and counters (OPC), condensation nucleus counters (CNC), differential mobility analysers (DMA), dilution systems and other measuring equipment are defined, explained and quantified.

Part 3: Testing Sheet Filter Media. The main purpose of the procedures in this part of the standards to measure the efficiency of the filter medium as a function of particle size. This enables the MPPS to be determined, and also provides initial guidance on the eventual classification of the filter.

The recommended procedure employs a monodisperse challenge aerosol generated by separation of a monodisperse "cut" from a polydisperse aerosol source using an electrical mobility analyser; CNCs may be used to count the particle streams both upstream and downstream. Alternatively a polydisperse challenge aerosol may be used directly, with OPC(s) to assess the particle content in each size channel, both upstream and downstream.

The procedure requires a minimum of six determinations of efficiency at particle sizes spaced uniformly either side of the MPPS; at least 5 samples of filter medium of diameter not less than 200 mm must be tested.

Part 4: Scan Method for Leak Testing and Efficiency Testing of Filter Elements.

This procedure may be carried out using either monodisperse or polydisperse aerosols; the particle size used must be close to the MPPS as determined by the procedures of part 3. When a monodisperse or quasi-monodisperse aerosol is used a condensation nucleus detector may be used (as an alternative to OPC) for assessing particle concentration.

The standard defines a monodisperse aerosol as having $\sigma_g < 1.15$, a quasi-monodisperse aerosol having $1.15 < \sigma_g < 1.5$, and a polydisperse aerosol as having $\sigma_g > 1.5$. The median size of a monodisperse aerosol should not deviate from the MPPS by more than 10% and that of a polydisperse aerosol by not more

than 50%.

The aerosol sampling probe geometry, velocity of traverse and flowrates for the scanning process are defined; calculation procedures to be followed to determine the presence or otherwise of significant leakage are also defined; these are based on the statistical premise of 95% confidence. Examples of calculated parameters are given for filter classes H13 to U17.

An annex gives a short description of the "oil thread" test which may be used to confirm the absence of leakage in filters of class H12 - H14.

Part 5: Testing the Efficiency of Filter Elements. This part gives requirements for rig testing of HEPA and ULPA filters when scanning is not a requisite, ie it gives an average or overall "single-point" efficiency. As in the case of the scanning test either a monodisperse or polydisperse challenge aerosol may be used in conjunction with CNC(s) or OPC(s) as appropriate. Detailed test-rig requirements are given together with statistical procedures for calculation of results. Examples of calculated parameter values are given for the range of filter classes from H10 - U17.

Cross-checking of Techniques.

Results of "round-robin" tests between European test laboratories using the techniques outlined above have been published by Wepfer¹. Although at the time of the test programme the test equipment assemblies were by no means standardised the comparative performance values obtained had at least as good a degree of correspondence and consistency as has been encountered in the past with other exercises of a similar nature.

Progress Towards Implementation of the New Standard.

CEN Technical committee 195 (TC/195) in 1990 instructed its working group 2 to develop a European standard test procedure for HEPA and ULPA filters. Preliminary work began immediately but was limited to the assessment of existing standards and underwriting the decision to develop a new standard rather than adapt an existing one. An early draft of Part 1 was available in 1993 and parts 2 & 3 appeared shortly afterwards. Parts 1,2 & 3 have now passed through several editing stages and are ready for a formal voting procedure. Parts 4 & 5 are somewhat less advanced. The target date for voting on the complete document is June 1997. Implementation in accordance with the results of the voting process will take place after that time.

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REFERENCES

- (1) Filtration and Separation 1995

FILTER GROUP	FILTER CLASS	MAX. OVERALL PENETRATION(%)	MAX. "LOCAL" PENETRATION(%)
H	10	15	--
H	11	5	--
H	13	0.5	2.5
H	13	0.05	0.25
H	14	0.005	0.025
U	15	0.0005	0.0025
U	16	0.00005	0.00025
U	17	0.000005	0.0001

TABLE 1: CLASSIFICATION OF HEPA AND ULPA FILTERS ACCORDING TO FILTRATION PERFORMANCE: (Penetration values refer to performance against MPPS aerosol)

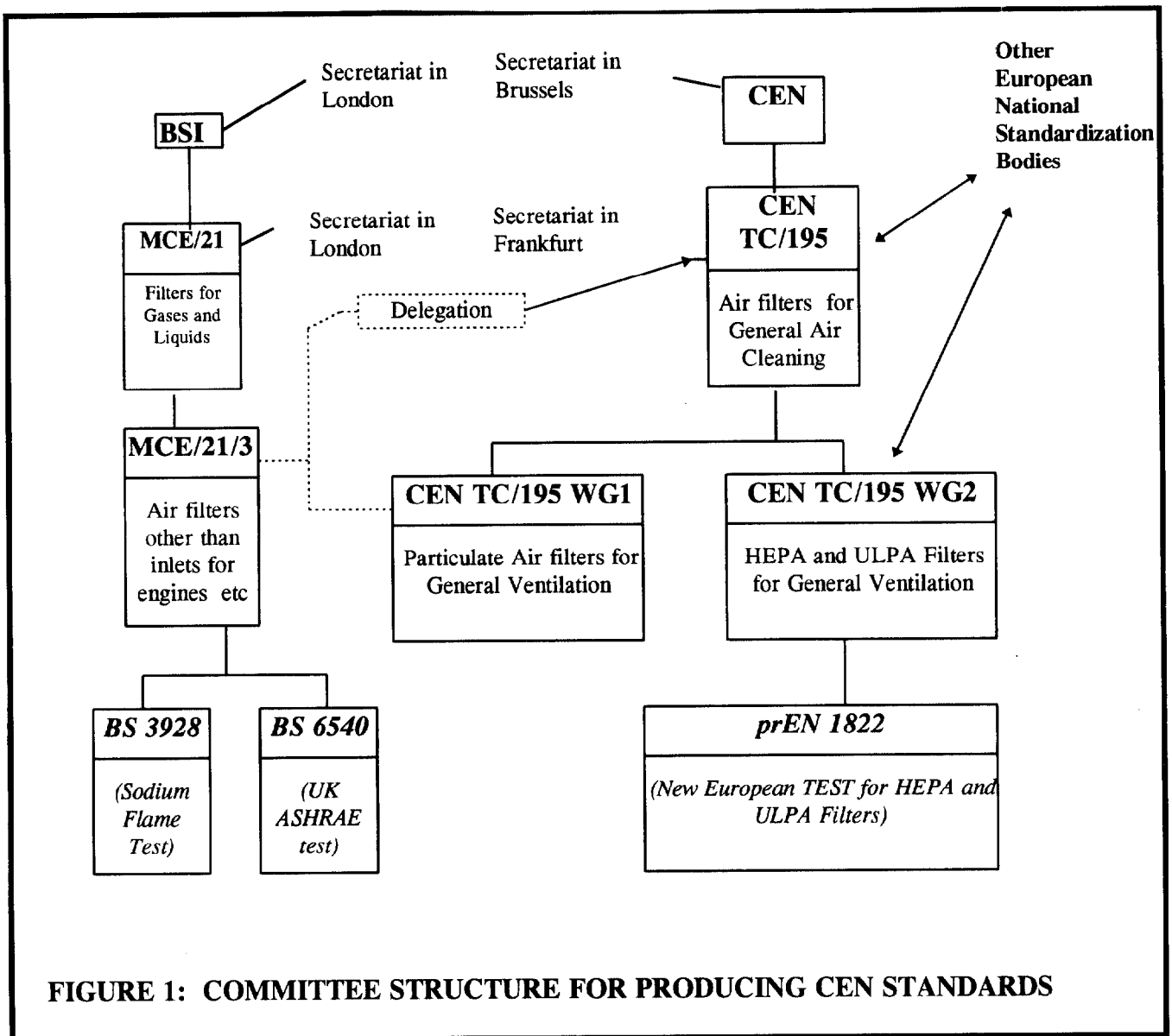


FIGURE 1: COMMITTEE STRUCTURE FOR PRODUCING CEN STANDARDS

DISCUSSION

BERGMAN: I have a question about very high efficiency filter testing. There comes a point where you no longer have a non-destructive test, where, when you try to measure the initial efficiency, you need a sufficient number of particles upstream to get enough particles downstream. About six years ago, in the Proceedings, there was a description of very high efficiency steel filters that had a minimum efficiency of eight or nine times. It took us about half-a-year to verify that the number was correct because the filter would plug up while we were trying to get enough downstream counts. I do not know what others' experience is on these more efficient filters, but you have to be very cautious in terms of filter clogging in order to get the filter efficiency. Just one recommendation, or caution: back-to-back efficiency tests can tell you quickly whether or not you are clogging. People have used pressure drop as a reference to indicate clogging, but we have observed practically zero change in the pressure drop over several orders of magnitude change in the efficiency. That is one caution for measuring very high efficiency filters. Another thing is selection of aerosols, whether you pick a solid or a liquid test aerosol makes a big difference. For example, when you test the same filter with liquid particles you lose at least three orders of magnitude of efficiency relative to filter efficiencies with solid particles. In this area of very high efficiency filters, using particle counting and statistical analysis, plus all of the other factors, it is very difficult.

DYMENT: Efficiency testing procedures, particularly for the highest efficiency filters, include the use of liquid aerosols in preference to solid particles. I think there is an awareness of the problems you mentioned, particularly for the highest efficiency filters.

SCRIPSICK: I was glad to hear what John Dymont presented today, it parallels a number of the activities that are going on in this country. It is good to see that people are coming independently to some of the same general conclusions about assuring performance of filters. I was confused by the distinction between leak testing and efficiency testing. My understanding is that leak testing is done to look at systems where you have particle size independent leaks, that is, $0.1\mu\text{m}$ particles might penetrate as easily as $1.0\mu\text{m}$ particles. If leak testing is referring to that, I think it is a step backward. Or does it just refer to scan testing? One of the later slides linked leak testing to scan testing and it is a qualitative rather than a quantitative test.

DYMENT: The aim is to integrate a scan testing result with an overall efficiency result. One has to take into account the fact that all the very high efficiency filters have a scan test. It is the test we carried out for the U16 and U17 filters and the procedure does specify that the scan test shall be carried out. The aim is to use the results of the scans to produce an overall efficiency result.

SCRIPSICK: So your test is associated with scan testing. In-place testing is sometimes referred to as leak testing, where you test a whole bank.

DYMENT: Yes, I think we have a slight difficulty in terminology here. This work I am discussing does not relate to in-place testing, a separate area.

SCRIPSICK: It is component testing, that is what it is.

DYMENT: We are talking about qualification of filters and filter elements, not installations.

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FRANKLIN: Is the CEN vote of approval of a standard by consensus?

DYMENT: I wish it was possible to give a yes or no answer on that. There is more than one international standardization body. ISO is worldwide, it has the disadvantage of being a voluntary system. If people do not want to adopt it, they do not, whereas when a CEN standard is voted in by a majority vote, everyone is obligated to implement it within a certain period of time, that is, everyone within the umbrella of CEN is obligated to do so.

FRANKLIN: It sounds like it needs to be approved only by a majority, not by everybody.

DYMENT: Approved by a majority, yes. The voting system is not just a straight yes or no, there are many shades of reservation, approval subject to technical change, subject to editorial change, and so on. And not all nations have the same status of voting. The answer is yes, but maybe.

PORCO: How long does the cycle take from inception of a working group to issuance of a standard? Approximately how many years are there in your cycle?

DYMENT: So far, it is about seven years. The first couple of years were taken up determining which way to go. Once having got moving, the process was on the order of five years. I think the official timetable allocation is a shorter period than that. If one was starting on a new standard today, one would not be allocated five years, it would be less.

WILHELM: The test that has been performed until now is the mass test, on the basis that a certain amount of mass on the downstream side compared to the upstream side gives you the decontamination factor. The decontamination factor is very important for health physics calculations. If you now count particles, then we have to know how many electrical charges are on one particle. Therefore, I do not see how this test could work in a way that fits the needs of the nuclear industry. It will fit the needs of the electronic industry because they always ask for particle counts. Clean room technology is related to particle numbers, but the decontamination factor is not.

DYMENT: I agree with you. The main driving force for this particular standard has been the microelectronic industry, they are particularly interested in particle numbers. But as the test is focused on a particular size of particle, the most penetrating particle, it is possible to calculate effective mass penetration. In fact, if one could obtain a strictly monodisperse aerosol, the answer would be the same whether you are interested in particle number, particle surface area, particle mass, it would give the same answer.

HAYES: You indicate that the European countries have been progressing toward a common standard. What do you believe is the feasibility of CEN and the United States reaching a common standard for HEPA filters?

DYMENT: I know that some members of the technical committee belong to international filter corporations which do have affiliations in the United States. I think there is a fair amount of interchange of views and knowledge of what is going on. As I said earlier, I do not know whether standardization is going to be driven entirely by manufacturers. It is also driven by regulation as far as the nuclear industry is concerned. For the microelectronic industry regulation is not a concern, the standard will have the requirements of the customers. I think the two areas are somewhat different, but, in the end, I think if there is a commercial incentive for an internationally-accepted standard, I am certain it will come.

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HAYES: You indicated that you have a copy of that standard with you. Is it a possibility that we could get a copy of that standard and maybe include it in the Proceedings?

DYMENT: I think we would not wish to include it in the Proceedings. As I said, it is a discussion document. I have discussed a summary of each of the five sections in my presentation, but for permission to print the full document I would have to consult with the chairman of the technical committee.

HAYES: If you do not want to include it in Proceedings, perhaps you could exchange it with the ASME Code Section FC committee. We are willing to provide you with a draft of our standards for a draft of yours, maybe we can cooperate a little bit. I have two more questions. I noticed your paper includes all filters. Are you currently using ULPA filters in nuclear facilities?

DYMENT: Not that I am aware of.

HAYES: Your testing requirements use laser particle counters. Are you planning on requiring all production filters to be tested using a laser particle counter? How much time is required for a statistically valid test?

DYMENT: For a very high grade filter such as an ULPA, U16 or U17, you need quite an appreciable length of time. For the H14, normally used in nuclear applications, the time would be much less.

HAYES: Do you know what that time is?

DYMENT: I am afraid I do not.

**THE CASE FOR IMPROVED HEPA-FILTER
MECHANICAL PERFORMANCE STANDARDS REVISITED**

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Abstract

Under benign operating conditions, High Efficiency Particulate Air (HEPA) filter units serve as reliable and relatively economical components in the air cleaning systems of nuclear facilities worldwide. Despite more than four decades of filter-unit evaluation and improvements, however, the material strength characteristics of the glass fiber filter medium continue to ultimately limit filter functional reliability. In worst-case scenarios involving fire suppression, loss-of-coolant accidents (LOCA's), or exposure to shock waves or tornado induced flows, rupture of the filter medium of units meeting current qualification standards cannot be entirely ruled out. Even under so-called normal conditions of operation, instances of filter failure reported in the literature leave open questions of filter-unit reliability.

Though developments of filter units with improved burst strengths have been pursued outside the United States, support for efforts in this country has been comparatively minimal. This despite user requests for filters with greater moisture resistance, for example. Or the fact that conventional filter designs result in not only the least robust component to be found in a nuclear air cleaning system, but also the one most sensitive to the adverse effects of conditions deviating from those of normal operation.

Filter qualification-test specifications of current codes, standards, and regulatory guidelines in the United States are based primarily upon research performed in a 30-year period beginning in the 1950's. They do not seem to reflect the benefits of the more significant developments and understanding of filter failure modes and mechanisms achieved since that time. One overseas design, based on such knowledge, has proven reliability under adverse operating conditions involving combined and serial challenges. Its widespread use, however, has faltered on a lack of consensus in upgrading filter performance standards.

One basis of the approach taken here is the premise that filter-unit mechanical failure needs to be prevented in humid airflow and at pressure drops as large as those which the system blower is capable of generating. To this end, improvements to current US filter codes and standards dealing with qualification testing are suggested. The introduction of a filter-unit factor of safety is viewed as indispensable, for example. Overall, recommendations are based upon more recently established failure modes and mechanisms of filters under adverse conditions of operation.

Though the focus is on guaranteeing the integrity of wet filter units for blower generated flows of humid air, reliability under more adverse operating conditions would also be increased. The realization of high-strength filter units overseas illustrates that the widespread implementation of more reliable filter designs can be driven only by more stringent performance standards. In particular, ones initiated by independent regulatory entities and resulting from close cooperation on the part of both filter users and manufacturers, working together with representatives of national codes and standards organizations.

Introduction

Ventilation and air cleaning systems provide for the health safety and the thermal comfort of personnel in facilities that contain hazardous or toxic radioactive materials. The air cleaning systems (ACS's) also prevent the release of contaminated airborne particulate and gases to the surrounding environment. The required high particle removal efficiencies at relatively low pressure drops are made possible by the use of High Efficiency Particulate Air (HEPA) filter units.

As part of the containment barrier between contaminated zones and the environment, HEPA filters must perform reliably not only during normal facility operations but also under possible abnormal or so-called accident conditions. Filter units may be called on to withstand individual or combined challenges of elevated temperature, pressure drop, or high air humidity: ideally without performance decreases that would result in a loss of containment or confinement. In addition, filters must be free of leaks and nonflammable, as well as resistant to the effects of high radiation fields, rough handling, mildew, and vibrations caused by blowers, airflow, or earthquakes. Some applications also demand a degree of resistance to corrosion, shock waves, or degradation by organic solvents.

To fulfill the wide range of requirements and the high levels of performance expected from contemporary filter units has taken decades of improvements in filter construction materials and their manufacturing processes, particularly in the case of the filter medium. Brittle as well as fragile, and thus easily torn, the filter medium has invariably been, and remains yet, the weakest construction material in filter design. Only slight physical damage to it can cause substantial decreases in filter medium removal efficiency resulting in filter functional failure. It is above all due to media strength characteristics that conventional filter units in the United States retain a susceptibility to damage, not only during manufacture, shipment, and installation, but also in service.

The testing of filter units under conditions intended to simulate those anticipated in nuclear facilities during various types of accidents dates back to the 1950's. After the necessity for requiring nuclear grade filters to be nonflammable became evident, for example, investigations during the mid 1950's led to the widespread use of aluminum separators and glass-fiber filter media ⁽¹⁾. These replaced separators of kraft paper and media of cellulose and asbestos fibers. Wooden frames began then also to be made fire retardant by impregnation with salt solutions.

During the development of filter units resistant to fire and corrosive fumes, pressure drop increases with resultant decreases in flow were first reported for filters exposed to an airflow saturated with water vapor ⁽²⁾. Tearing of the filter medium at low pressure drops was also observed. A search began for measures to counter the detrimental effects of moisture on filter-unit integrity and performance.

Evaluations were initially carried out to determine the effects of fog-entrained air at elevated temperatures and higher than design flows on filter-unit performance. Test conditions simulated those associated with loss-of-coolant accidents in water-cooled power reactors. Later studies dealt with the adverse effects of water sprays proposed to protect filter units from hot combustion gases and high soot-particle concentrations in the event of fires. Results of the investigations of the 1960's and 1970's into the effects of moisture exposure led to the realization of important countermeasures: some intended to prevent the exposure of filter units to high humidity air, others to mitigate any adverse effects of water on filter-unit construction materials in cases of inadvertent exposure. Droplet separators and air heaters upstream of HEPA filter and iodine adsorption filter stages typify exposure prevention countermeasures.

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Those oriented toward damage mitigation during unintentional exposure are, for example, water-repellant filter media and the so-called "resistance to pressure test", specified to help qualify new, clean filter units as nuclear grade ⁽³⁾. The latter is essentially a proof test conducted at an elevated pressure drop under extended exposure to the flow of air laden with fine water droplets. The minimum function of this test should be to simulate the magnitude of the mechanical loadings that the wet, fatigued filter medium and the pack adhesive of aged, dust-loaded filter packs could have to sustain without damage under normal operating conditions.

As illustrated by the examples noted above, test results for a number of adverse operating conditions have found direct applications in the development of the codes and standards that set minimum filter performance characteristics. These, in turn, have led to numerous and significant performance improvements. Such cases exemplify successful application of research results to nuclear safety practice, via performance specifications in codes and standards.

In other instances, published test results remain yet to be exploited in furthering development of codes and standards in the United States. Such information has potential application for additionally improving filter reliability in US nuclear facilities. Relevant to filter mechanical performance in this context are results obtained during the 1970's for pressure pulses simulating tornados ⁽⁴⁾ and explosions ⁽⁵⁾. Understanding gained from tests carried out in the 1980's under hot dynamic conditions ⁽⁶⁾ or high air humidity ⁽⁷⁾, or more recently those into aging effects ⁽⁸⁾ and serial-challenge qualification testing ⁽⁹⁾ also falls into this category. Full implementation of this knowledge could engender relatively extensive revisions of some US filter standards, a potentially arduous if not impossible endeavor if not well planned.

For example, developers of improved filter units overseas made use of more recently established modes and mechanisms of filter failure documented in the open literature for a range of adverse operating conditions ⁽¹⁰⁾. The resulting high-strength filters were then prescribed in purchasing specifications by the particularly safety-conscious filter user responsible for their realization ⁽¹¹⁾. Nevertheless, it has not yet been possible within the country of the filters' origin to build consensus for revisions to national codes and standards that reflect the full potential of the actual improvements achieved. Both the opposition of filter manufacturers and users and the variations in regulatory policies and inspectorates by region have limited widespread implementation of the improved filter units. This illustrates the need for independent national regulatory entities, as well as close cooperation on the part of both filter users and manufacturers, working together with representatives of national codes and standards organizations.

Intended functions of codes and standards pertinent to HEPA filter performance

The intended function of codes and standards dealing with hardware is to provide minimum requirements covering all component-related aspects - from design through maintenance - that will ensure proper operation of the given component throughout its service lifetime. The fundamental performance characteristics of nuclear-grade filter units can be considered to number six. One, dust holding capacity, though much investigated ⁽¹²⁾, is generally not directly safety related and therefore not dealt with in codes and standards. Typically addressed are particle removal efficiency, pressure drop at rated flow, and some measure of minimum burst strength, usually in the form of a proof test ⁽³⁾. Also in this group are nonflammability and resistance to the effects of moisture. For practical reasons, requirements are specified solely for new filter units in a clean state.

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Codes and standards covering performance characteristics of filter-units and their construction materials

For HEPA filter units in the United States alone, there exists a plethora of codes and standards that partially overlap each other⁽¹³⁾. Even for the estimated 5% of the total market for glass fiber filters represented by the nuclear industry⁽¹⁴⁾, duplication of standards has been noted⁽¹³⁾. The code with the most promise of long term viability for nuclear applications, nationally as well as internationally, appears to be ASME AG-1-1994^(3, 15).

In addition, regulatory guidelines exist that address some of the service conditions to which air-cleaning system components could be exposed in systems designed for normal operation⁽¹⁶⁾ and those for atmosphere cleanup following postulated accidents⁽¹⁷⁾ in nuclear power plants. Moreover, users of filter units or owners of facilities typically have their own set of standards⁽¹⁸⁾. These rely heavily upon commonly accepted predecessors to AG-1, AG-1 itself, and military standards for filter media and units, as examples.

Characterization of filter-unit mechanical failure

Filter-unit mechanical failure can be said to take place when the particle removal efficiency irreversibly falls below the minimum value specified for new, nuclear grade units. This can result from physical damage to, or deterioration in, almost any of the components making up a filter unit. Though tears in the filter medium constitute the most likely potential cause, functional failure of the frame, the gasket, or the pack sealant can also cause unacceptable decreases in filtration efficiency.

The prevention of filter mechanical failure, however, does not rule out malfunctions of air cleaning systems and filter units due to other potential causes^(7, 19, 20). In the case of humid airflow, for instance, these include increases in filter flow resistance that restrict airflow such that the distribution of facility subatmospheric pressures is adversely affected. Another example involves decreases in particle removal efficiency involving phenomena other than macroscopic physical damage to the filter medium. These can encompass penetration of the filter medium by liquid water or moisture-induced changes in conditions affecting the filtration properties of the particles or the filter medium.

The above examples indicate that in some cases, maintaining the physical integrity of filters, by itself, will ensure proper functioning of neither the units nor the air cleaning system within which they are located. Nevertheless, ensuring physical integrity under normal operating conditions would constitute an overdue first step toward improving filter unit reliability for all adverse conditions of operation. It would also address not only user requests for filters with greater moisture resistance⁽²¹⁾ that have gone unheeded in this country for more than a decade, but also more general concerns⁽²²⁾.

Mechanical loadings on filter units

The maximum pressure loading that might occur for a HEPA filter operating under normal conditions can be assumed to be the maximum pressure drop that the blower supplying the airflow to the filter can generate. For a nuclear air-cleaning system in a US facility, a pressure drop at the upper end of the range is 3.8 kPa (15 in w.g.)⁽²³⁾, but in other countries the pressure drop can be higher, for example 10 kPa (40 in w.g.)⁽⁷⁾.

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Under adverse operating conditions, pressure loading can be much higher. For example, a maximum pressure drop of 20.7 kPa (83 in w.g.) is specified for a NRC Region I tornado ⁽²⁴⁾. In the contiguous United States, tornado passage over a nuclear facility has a fairly high probability of occurring. For ACS's not equipped with flow limiting devices, expanding steam, combustion heat, or damper-actuated diversion of airstreams could also generate transient flows and pressures above those capable of being produced by the blowers at steady-state conditions. Estimates of filter loadings for such instances can be obtained from computer simulations of air-cleaning system operation during nuclear facility accident conditions. In the case of earthquakes, loadings are specified in terms of ground acceleration ⁽²⁵⁾ rather than pressure drop.

It is more difficult to pin down the loadings on HEPA filters that might occur due to explosions. Pressure impulses caused by shock waves generated by explosions depend upon the location of the explosion relative to the location of the filters ^(5, 26). However, one might specify a range of 3.4 to 34 kPa (13.8 to 138.0 in w.g.), which is equivalent to the specifications for the strength of single-pane window glass and frame walls, respectively, typically stipulated in building structural codes. Actual explosive overpressures can be much higher than these.

Burst Strengths of filter units

Actual burst strengths of HEPA filter units have been reported by numerous investigators for various adverse operating conditions and well summarized by Bergman et al. ⁽²⁷⁾ in the form of threshold values required to damage deep-pleat filters. The burst strength is highly dependent upon design, manufacturer, and filter medium tensile strength, as well as the parameters defining the test conditions. For pressure change rates equivalent to the NRC Region I tornado ⁽²⁴⁾, burst pressures have been found to range from about 6.9 to 20.7 kPa (27.7 to 83.0 in w.g.) ^(5, 26), one baseline datum of the compilation and comparisons made by Bergman et al. According to their summary, five of the six factors addressed can reduce filter burst strength by more than 50%, acting individually.

The burst strength of HEPA filter units challenged by the sixth, shock waves, depends upon impulse per unit area rather than simply upon shock overpressure. However, explosive shock waves have very short duration, so overpressures reported for the shortest shock duration give a good estimate of the explosive overpressure needed to tear the medium of HEPA filters. For units from six manufacturers, the damage overpressure was reported to range from 6.9 to 17.5 kPa (28 to 70 in w.g.) ^(5, 26).

New, clean filter units have been documented to sustain respective peak accelerations above 1 g ⁽²⁸⁾ and above 10 g ⁽²⁹⁾ without notable decreases in filtration efficiencies. Yet, earthquake related damage to aged filter units during service has been reported to occur for estimated peak ground accelerations of less than 0.3 g ⁽²⁵⁾.

Deteriorations in construction materials related to mechanical failure of filter units

Aging of the filter medium during normal operations has been implicated in explaining decreases in tensile strength ⁽³⁰⁾ and filter-unit burst strength ⁽³¹⁾, not to mention losses in water repellency ⁽⁷⁾. During long-term service, the outgassing of volatiles from some prospective pack adhesive/sealants of the elastomeric type has the potential for causing shrinkage and resultant adverse effects on the filter medium or the adhesion of the filter pack to the frame.

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Exposure to humid air, as another example, can degrade the performance characteristics of HEPA filter units through detrimental changes in the properties of the filter construction materials. High air humidity fosters the corrosion of aluminum separators and metal frames. Moisture can also work to reduce the adhesion forces between the filter pack and frame or leach the fire retardant salts from wooden frames. The filter medium is particularly liable to deteriorations in performance. The presence of liquid water in the glass fiber microstructure can effect significant and partially irreversible decreases in tensile strength, the rigidity of the pleats, and the tightness of deep-pleat filter packs. All of these result in decreased filter-unit burst strength.

Decreases in filter medium tensile strength⁽³²⁾ and elongation at rupture (see Table III in Appendix) resulting from elevated temperature involving sublimation or burn-out of the binder can also be very significant.

Modes of mechanical failure (deep-pleat designs)

The modes of mechanical failure for deep-pleat filter designs have been noted to be very similar for greatly differing, adverse conditions⁽⁷⁾. Each of the three frequently documented modes that involve tearing of the filter medium has been observed to result from filter exposure to most, if not all, of the numerous single challenges investigated. These include high air velocities, elevated temperatures, shock waves, and flows of high humidity air; not to mention handling and shipment. The many causes of such similar failures point to locations of inherent weakness or maximum stress in the filter pack.

Mechanisms that contribute to mechanical failure

Many of the mechanisms responsible for filter-unit mechanical failure are also common to failures caused by different adverse conditions. This implies that known failure mechanisms have not been sufficiently well addressed in current filter designs.

A summary of the primary underlying failure mechanisms would include the following. First, the inherent weakness and brittleness of glass fiber filter media lacking reinforcement: typical characteristic values are 1 to 2 orders of magnitude below those of other construction materials as indicated in Fig. 1 and Table I of Appendix. Equally relevant are the additive decreases in filter medium tensile strength and elongation at rupture; due to the effects of pleating, aging, and fatigue in normal service, or exposure to moisture or to elevated temperature. A relative comparison of the respective decreases is given in Fig. 2 and Table II in the Appendix.

Of no less significance is the loosening of conventional filter packs that leads to increased stresses and fatigue in the filter medium, as well as to mechanical interaction between filter medium and separators. Though of secondary nature, the nonuniform distribution of pressure drop induced stresses in the filter medium of deep-pleat designs, nonetheless explains the failure modes and weaknesses of certain deep-pleat geometries and why they should be avoided⁽¹⁰⁾.

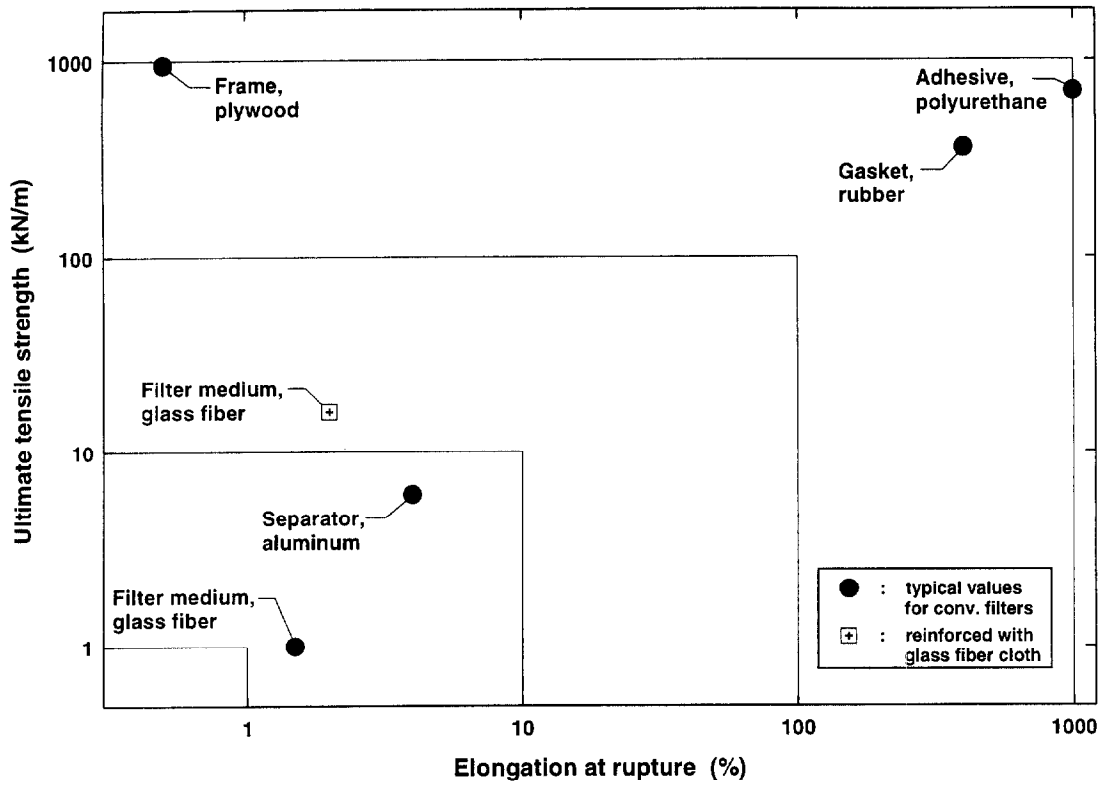


Figure 1: Strength characteristics for the fabrication materials employed in the designs of conventional deep-pleat HEPA filter units.

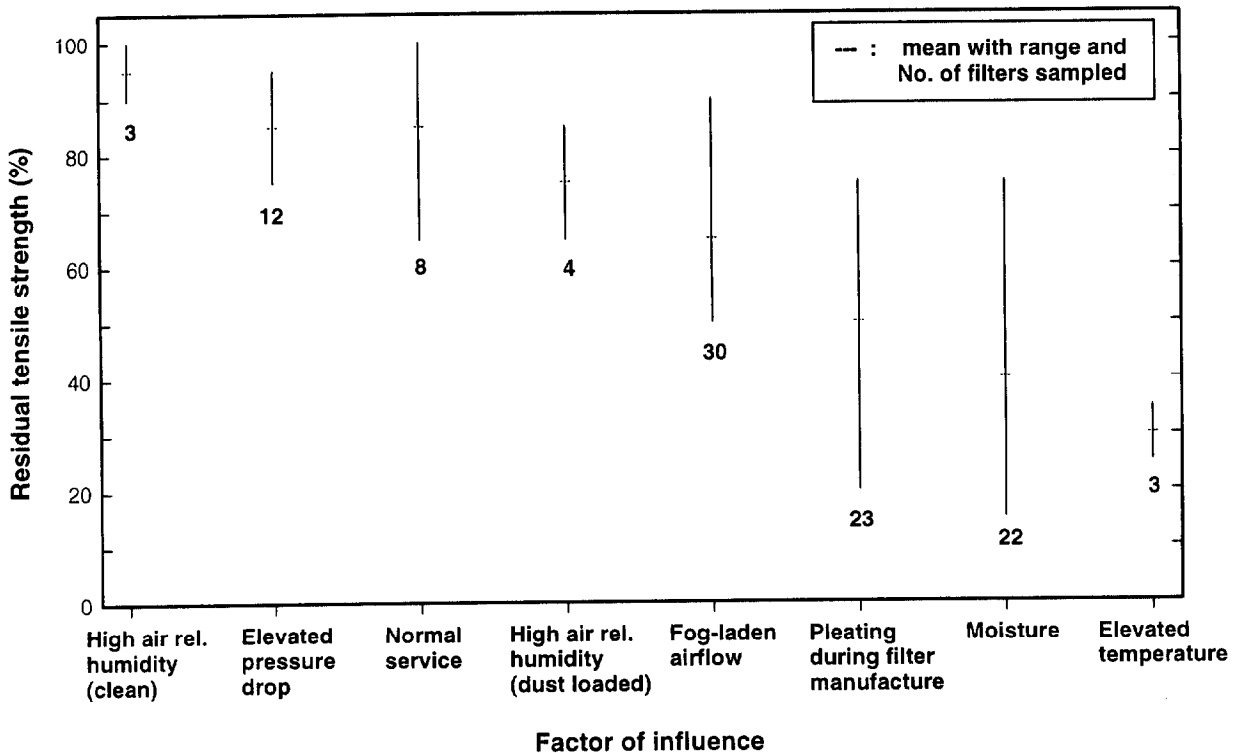


Figure 2: Comparison of the residual ultimate tensile strengths for non-reinforced, conventional HEPA filter media of nuclear grade, resulting from various factors of influence.

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Suggested approaches toward eliminating the risk of filter-unit mechanical failure during normal operations and reducing it during other than normal operations

It is to be expected that glass-fiber filter media will continue to play a dominant role in nuclear applications for the midterm future. Moderate cost, high filtration efficiency, low flow resistance and density, reasonable degree of chemical inertness, fair resistance to radiation, elevated temperature, and fire constitute a set of characteristics that other materials cannot presently match. Similarly, the deep-pleat design with separators has proven itself superior in strength to separatorless and mini-pleat designs under most operating conditions. Hence, it has been assumed that the filter-unit design of the following discussion is one characterized by deep pleats, separators and a glass fiber medium. An additional premise is that the prevention of filter structural failure in humid airflow generated solely by the system blower needs to be absolutely ensured. Though the following recommendations focus on guaranteeing filter-unit reliability during exposure to moisture at pressure drops up to the blower maximum, their implementation would also increase reliability under more adverse operating conditions.

With the shortcomings of current deep-pleat filter-unit designs identified, solutions for addressing them can be proposed. For instance, increasing the initial tensile strength of the filter medium and its residual strength under pertinent adverse conditions should have the highest priority. To minimize mechanical interaction between the filter medium and separators, filter pack tightness and stability need to be ensured, particularly under relevant adverse conditions. The concept of a factor of safety for filter-unit mechanical strength needs to be implemented.

Calculation of a safety factor requires knowledge of two values. One is a measure of minimum filter mechanical strength for a given set of operating conditions as compiled by Bergman et al. ⁽²⁷⁾, for example. The other, a measure of the maximum conceivable mechanical loading under the same conditions, possibly obtained from computer simulations, preferably ones verified experimentally. The ideal safety factor would be based upon values for the most adverse conditions anticipated. In practice, however, the economics of enhancing the strength of this weakest of all air-cleaning system components to the level of other ACS components would be prohibitive for the most adverse conditions. This is primarily due to the need for periodic filter-unit disposal. Only for nondisposable, or reusable components, or those with extremely long service lives could the greatly increased costs be justified.

At a bare minimum the safety factor could then, for instance, more advisably be one based upon the maximum pressure drop of the air-cleaning system blower and a proof strength for filter units in a wet condition. A proof strength that should be demonstrated after extended exposure of filter units to elevated temperature, as a separate part of a multi-step test sequence that comprises a qualification test process for nuclear-grade filter units. This should essentially eliminate the risk of filter-unit mechanical failure during normal operations and reduce it during other than normal operations. One overseas high-strength filter design, for example, has a demonstrated safety factor of 1.5 for new units under extended exposure to fog at design flow, after sustaining 23 h at 120 °C in still air ⁽¹⁰⁾. This is based upon a typical maximum blower pressure drop of 10 kPa and a filter burst strength > 15 kPa when wet ⁽⁷⁾.

The above approaches fall into the category of counter-measures aimed at mitigating the adverse effects of moisture. An additional measure, aimed at preventing moisture exposure in power plant ACS's, would involve specifying droplet separator and air heater performance characteristics in detail. This should be based upon experimentally-verified, combined effectiveness of droplet separators and heaters in protecting aged, dust-loaded filters from condensing steam under the transient temperature and flow conditions that simulate a severe LOCA.

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The importance of experimental verification is emphasized by two sets of preliminary test results reported for aged, dust-loaded filter media. One indicated that increasing temperatures above 20 °C can, for at least one dust type, shift the relative humidity, at which moisture-induced, peak filter pressure drops occur, to values below 70% RH ⁽⁷⁾. In such cases the intended protection offered by heaters in limiting air relative humidity to < 70% could be viewed as ineffectual. A second data set demonstrated proportionally greater increases in pressure drop with decreasing values of constant airflows at lower than design levels ⁽²⁰⁾. Given filter units of sufficiently high burst strength, such increases in pressure drop could become irrelevant with respect to filter mechanical failure. The potential ramifications of decreased airflows and resultant redistribution of air-cleaning system pressure drops would, however, remain to be evaluated.

Selected recommendations for augmenting current US codes and standards

Prerequisite to any implementation of the above suggested approaches in actual practice would be revisions to existing codes, standards, and regulatory guidelines. Based upon known failure modes and mechanisms and the authors' interpretation of them, consideration should be given to adding the following functions to specifications presently lacking them. These relate, for the most part, to typical requirements in current documents considered to be in need of change or augmentation.

Filter medium specifications should

- reflect the large differences (1 to 2 orders of magnitude) between typically low tensile strength values of unreinforced, glass-fiber filter media and those of the other filter construction materials
- adequately reflect the potentially adverse and cumulative effects of pleating, aging, fatigue, elevated temperature, and moisture exposure on filter medium tensile strength
- reflect the commercial availability of filter media reinforced with a scrim or cloth of glass fiber
- require a minimum tensile strength in a folded condition
- require a minimum tensile strength in a wet condition.

Filter-unit specifications should

- require that the allowable continuous, peak operating temperature be indicated on the filter label
- require the same test filter units to sustain as many of the stipulated qualification tests as possible

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- include extended static exposure of filter units to a temperature at the upper limit of the design range of operation; in order to induce artificial aging effects in the form of accelerated off-gassing of volatiles from the filter medium, the adhesive/sealant, the gasket, and the frame
- include a resistance to overpressure test that simulates the magnitude of the mechanical loadings that the wet, fatigued filter medium of aged, dust-loaded filter packs could have to sustain without damage under normal operating conditions: this to be performed after the extended static exposure of filter units to a temperature at the upper limit of the design range of operation
- include stipulations of adhesive/sealant performance, e.g., nonflammability, thermal stability, and resistance to: shrinkage, relaxation, cracking, and moisture effects
- include a resistance to overpressure test that simulates the magnitude of the mechanical loadings that the wet, aged adhesive/sealant of aged, dust-loaded filter packs could have to sustain without damage under normal operating conditions: this to be performed after the extended static exposure of filter units to a temperature at the upper limit of the design range of operation
- include stipulation of a minimum value for a factor of safety: at the very least, one based upon the maximum pressure drop of the air-cleaning system blower and a proof strength of filter units in a wet condition; after extended static exposure of filter units to a temperature at the upper limit of the design range of operation
- include a stipulation for deep-pleat pack tightness in a new condition such as ⁽³³⁾ does
- address the potential loosening of deep-pleat filter packs that can result from exposure to moisture, high air velocities, or elevated temperature.

Droplet separator and air heater specifications should

- stipulate droplet separator and air heater performance characteristics in detail; based upon the experimentally-verified, combined effectiveness of droplet separators and heaters in protecting aged, dust-loaded filters from condensing steam under the transient temperature and flow conditions that simulate a severe LOCA.

Conclusions

Published research results obtained during a period extending from the mid 1950's through the 1970's appear to have been extensively utilized in the development of contemporary codes and standards. The realization of numerous improvements in filter-unit performance and reliability can be traced to these early investigations. However, knowledge gained since then does not appear to have been fully exploited in revisions of codes and standards specifying filter-unit performance. Current specifications in the United States do not reflect more recently gained knowledge of the modes and mechanisms of filter-unit mechanical failure documented in the open literature for a wide range of adverse operating conditions. This information has potential application for further improving filter reliability.

Despite some 30 years of performance advances, conventional HEPA filter units remain not only among the least robust components to be found in a nuclear air cleaning system, but also the most sensitive to the adverse effects of conditions deviating from those of normal operation. In this respect, they constitute the weakest link in a chain of crucial components forming the barriers between contaminated zones and the environment. One reason for this is the inherent fragility of conventional glass fiber filter media. Another is the sensitivity of unreinforced media to cumulative reductions in strength properties caused by pleating, aging, fatigue, elevated temperature, and moisture exposure. A third factor is the loosening of the filter pack that can result from exposure to high air velocities, temperature, and moisture.

Further enhancement of filter reliability will realistically be achieved only by increasing performance specifications in codes and standards to levels that are both technically feasible and economically justified. This process, however, needs to begin at the initiative of regulatory entities, which carry the ultimate responsibility for ensuring public health and safety. Meeting more stringent standards will have to entail cooperation and coordination on the part of both filter users and manufacturers working together with representatives of codes and standards organizations. The final step, optimizing the design and minimizing the cost of filter units that meet upgraded standards, can only be left to manufacturers and the free market.

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Appendix

Table I: Typical ultimate tensile strength and elongation at rupture for the construction materials of nuclear grade HEPA filter units in a new, dry condition at room temperature ⁽⁷⁾.

Filter-unit component (material)	Thickness (mm)	Ultimate tensile strength		Elongation at rupture (%)
		(kN/m ²)	(kN/m)	
Filter medium (conventional glass fiber)	0.5	$2 \cdot 10^3$	1	1.5
Filter medium (glass fiber reinforced with glass fiber cloth)	0.55	$3.2 \cdot 10^4$	16	2.0
Separators (aluminum)	0.035	$1.4 \cdot 10^5$	6	4
Gasket (neoprene foam)	6	$6 \cdot 10^4$	360	400
Adhesive/sealant (solid polyurethane)	5	$1.4 \cdot 10^5$	700	1000
Frame (plywood)	19	$5 \cdot 10^4$	950	0.5

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Table II: The influence of various factors on the residual tensile strength of new¹, glass fiber, HEPA filter media of nuclear grade, in the machine direction at room temperature² ⁽⁷⁾.

Factor of Influence	Residual Tensile Strength (%)		Quantity of Filter Units Sampled
	Average value	Range of values	
Elevated temperature (after 1 h @ 250 °C)	30	25 - 35	3
Moisture (after 1 h soak @ p _{abs} = 5 kPa, specimens wet)	40	15 - 75	22
Pleating during filter-unit manufacture	50	20 - 75	23
Fog-laden airflow (up to burst pressure of filter, specimens dry)	65	50 - 90	30
High air rel. humidity (after 1 h @ 99% RH)			
dust loaded (used)	75	65 - 85	4
clean	95	90 - 100	3
Normal service (after approx. 24 months, used)	85	65 - 100	8
Elevated pressure drop (after 3 s at approx. 20 kPa)	85	75 - 95	12

¹ except where noted with (used).

² except for tests at 250 °C.

Table III: The influence of various factors on the residual elongation at rupture of new¹ glass-fiber, nuclear-grade HEPA filter media in the machine direction at room temperature² (7).

Factor of Influence	Residual Elongation at Rupture (%)		Quantity of Filter Units Sampled
	Average value	Range of values	
Pleating during filter-unit manufacture	40	20 - 60	23
Elevated temperature (after 1 h @ 250° C)	45	35 - 55	3
Elevated pressure drop (after 3 s at approx. 20 kPa)	80	45 - 95	12
Moisture (after 1 h soak @ p _{abs} = 5 kPa, specimens wet)	85	45 - 160	22
High air rel. humidity (after 1 h @ 99% RH)	90	85 - 90	3
clean			
dust loaded (used)	95	90 - 100	4
Fog laden airflow (up to burst pressure of filter, specimens dry)	105	60 - 150	30
Normal service (after approx. 24 months, used)	110	85 - 125	8

¹ except where noted with (used).

² except for tests at 250 °C.

DISCUSSION

BERGMAN: HEPA filters in the US have to pass qualification tests: a heated air test for five minutes at 700°F, an over pressure test for one hour at 10in.w., and a vibration test. Could you share with us some of your thoughts about these specifications and what you might recommend for improved qualification tests?

RICKETTS: I would not at all want to disparage the current qualification tests. Most of them (I can only think of one exception) involve testing different filters during the qualification process for the different challenges. In other words, you do not take the same filter that you put through the heated air test and run it through the resistance to over pressure test, which involves exposing filters to a pressure drop of 10in.w. and to a flow of fine droplets or fog. I think our primary recommendation, to answer your question in as short a time as possible, would be to test the same filter units under as many of these challenges as possible during the qualification process. I hope most of you were there yesterday when Dr. Bergman showed us another horror story with a blowout of filters following a fire and fire suppression measures taken at Rocky Flats in, I believe, 1980. This was a case where the same filters were exposed simultaneously not only to high temperature but also moisture and a high pressure drop caused by the moisture essentially clogging the filter medium. As I recall, there were four stages of filters in the air cleaning system, the first three stages were taken out completely, and the fourth stage was severely damaged. I think this provides an example of why some of these qualification tests might need to be reconsidered.

SCRIPSICK: I agree with this line of logic. I think Bergman and the people at Rocky Flats have done some sequential exposure tests on the same filter. What is needed, and we have to be careful in stating this, is simultaneous exposures. That is what can occur in the field, airflow resistance and heated air. I want to acknowledge that the United States has done its fair share in terms of nuclear air cleaning. Its technology is being used world wide now, so you can't fault the researchers here. I think you were very careful in the beginning of your talk to say that.

RICKETTS: I too think they have made enormous contributions, without which we would not be where we are today.

SCRIPSICK: This country is in a nuclear power reactor lull of a decade or so long. We are now behind the wave in nuclear power research. Although the DOE, as the manager from Hanford indicated, is knocking down our facilities, there is still a need for research. It should have been funded a number of years ago so the country could have gotten the most utility out of the research. Doing it now, I think it is still needed but it will be less useful.

FIRST: Because you did not mention it, I assume you did not get around to testing minipleat filters or separatorless filters. Based on what you already know, what would be your opinion regarding the relative safety of these alternative manufacturing methods? I also wonder about the difference between a six inch deep filter and a twelve inch deep filter. Would the deeper filter be more stable? I think your challenge is well stated, we have to be challenged to look at alternative methods of construction and materials to overcome the deficiencies which you have pointed out. I realize I am asking you for an opinion, but if you are willing to give it, I would appreciate your comments.

RICKETTS: I am willing to answer your first question concerning the minipleat design and the

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separatorless design. Both designs are a very big improvement, or have the potential for being a big improvement, as far as dust holding capacity goes. It is my personal opinion that one of their advantages is not high strength. I think you will find, if you go to the literature, that deep pleat filters with separators do have a higher burst strength under most conditions of operation than the other two designs. I can recall approximately twenty years ago when the work in Germany first began, that prototype minipleat filters were tested and could not match the burst strength of the conventional deep pleat filters even when reinforced. We have stress models available now that tell us that the deeper the pleat, the stronger the filter. Pack depth is in the denominator of the stress term and I believe it is squared, so the larger the depth squared, the lower the stress is for a given pressure drop. I think that very well explains cautions that I recall running across in the literature many years ago from Mr. Burchstead saying please avoid the six inch pack depth because of its susceptibility to catastrophic failure, the whole pack would bulge out at very low pressure drops.

ADAMS: Did you look at the products of several manufacturers or did you restrict your investigation to just one manufacturer? A second question is, are there specific guidelines that you would say need to be changed, possibly by the regulatory agencies?

RICKETTS: Let me answer your second question first. I think you will find a whole list of recommendations in our preprint, more detail than anyone may want to read, but we took the liberty, anyway. Your first question had to do with how many manufacturers. Were you looking for brand names?

ADAMS: I do not know. I know there are several manufacturers of that filter design. Did you find similar findings in all of them, or in just one?

RICKETTS: In general, the results for filters from various manufacturers were similar. Naturally, there was a range that correlated primarily with filter medium tensile strength. Not all manufacturers use the same filter medium. To put this work in a little better context, I presented a summary of knowledge that goes back over the last fifteen or twenty years of testing filters under adverse operating conditions such as tornadoes; conditions that simulate loss of coolant accidents and so on.

PORCO: To build on Dennis Adams' questions, were all the filters you tested built and qualified to MIL-F-51068, to N-509, or to any current standards? Did they go through a QA Station? Do you have a baseline for comparison?

RICKETTS: Most of the results upon which these conclusions are based were for filters from European manufacturers and tested in Europe. To answer your questions specifically, no, they did not go through the qualification process. They were very, very similar in design to American filters. We have tested a few American filters under tornado conditions. Under those conditions the differences between the European brands and the American brands were insignificant.

PORCO: The reason I bring this up is that I know US manufacturers' nuclear grade filters look very similar to commercial grade filters, but their performance and the strength are quite different due to manufacturing methods and materials.

RICKETTS: In Europe there is also a grade of filter referred to as nuclear grade. It also has to be much, much higher quality than run of the mill filters used in non-contaminated applications. Just to go one step further, I think it has to do with the tensile strength of the filter medium. That is in essence what we feel

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needs to be changed.

PORCO: I agree with you. Your slide was very interesting.

SCRIPSICK: One of the things that flies in the face of your premise that the medium is very weak is that we have had filters in place in this country for thirty years in some instances. They are still performing and they pass the in-place test. If the medium is now very weak (and I do not think there is any doubt about that) they have had an awful lot of exposure. This seems to go counter to what you are saying. Could you expound on that?

RICKETTS: I assume that any filter that has been in service for more than five years is probably in a second, third, maybe even a fourth stage in a train. It has not been loaded with much particulate and its pressure drop is probably going to be very close to its new pressure drop. For that reason, it probably hasn't been fatigued to the extent that a filter in the first stage has because first stage filters are changed out much more frequently. That would be my thought.

SCRIPSICK: Are you saying that it is not just long term exposure to low differential pressure or sudden new differential pressure but that the stress really multiplies at higher differential pressures?

RICKETTS: I can tell you it is probably approximately linear, but we do not have firm evidence. We certainly have some strong circumstantial evidence that indicates there is a fatiguing effect at the locations of highest stress in a filter pack and that location is typically at the top of the pleat, close to the adhesive, or at the bottom of the pleat, close to the adhesive.

SCRIPSICK: Would you think it would be proportional to pressure drop times time, the pressure exposure? With a thirty year filter, is there a time component?

RICKETTS: I have no basis to give you an answer on that, I can only speculate and I am not sure that would be useful.

BERGMAN: About eight years ago there was a paper published in which Jim Johnson and several other people from Livermore took third or fourth stage HEPA filters from our plutonium building. These filters were clean, and that is why we used them to assess performance. They ruptured at thirteen inches of water. We took new filters out of the box that had just been sitting at warehouses. We had published in either the last Proceedings or the Proceedings before that these filters that had been sitting in the warehouse had at least one half the strength of a brand new filter. So this is to counter the thought that if you do not have any challenge, these filters are going to be fine, and that is not true. These filters deteriorate from day one and it is unfortunate that Tim Sing from Evanite Fibers isn't here. He informed us that glass fibers themselves begin aging from the minute they are produced and some industries require glass fiber manufacturers to package the fibers in a hermetically sealed bag so they effectively stop this aging process.

OPENING COMMENTS OF SESSION CHAIRMAN

**PANEL SESSION: CHANGES TO ASME
CODE AG-1, SECTION FC, HEPA FILTERS**

This session is on changes to ASME Code AG-1, Section FC, HEPA Filters. The participants are Jack Hayes with the US Nuclear Regulatory Commission, Jim Slawski, with DOE; Bill Rown, with the US Army, Edgewood Research Development and Engineering Center; Ben Franklin with AAF; and Steve Klocke with Flanders Filters. I am Rich Porco with Ellis & Watts. We are going to give each of the panel participants a chance to say a few words starting with Jack Hayes.

PANEL DISCUSSION

HAYES: As an introduction to this panel session I would like to provide some background on the changes which have been made to Section FC, HEPA filters, and the basis for making the changes. In March, 1994, the Department of the Army proposed a review of ASME Code Section AG-1 to determine whether it could be utilized in lieu of two existing military standards, MIL F 51068, for high efficiency particulates filters, and MIL F 51079, dealing with filter media. Based upon the review, the Army determined that the ASME AG-1 code, specifically, Section FC, could be utilized. In April, 1995, the representatives of Code Section FC met with representatives from the Department of the Army and Department of the Navy to discuss incorporating all of these MIL standards into code section FC. Previously MIL F 51079 and 51068 were incorporated into the code by reference only. In addition, we wanted to discuss with the Departments of the Army and Navy the rough handling test, use of challenge agents other than DOP for aerosol testing, and alternative HEPA filter frame materials (because FC was initially limited to nuclear power plant applications and did not incorporate some of the frame materials in the Army standard.) We also wanted to talk about the acceptability of laser spectrometer testing for filter efficiency and, finally, we wanted to discuss seismic and environmental qualification. I might add that these discussions with the Departments of Army and Navy representatives were quite useful in developing the changes which were ultimately made to Section FC. Now, I am going to highlight important changes made to Section FC that I think will be of interest. We have defined an independent filter test laboratory. It is intended to allow any entity not associated with either a filter manufacturer or a supplier, that is capable of performing the laboratory tests called out by code section FC, to do so. This was done because Edgewood, the Department of the Army facility, may not continue to do this type of testing for others. We defined "test aerosol" to allow substances other than DOP.

I will now break the changes we have made to Section FC into two categories: first, those associated with the incorporation of the MIL Standards, and second, the changes that are independent of the MIL Standards. The MIL Standards have designations for framing materials, including one for plywood. Section FC did not previously incorporate filter designs using plywood but we now have direction from the Board of Nuclear Codes and Standards of ASME that we must broaden our code application. Therefore, we can not restrict the code to nuclear power plants applications alone, but must provide code assistance to other entities. That being the case we have added designations from the MIL Standard that will cover plywood. In the MIL Standards separators must have the ability to withstand corrosion. This aspect, as it applies to DOE-type applications, has been added to Section FC. We also added a new filter size to Code Section FC, a 12x12x11.5 in. filter, referred to as "size nine". It has a design flow rate of 250 CFM and a maximum resistance of 1 in.w. Because cancellation of MIL F 51079, is likely, mandatory. Appendix FC-1 now contains parts of F 51079, such as tensile strength. We also added a requirement for a certificate of conformance as a substitute for QPL qualification testing. Another significant change is to allowed qualification testing by an independent laboratory. We have also allowed the use of laser particle counters; previously, Section FC did not. A method for the filter rough handling test was added. We corrected the efficiency acceptance criterion for the heated air test. In the prior version of FC it was incorrectly stated as 0.3%. It has been corrected to 3%, and now it is consistent with the requirements of the MIL Standard. The radiation resistance section was deleted, not because it is no longer required, but because it is handled by another section of the AG-1 code. In early 1996, Section FC was balloted by the Board of Nuclear Codes and Standards of ASME and received three negatives. The comments associated with the three negatives have been resolved and we went back to the Board of Nuclear Codes and Standards to determine if

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they had any further objections to the changes we made to FC. They had until July 5, 1996 to respond. It is my understanding that no objections were received and Section FC can now go to ANSI for concurrence, a thirty day process. After ANSI concurrence, Section FC will be available for use, but an official publication will not be made until the next addendum to the AG-1 Code. However, the revised version can be obtained from ASME or from Rich or me.

PORCO: I thought it would be appropriate to say a few words about ASME AG-1 Code and how section FC fits in. ASME AG-1 is an equipment code covering four general areas. Division I contains general requirements. Division II contains the requirements for ventilation air cleaning and ventilation air conditioning. FC is a subsection of Division II. Division III contains the requirements for process gas treatment. Division IV contains testing procedures. We are mostly concerned with Divisions I and II. Division I, section AA, contains the common sections that apply to section FC. The general requirements were pulled out of the each of the sections covering ventilation air cleaning and ventilation air conditioning equipment. Design criteria is one of the categories that is common. The division and section titles are shown in Table 1.

TABLE 1

DIVISION I	- GENERAL REQUIREMENTS
SECTION AA	- COMMON ARTICLES
DIVISION II	- VENTILATION AIR CLEANING & VENTILATION AIR CONDITIONING
SECTION BA	- FANS AND BLOWERS
SECTION DA	- DAMPERS AND LOUVERS
SECTION SA	- DUCTWORK
SECTION RA	- REFRIGERATION EQUIPMENT
SECTION CA	- CONDITIONING EQUIPMENT
SECTION FA	- MOISTURE SEPARATORS
SECTION FB	- PREFILTERS
SECTION FC	- HEPA FILTERS
SECTION FD	- TYPE II ADSORBER CELLS
SECTION FE	- TYPE III SORBERS
SECTION FF	- ADSORBENT MEDIA
SECTION FG	- FRAMES
SECTION IA	- INSTRUMENTATION AND CONTROL

PROPOSED NEW SECTIONS UNDER PREPARATION

SECTION FH	- TYPE IV SORBERS
SECTION FI	- METAL FILTERS

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As can be seen from Table 1, CONAGT is very busy. Going down the list almost all the components, fans and blowers, dampers and louvers, prefilters, HEPA filters, Type II adsorbers (tray type) Type III adsorbers, filter frames, and racks are complete. There are also sections that are currently being worked on, e.g., Type IV adsorbers (v-type configuration), and Section FI on metal filters. Papers were given at this conference on metal filters; the code is active. The points to be made here are: (1) AG-1 is a code that has general requirements with common articles, therefore, Section FC is not a stand-alone document. (2) The code is interrelated with ASME N-509 and ASME NQA-1, which has the QA requirements. And (3) the code is a living document so we have active writing groups; not only in new areas like metal filters, but also for Section FC. The writing group currently is looking at ways of improving FC and meeting industry requirements. Therefore, suggestions made at this conference will be integrated into the code during the next revision. The writing group is made up of a cross section of industry and includes representatives from DOE, Army, Navy, Nuclear facilities, AE firms, and equipment manufacturers. If anybody is interested in participating in this code work, please give your name to any member of CONAGT. The code provides means for technical inquiries, both questions and concerns on how to apply the document. At the back of the code there is a mandatory appendix that gives instructions on how to submit questions. It is designed to provide a quick response to questions on the code.

HAYES: Prior to starting our panel discussion I would like to emphasize that this revision to section FC was done very quickly to avoid being left without documented guidance after military standards F 51068 and F51079 were voided. We have no more than just finished this revision and here we are looking to make the technical changes which need to be made to section FC. At the CONAGT subcommittee meeting on ventilation air cleaning equipment, we generated a list of about ten individuals who volunteered to participate in the revision. The changes so far just reflect correction of certain errors and recall of the MIL Standards. We would be interested in the participation of everyone willing to work with the committees and writing groups to make the needed changes. I think we are ready to discuss the changes to code section FC.

PORCO: Let me add another point. Some questions have been asked concerning design criteria. The code is different than the military standard in that it not only gives specific requirements for HEPA filters but also requires all the other design criteria to be addressed. For people looking for simple cookbook solutions, let me point out some of the other things the code and the standards require you to do. You need to address design criteria and environmental qualifications, volumetric air flow rate, minimum and maximum design pressures. In other words if you have a high design pressure, or a pressure-time transient, you must address it in addition to the requirements that are in FC. You must address how your filter selection is going to meet all requirements and determine if the filter specified in FC can meet it. When you have high temperature, entrained water droplets, or high relative humidity applications you must address them. Dr. Bergman has mentioned, time and again, the effects of entrained water blinding filters and causing failures. All the environmental conditions must be cited by the specifier, and the designers, or the engineers, must design the system and components to meet all the requirements. Other considerations, among others, are concentration of specific contaminants in the air stream, required decontamination factors, radiation integrated life dose, and structural loading. I repeat, you cannot use the code by just looking at section FC, you must also consider how the housing, fans, dampers, in fact, every component in the system, interacts to assure environmental and seismic qualification. The metal portions usually do not pose much of a problem, but the non-metallics definitely need to be addressed for environmental requirements. The

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point that Dr. Ricketts made about different materials within HEPA filters was very important. There are also different materials within the houses that interact and affect overall system performance. The key is to have components, systems, and the complete air handling and facilities operation meet all the needs of your application.

FRANKLIN: I look forward to changes in the code. I think of the present code as an optimization of the HEPA filter, materials, thicknesses, et cetera, as it was thirty years ago. It does not pay attention to what the HEPA filter industry has become since then. At that earlier time, all HEPA filters were built the same way. Today, the Mil. Spec. or government specification HEPA filter for nuclear power plants are the least efficient filters we have. There are many other applications. I look forward to future modifications for handling new types of filters, and other types of applications. I think it will be a help to the industry. I see that European standards cover all kinds of filters, not just nuclear filters, in their standards.

KLOCKE: I think there is still plenty of room for improvement in section FC, although it is now very usable. Basically, it carries on our historical specifications without losing continuity. There are a couple of things that got dropped in the transition from the Mill Spec to section FC. They included the climatic exposure test which exposed filters to arctic, tropical, and desert conditions. These tests were not of major concern in the past, even when they were included by reference in DOE specifications. Most DOE customers would waive these specific requirements. Presumably they came from defense-related applications, but they are not of major importance or concern anymore. Other qualification tests, rough handling, wet over pressure, heated air, are still only required once in five years by an independent lab. Certainly, that's a long time to go between tests. We are very much a proponent of doing more testing of a lot of these design qualification criteria. However, there is not a lot of guidance for acceptance criteria on them, and it is certainly a point of discussion. We used to have to submit a very small number of filters, typically four filters for each type of test, to Edgewood, four for rough handling, four for the wet overpressure. You had to pass four out of four. Now, when we get into more routine testing of such filters, we obviously can't expect 100% compliance every time. Sooner or later, we will observe a test failure. How do we resolve it? What are the acceptance criteria levels to be used on a more ongoing basis? We need to discuss that and come to agreement through the consensus work of the committees and resolve the issues. Here is another point, we talked about media tensile strength earlier. The specifications still only require tensile strength of new media to be only 2.5 pounds per inch. I know that all good HEPA filter manufacturers of the nuclear grade filter are buying or manufacturing media that has twice or even higher tensile strength, right now. In fact, if you try to make HEPA filters for nuclear application with that low tensile strength, you can expect some failures on a design qualification basis. Therefore, there are many areas for improvement. We have to go back and ask why we adopted the old qualification tests, and then come up with a sound basis for what the new qualifications should be. A lot of work needs to be done by a lot of people in every area, from suppliers to users.

SLAWSKI: When I started working in this area, not long ago, one of the tasks that I picked up was to update the DOE technical standard on specifications for filters. And then I also got involved with CONAGT on the FC committee. We are definitely working our way to transferring to FC. I cannot say that we are ready to do that today. We have just had one more meeting on technical issues in the DOE draft standard, and are trying to get it to the point where it is compatible with FC. We have made some progress. We will do one more review and revision of the draft standard, and compare it, line-by-line, with what is issued as FC, and see where we are. I am just looking at the items discussed here this morning and I see that the DOE standard's reference to a size 3A seems to be the FC size 9,

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and our pressure drop is higher than the value in the FC section, i.e., 1.3 versus 1.0. We have to resolve such issues. I think it is fair to say that except for the size 7 and size 8 there is a pressure drop difference of 1.3 versus the DOE's 1.0. We probably have a lot of tiny technical issues, and probably more in the area of what I would call "pick up errors", as opposed to "intentional errors", in pulling over the important parts of the Mil. Standards that have been dropped. That is what both ASME and DOE have to do, make sure that we haven't dropped things that we should pick up, and that we pick them up correctly.

ROWAN: There is also a correction in your program. As you probably know, we in the army have been custodians of MIL-F-51068 and MIL-F-51079 for over thirty years, plus the corresponding qualified products list (QPL). Of course we are vitally interested in particulate filtration in our mission to protect troops from chemical/biological warfare. However, this particular filter never really fit too well into the army's theme of management. When we develop filters, we start the configuration management system with a requirement from the field, i.e., they tell us they need such a filter for such-and-such a flow and such-and-such conditions, and then we develop the requirements from that. I am not really sure where all the requirements for MIL-F-51068 came from. I don't think anyone is around who was there when it was first developed. Another thing is that we have about six other particulate filters that we have Mil. Specs for. They were all developed in the conventional manner. They are procured with material procurement money and managed under a logistical system of inventory control and things like that. The MIL-F-51068 filters are used primarily in what we call fixed installation filter phases; they are mostly doomsday-type control centers. They are very highly secret. I do not know where they are and I don't even want to know much about them for fear I might disclose some information I am not supposed to. But it has been very difficult getting information as to what they need. We know they buy them, but we could never find out how many they bought. That is one reason we were unable to argue effectively against the canceling of MIL-F-51068. There is definitely a need for it. We know those installations are buying them regularly. We have a representative who serves as a point of contact with them, and we are going to have to use AG-1 for their purposes. There are several things we are going to have to undo in order to accomplish this, or make some kind of compensation for it. One is in MIL-F-51079, the text of which is being appended in AG-1. Things like mildew resistance and environmental resistance were left out. We will probably have to get them reinserted or make up our own document for our customers because they want them. The bottom line is that we are going to take a very strong interest in this in the future, probably much stronger than we did in the past. We know the requirements are going to be driven primarily by nuclear needs, but we have our own needs, and we are going to need this document.

PORCO: Thank you. I think we can now open the floor for general questions.

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DISCUSSION

FRETTHOLD: Will a list of qualified filters be kept, and if so, by whom, or will the certification of conformance be kept by the manufacturer in lieu of the list?

PORCO: I think the issue here is not understanding the current code. The code requires you to have a QA program in accordance with ASME NQA-1. The NQA-1 program requires each manufacturer to have an auditable quality program that is in compliance with eighteen criteria. They include auditing, design, purchasing, and engineering, encompassing every facet of the facility. That program is the key here. In other words, manufacturers will have to have a program that is in compliance. They must be able to defend that program, it must be auditable. The purchaser may choose to audit them to make sure that they are in total compliance in order to have positive proof that all the qualification tests were performed and all the material certifications, *etc.*, are in place. Or they may choose to use a group such as NUPIC, a group of utilities that have come together to make auditing and verification a little cheaper. If you subscribe to their service, they will provide you with all the audit reports. The bottom line answer is no, there won't be a list.

GRAVES: If I am a nuclear utility, for instance, and I need to design, have built, and then commission an air cleaning system, what would you recommend I use, AG-1 or N-509? Are there any regulatory implications if I have to live with Reg. Guide 1.52?

HAYES: Our recommendation would be that you have to incorporate both AG-1 and N-509, because at this time I don't believe AG-1 is complete enough to exclude N-509. Once the code is completed, you will be able to utilize it exclusively, but until that time, it will still be necessary to use AG-1 and N509 as part of your design process. With respect to the acceptability of AG-1 to a regulatory agency such as the NRC, the NRC has already endorsed part of AG-1 in the implementation of improved standard technical specifications. Also, I believe, as part of the review of some of the advanced light water reactor designs such as the AP600 by Westinghouse, the Combustion Engineering System 80, and the advanced BWR from GE. So I think it has been incorporated into the advanced designs and would certainly be acceptable for consideration by any operating facility if they wanted to do a back fit to their existing ventilation systems.

FIRST: Let me get on to another topic, one that I have presented to sessions of this organization in past years. It refers to the efficiency requirements for HEPA filters used at nuclear facilities. The original efficiency requirement was for 99.95%, with 0.3 μm DOP. This requirement originated in the early days of the filter. Then in the 1960s, approximately, the minimum acceptable efficiency was raised to 99.97%. The question is, why was it raised at that time? I can assure you nobody did any research on the subject, it was a very simple matter. All of the manufacturers were sending in filters that were at 99.97% or above. And someone wisely said, why don't we raise the criteria since it is not a problem for the manufacturer? Here we are, thirty years later, and what we find in practice is that the filters that are sold for nuclear applications have minimum efficiencies in excess of 99.99%. My request to the committee is that they take this to heart, and that the revisions to this HEPA filter section recognize the fact that we need to raise our sights. Inasmuch as the filters already come through that way, anyway, is it important? I think the answer is, yes, it is, because we have people who are critical of the nuclear program who will be likely to rub our noses in the fact that we are not using standards that represent the best that the industry can produce. I think it is very important that

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we recognize advances in technology and that we make this change in the definition of the HEPA filter for use in nuclear applications.

PORCO: Very good comment. I think we have a few panel members that want to respond as well as a few people in the audience.

KLOCKE: First, I want to point out where these higher efficiencies are rooted. In this industry, contrary to a lot of other ones, we have both a media specification and a finished filter specification. MIL-F-51079 very clearly points out that the minimum efficiency for the filter medium must be 99.97% for 0.3 μ m particles at a velocity of about 10.5 fpm. It has been that way for many, many years and unchanged since the original specification. Most filters, on the other hand, are designed with a maximum media velocity of only about 5 fpm. As theory predicts, by reducing the flow rate, efficiency improves. So, when we start with media that perform well at twice the velocity used in the filter, we get the natural benefit of increased efficiency when we operate them at something less than 5 fpm. These days, most designs have enough filter area that the velocity can be significantly less than even 5 fpm. Also, media manufacturing technology has certainly progressed well beyond the basic minimum efficiency of 99.97%. We have the capability, as we saw on slides in earlier presentations, to make filter media that are two, three, four orders of magnitude more efficient than basic HEPA filter media. Obviously, pressure drop increases go along with it. There is always a cost/benefit issue here that needs to be addressed when considering choices of higher efficiency filters. Another thing we have talked about, but breezed over here at the session today, is that in some cases systems are designed with a number of filter banks in series, and penetration is multiplicative. Therefore, when we have a maximum of 0.01% penetration through the first bank, we can multiply that times the second bank and the third and the fourth. By the time air passes through the third or fourth bank, the overall efficiency of the system may be seven or eight nines. This is very difficult to verify in the field, for certain, but that is, in effect, what is happening. When dealing with the public, this certainly needs to be brought to light. Even though there may be higher efficiency filters available, systems may be designed that provide higher efficiency by using basic HEPA filter construction.

FIRST: I would like to offer a couple of items of rebuttal to your presentation. The first one is that the user is concerned with the performance of the fabricated filter, not with the paper. The paper is the manufacturer's concern, not the user's concern. No matter how efficient the paper may be, if the filter is not put together as it should be, it is going to leak. I think it is important, in addition to having good paper, to have good construction, and this is why I made the proposal that I did. That is item number one. The second is this matter of efficiency of filters in series. When you have a monodisperse aerosol, such as 0.3 μ m monodisperse DOP, each identical filter in the series can be depended upon to have equal efficiency, but when dealing with a polydisperse aerosol, there is differential efficiency by particle size. The effect of multiple filters in series is not the same efficiency with each stage, but a lesser efficiency for each stage because you are taking out the more easily filtered particles in the first stages and are left with the more difficultly filterable particles for the later stages. Therefore, equal efficiency for each stage in series is not quite correct.

FRANKLIN: We purchase our media. We are getting to the point where our supplier is trying to make better and better media for us, and we are getting more efficient media. We could probably convert without any change in anything to a minimum 99.99% HEPA filter, except that the pressure drop starts to rise, as Mr. Klocke advised. The pressure drop rises, and then there will be some rejects, either in our factory or by DOE, because the filters would exceed 1.0 in.w Therefore, there is a compromise that has to be made.

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PORCO: In the same train of thought, we are talking about filters and we are keyed in on efficiency. Remember, for nuclear applications that is not the only design criterion. Filters are available to 99.999999% efficiency or higher, but do they meet the other design criteria? No. Right now, as far as I know, the only media that will meet all of the requirements, not just efficiency, but all of the requirements of the codes and standards, are those conforming to Section FC and/or Mil. Spec. F-51069. Is there anything out there that is more efficient and still meets all the design criteria, including strength?

FRANKLIN: I had an informal discussion with DOE about this and was advised that at present the measurements of what is leaving the facilities are very, very satisfactory using the present filters. Therefore, there is no administrative pressure to change the efficiency of the filter at this time. It may be advisable from a public awareness standpoint to say that the manufacturers have a standard of 99.97% and yet, they are meeting 99.99%. They always exceed the standard. That may be better from the public standpoint.

FIRST: The point I was trying to make was that the filters that pass through the filter test stations do meet all the requirements and do have efficiency in excess of 99.97%. So it is not a question of, will they meet it? They do, in fact, meet it. The other factor is that the filter manufacturers are selecting their best filters to go to the filter test stations. There is no question about it. Nevertheless, there are users who need less strict compliance to a very rigorous standard and, obviously, filters are not being discarded. There are other applications for them. So I do not think there is a real barrier in terms of availability, or even of cost. They have already met that proposed standard.

KLOCKE: I concur with both your statement and Ben's. We are building according to the current specifications and building good filters. We can essentially meet a 99.99% criterion with no impact at all today. Essentially all the filters are meeting the proposed requirement.

FIRST: The fact that DOE is not asking for a higher standard is not the only consideration. Sometimes we have to push DOE a little bit and sometimes we have to push NRC a little bit, to help them break through the red tape of their own organizations with which they struggle all the time.

SLAWSKI: We do argue internally about these things and one argument I heard about two weeks ago, from a person not an industrial hygienist, was that the respirable size of particles is larger than the size that is getting through. Therefore, we don't care about them. I am not sure I would put it that way, because it is a public issue. I do want to give the idea consideration within the department as well as with the manufacturers. If we are already doing it why not recognize it and take credit for it? It will not hurt us in any way.

WEIDLER: My question falls on what you have just said. What is more basic to me than the efficiency of the filter is what size particles we are concerned about dealing with. We are selecting 0.3 μm but is there a smaller particle that we need to deal with to have good efficiency? What is the basis of the 0.3 μm ?

SLAWSKI: I do not know the history, Mel First or Werner Bergman may know. I know Werner Bergman has repeatedly stated to me that the most penetrating particle is smaller than 0.3 μm . Depending on who you are listening to there is a range roughly between 0.15 to about 0.18 μm .

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FIRST: Yes, $0.3\mu\text{m}$ is historic. When Irving Langmuir was asked to advise the army on the size of the aerosol to use to test their gas mask filters, he did the same analysis that Werner Bergman showed yesterday with his computerized program and he advised the army that $0.3\mu\text{m}$ was the minimum filterable size. He included impaction and diffusion, but did not include interception. Incidentally, interception was an advance that was made by Wendell Anderson and his colleagues at the Naval Research Lab at a somewhat later date. Please keep in mind that the filters we have today are quite different than the filters that were manufactured in 1943, or thereabouts. The fact that today's filters have a different minimum filterable size is not at all surprising. More basically, you might ask, what is the significance of the minimum filterable size in terms of what we are looking for in a filter? We have no idea what the aerosol is going to be that the filter will encounter. We can not say precisely what we will need in that regard until an accident happens or some other event occurs that gives us a real life situation. Nevertheless, any rigorous test of the kind we are talking about, even though it may not use the minimum filterable particle size, assures us that we have a high quality product. The test gives us a "figure of merit" even when it does not give us a precise efficiency number for what the filter will do in normal service.

WEBER: I would like to focus on some comments that Steve Klocke and Ben Franklin made by combining them. The issue is the clean pressure drop of a filter. This reflects some comments that Dr. Bergman made yesterday. Clean pressure drop is limited in most cases to 1.0 in.w. I think that number is held too affectionately because face velocity is by and large the big parameter with respect to dirt loading and I think the intent behind 1.0 in.w. is to assure the maximum useable life of a filter that will be disposed of in the end. Consider also the physical limitations of the filter, whatever they may be. To me, the important point is, what is the dirt capacity of the filter? For a given filter medium, that is mostly a function of accessible surface area. One could conceive of a fiber filter, or a metal filter, which has a low face velocity, but a somewhat higher pressure drop, and lasts longer. When Dr. Bergman said that a filter made of metal fibers of $1\mu\text{m}$ would fail, I think what he meant to say was that it would not meet the 1 in. w. pressure drop requirement. That is true. In a prior paper by Dr. Bergman, he said that the metal medium had twice the unit pressure drop of comparable efficiency glass media. I think the state of the art has improved considerably since that time. The upshot is, if you split the difference between 1.0 in.w. and twice that much, you may be getting enough additional area that the filter will last longer before it reaches the fan's limit. In the case of metal media, you would be cleaning the filter. My point is a generic one, I think that the 1 in.w. is held too affectionately and that some more consideration should be given to accessible filter area since plugging of a HEPA filter has been shown in these conferences to be principally a surface phenomenon. If that is agreed to, then there could be some other test which could be used to validate the dirt capacity of the filter, such as the ASHRAE 52 test.

FRANKLIN: As a filter manufacturer, we try to meet what the industry and our clients require. This change in the FC code allows 1.3 in.w. for a 1,500 CFM, 24 in. by 24 in. separator filter. We have had no problem with building higher pressure drop filters. It depends on the user's fans, system, et cetera.

ROWAN: We get into arguments sometimes on setting requirements. The general argument I hear against setting requirements is that, when you do not really have to meet them, you lose flexibility in design. For instance, later on something may come up that means you have to have higher temperature resistance, or something like that, as a first priority, but once a specific penetration requirement gets into the code it is pretty hard to get around it. Quite often, you can meet other requirements by relaxing the pressure drop requirement. It is one of the disadvantages of rigid

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requirements. We have seen cases where they set requirements way, way too high for certain items simply because they could meet it but then they run into trouble later.

PORCO: That is a good point. Those of you who are close to the working groups in the CONAGT committee know that there is a conscious effort to move towards performance-based standards and code sections rather than equipment-based standards. In the future, I hope you will start to see more flexibility because of that. This question was from Laurie Todd, Farr Company. What is the quantity of filters required for testing? FC reads eleven, it is in table FC 5100-1. Are all eleven required?

HAYES: Yes, all eleven are required.

PORCO: The next question is also from Laurie Todd. Since the QPL is technically obsolete and a certificate of conformance (C of C) is required per AG-1, section FC, will all manufacturers have to submit filters for test to obtain C of Cs now? In other words, if the QPL is gone, doesn't the C of C time frame of five years begin now?

PORCO: The answer relates back to the QA issue. The code requires adherence. If the individual manufacturer presents proof of compliance, and it is acceptable within their QA program, and auditable, then it would be acceptable. If they have previous tests that are acceptable, *ie.*, they have positive proof, all of the necessary calibrations, necessary certifications, etc. in a format required by NQA-1, then I would say from that point on, the data are valid through the five year period and should be acceptable.

FIRST: We heard John Dymant speak about the British and the European standards and that they do their testing somewhat differently than we do. There is no indication, nevertheless, that the quality and performance of their filters is any different than ours. I believe they are quite the same. If we try to prove comparability, as we have in the past, by spending uncountable dollars trying to reconcile the various tests that use different particle sizes, different particle size distributions, different particle shapes, what we find is that there is not a convertible number that we can use with reliability. Rather than getting into that quest again, I would suggest to the committee to open the code and make it more acceptable from the standpoint of performance rather than hardware; so that there can be alternatives. In other words, when filters meet the European standard or the British standard, or any other standard that we recognize as being comparable to ours, we would accept that test as comparable performance. That would make things a lot better for manufacturers who want to sell from country to country. They could simply say, whichever one of these valid standards or codes that you have to conform to, they are all the same.

PORCO: That is an excellent point. The ASME is moving towards globalization. I think the leader in global standards is the QA Standard ISO 9000. For performance standards, I am sure we are somewhat restricted within the ASME code. Ray, would you like to comment on how easy it would be to do it?

WEIDLER: I don't know how you would recognize that concept through ASME. To me, this is a purchasing issue. If you could have a truly international standard, *i.e.*, twelve, fifteen countries could agree on one standard and have it be governed by one body, then we probably could do it. But we can't say we are going to do it through ASME; it would be desirable but difficult because we have not done that at this point.

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FRANKLIN: I have a question for Mr. Slawski. We have a QPL on a filter with exterior fire retardant plywood, as required. If we wanted to switch to marine fire retardant plywood, would we have to get a new QPL, or would DOE accept a proposal for a QPL filter revised to use marine plywood?

SLAWSKI: I don't know the answer to that. I think I would have to discuss it with the manufacturers, people like Rich Porco, and people from Aberdeen. Having said that, I will now say that, intuitively, it does not sound like that is a degradation. But I think you would still want some agreement among more than one party because it would affect other manufacturers.

DERDERIAN: A lot of the fire protection specifications within the code have been placed there in past years by the fire protection community to lessen the probability of fires. Basically, they are intended to reduce combustibility, or reduce the level of susceptibility to fire. Some of the provisions are beginning to change in the code. I am wondering if prescriptiveness is going to become the design basis. Is it going to be related to a design basis, as you seem to be indicating, or is it some other situation?

PORCO: I am not sure we are changing the requirement. In FC, there are two very tough requirements; UL 586, for the filter, and a heated air test. You cannot pass the heated air test if you add additional volatiles. I am no longer in filter manufacturing, but one of the toughest things for filter manufacturers to do is to manufacture a very rugged filter and still limit the amount of volatiles in the binder and adhesive used in the filter. What I am saying about performance-based requirements is that, in addition, you have application specific requirements and you must add them to the requirements of FC.

DERDERIAN: Is that specifically stated within the code, or is it something that is implied?

PORCO: That is something I went through this morning, it is stated in Section I, but I am not sure it is as clear as it should be. I think that is the reason why ISNATT, for instance, is looking at design guides to help the user apply the codes and standards.

FRETTHOLD: To expand on Laurie Todd's question, you need to define the number of filters that are required for each of the QPL tests. It is a bit vague right now. It is something we need to work on in the committee to permit people to qualify their filters.

HAYES: I agree. I think the concern is the call for eleven filters of each size. Is that the issue? That is something we will take under advisement with the working group.

FRETTHOLD: The thought was to get it into the record of the meeting, that would serve for people who want to qualify filters.

PORCO: Since this is a living code, the way to find problems and improve the document is through implementation and use. My experience with AG-1 is that it is being applied in the far east, in Korea and in China. All of a sudden, the things we put in the codes and thought were very clear are being read by Asians. They take a very literal interpretation of the code. So it is important that we make sure that all requirements in the codes are very clear and are not subject to different interpretations. I think that is a very difficult task for those working on the codes. We welcome all suggestions, recommendations, and constructive criticism. We will work on all problems to make sure

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that they do meet the needs of industry. If there are no other questions, I will ask Jack Hayes to summarize.

HAYES: As the subgroup chairman for section FC, I would like once again to emphasize to all those present that, it is our intention to upgrade the code section and that we have no hidden agenda. It is not our intention to perpetuate the existing designs. If you have contributions you can make in terms of where we should be going, I encourage you to give your name to me, to Ray Weidler, or to Rich Porco. We solicit your participation. We need your participation. Based upon your participation, this will be either a good or a bad code section. In summary for this morning, we heard first from Ray Weidler who discussed the first twenty years of the ASME committee on nuclear air and gas treatment, as prepared by one of the founding members, Jack Jacox. We also had a discussion of the progression of the European standard for the HEPA filter. It is under development and will be completed in June, 1997. There were additional discussions on HEPA filters from the US perspective. The weaknesses associated with particular designs were cited and where we should be going, both with respect to the design and with respect to the standards, was presented by Dr. Ricketts. Finally, we had a panel discussion on revisions to code Section FC of the AG-1 code. Issues raised during this panel discussion included the frequency of testing, whether it should be more frequent, the acceptance of failures of certain of the qualifying filters, and the need, or the lack of need, to have 100% of units passing. We also discussed whether there is a need to improve the acceptance criteria for penetration by moving up to 99.99% from the 99.97% required by the present standard. The comment was tempered by the fact that raising qualification standards may close off a particular design to some needed applications.

CONFERENCE CHAIRMAN'S SUMMARY AND CONCLUDING REMARKS

Some of the things that came out of this Conference are that we need to look more and more at performance based codes and standards and get away, as much as we can, from the hardware type. We also need to look at risk based requirements, a still more difficult step ahead for us. In other words, all situations are not the same, we have to look very critically at the requirements to determine the best possible way to handle each of the situations. We heard a great deal about how filters might be modified, and why they should be modified. The work that Werner Bergman showed us yesterday with computerized fluid-dynamic simulations, whereby we can follow one particle at a time as it goes through the maze of a filter is an indication of what the future holds. This is where we are going, but we have to keep in mind that we should always endeavor to verify the results of these very powerful tools to make sure that we still have our feet on the ground and know precisely what we are doing. We had a lot of input on HVAC, and I think that's a good thing because air and gas cleaning is basically inseparable from the subject of HVAC in general, they do go together very well. We had a session on waste management and this, again, is a wave of the future. We have to become more and more involved in this; not because we want to guide these operations but because we have to look closely at the operations in order to design the air cleaning and HVAC systems that will be necessary to carry out the decommissioning, remediation, and the restoration without endangering people, the environment, and all the other things that we stand for in this activity that we are engaged in.

I think it has been a very successful conference. I do want to thank all of you who have participated, particularly those who participated by presenting papers and those who made commentaries at the conclusion of presentations. As you know from past conferences, some of the most valuable parts of the Proceedings are the discussions which follow the presentation of papers and panel sections. I have one last thing to do before concluding this conference and that is to ask where would you like to have the next conference, in 1998? We try to determine where the majority of people would like to go, and try to make such arrangements. We meet in July or early August, before schools start so families can come together. I will make inquiries at the locations suggested and will consult with the program committee on a final decision. It has been a great pleasure to meet you all again, and I thank you all for coming and contributing.

Note: Minneapolis has been selected for the site of the 25th DOE/NRC Nuclear Air Cleaning and Treatment Conference, the meeting dates are August 3-6, 1998 at the Minneapolis Marriott City Center Hotel.

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