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PRELIMINARY STUDIES TO DETERMINE THE SHELF LIFE OF HEPA FILTERS

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Abstract

We have completed a preliminary study using filter media tests and filter qualification tests to investigate the effect of shelf-life on HEPA filter performance. Our media studies showed that the tensile strength decreased with age, but the data were not sufficient to establish a shelf-life. Thermogravimetric analyses demonstrated that one manufacturer had media with low tensile strength due to insufficient binder. The filter qualification tests (heated air and overpressure) conducted on different aged filters showed that filter age is not the primary factor affecting filter performance; materials and the construction design have a greater effect. An unexpected finding of our study was that sub-standard HEPA filters have been installed in DOE facilities despite existing regulations and filter qualification tests. We found that the filter with low tensile strength failed the overpressure test. The same filter had passed the heated air test, but left the filter so structurally weak, it was prone to blow-out. We recommend that DOE initiate a filter qualification program to prevent this occurrence.

I. Introduction

Although it is a widely held belief that HEPA filters degrade with age, there is little technical information on which to establish a shelf life. The components of a HEPA filter such as the organic

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binder that holds the glass fibers together in a sheet, the organic sealant that glues the filter pack into the frame and forms a seal, the organic gaskets, and even the glass fibers themselves are subject to ageing. An informal statement (1) made more than two decades ago that glass fibers, used in medium manufacture, start to age and weaken at the moment it emerges from the platinum orifice of the melting pot from which it is extruded. Further private information from a significant manufacturer of continuous - strand glass fiber, employed as the reinforcing agent in fiberglass and plastic lay-ups, indicates that his product is placed in a conditioned storage space after manufacture to inhibit loss of strength.

Previous studies on the related in-service ageing have shown significant reductions in filter strength (2,3). Johnson et al (2) studied the effect of age on the structural integrity of HEPA filters. They conducted simulated tornado pulse and shock overpressure tests on HEPA filters that were in service for 13-14 years and found no loss in efficiency, but a significant decrease in filter strength. The HEPA media pack was blown out of the filter housing at a differential pressure as low as 13 inches of water. The HEPA filters used glass fiber media that was folded in a deep pleat configuration with asbestos separators and glued into the plywood frame with a urethane foam sealant. Tests on the filter media showed it was weak and brittle; 42% of the samples failed the tensile strength; and 100% of the samples failed the water repellent top test and 57% the water repellent bottom test. The media was so brittle that it was not possible to test the tensile strength across the bends.

Robinson et al (3) examined filters with a service life of up to ten years and observed significant reductions in the paper strength and severe corrosion of aluminum separators. They found that the corroded aluminum separators formed a strong bond to the HEPA paper and would therefore have an increased tendency to tear the filter media when subjected to pressure stresses. They also found the aged HEPA media had lost its water repellency.

These previous studies imply that ageing and weakening continue even after the fiber has been made into medium and the medium fabricated into a filter. Although the previous studies were conducted on in-service ageing, and not shelf-life ageing, they suggest the type of effects one can expect for shelf-life ageing. The

because the filters were second-stage filters that were effectively only exposed to clean air and were housed inside a building characterized by moderate temperature and humidity conditions.

II. Experimental Plan

The experimental plan that we selected for this study was to first accumulate unused HEPA filters that had been stored for various years in warehouses. We wanted a minimum of four filters from the same manufacturer for each filter age; one filter would be cut open and provide samples of filter media and other components, while the remaining three filters would be tested separately for resistance to overpressure, heated air and rough handling. After we accumulated the available filters, we would first conduct tests on the filter media to identify candidate parameters that show a relation to filter age. Following the media tests we would conduct the overpressure, heated air and rough handling tests on those filters for which a trend is established between a media parameter and the filter age. The experiments conducted in this study were limited in both scope and depth to keep the costs within the available budget. The study should therefore be viewed as a preliminary effort for a more in-depth investigation to follow.

III. Test Results

We were able to locate a number of size 5 (2 x 2 x 1 ft.) HEPA filters that had been stored at the Rocky Flats Plant (RFP) and at Lawrence Livermore National Laboratory (LLNL). The filters ranged in age from 0.2 to 18 years. All of the filters came from Rocky Flats except the June 1984 filter of Manufacturer A. In addition to the size 5 filters, we obtained media samples of Manufacturer A for 1976 and also cut media samples from a 1991, 50 cfm HEPA filter (Manufacturer A) found at LLNL. All of the size 5 filters were open-faced with the media folded in a deep pleat configuration and were made with organic sealant and plywood frame. Except for the January 1976 filter of Manufacturer B, all were equipped with aluminum alloy separators. The exception had chrysotile asbestos separators.

Filter Media Tests

The laboratory tests on the filter media selected in this study consisted of measuring the tensile strength, quantity of binder and Nomex (du Pont trade name) fibers, media thickness and weight. We carefully cut open the filters and extracted several layers of media with the separators in-tact. The media was unfolded and appropriate samples cut for the different measurements. We used a thermogravimetric analyzer (TGA) for determining the amount of binder and Nomex fiber in the media and an Instron tester for measuring the tensile strength. We omitted many additional tests that would be included in a more comprehensive study. The primary tests omitted are air flow resistance and DOP penetration for newly cut samples and samples after flexing; tensile strength in across-machine direction, after heated air, and after wetting; and water repellency (4). Since the previous studies (2,3) suggest that aged filters lose their water repellency treatment and become brittle, it is important that the additional tests be conducted in a more complete study.

The medium thickness was determined with a Scherr-Tumico micrometer having a 0.5 inch diameter anvil and foot and is designed for measuring the thickness of sheet stock like paper and rubber. The filter medium was compressed in the micrometer until the first click of the tension ratchet assembly.

To determine the amount of binder and Nomex, the TGA was used rather than the conventional TAPPI T-413 method of weighing the sample before and after heating in an oven at specific temperatures (5). We found the TAPPI method prone to error, time consuming, and requiring modification to evaluate Nomex. Temperature settings are required @ 107 C. to drive off adsorbed water, at 400 C. to drive off the binder, and at 550 C. to drive off the Nomex. Preliminary tests with the oven method showed rapid weight gain, due to moisture adsorption, during the weighing operation after removing the filter medium from the oven.

We determined the medium tensile strength with an Instron tester in accordance to MIL-F-51979 (4). We cut several 1 x 6 inch samples in the flat portion of the medium and additional samples with a pleat in the center. The 1 x 6 inch samples were cut with the length in the machine direction (the direction in which the medium moves forward during the paper manufacturing).

A TGA model 2950 from TA Instruments, New Castle, DE, was used to determine the percent by weight of binder and Nomex fiber in 1/4 inch disks punched from the media samples. Nomex was added to the filter media for RFP in the early 80's to make it more resistant to attack by nitric and hydrofluoric acid. Asbestos was formerly used to provide the acid resistance. Although other DOE facilities do not specify the addition of Nomex, it sometimes appears in the media.

After inserting the sample into the TGA, the instrument automatically measures the amount and rate of change in the sample weight as a function of temperature in a nitrogen atmosphere. The amount of weight loss in known temperature regions is used to determine the percentage of the acrylic binder and du Pont's Nomex in the filter medium. Figure 1 shows the TGA curve for the 17.5-year-old sample of Manufacturer A. The sample shows the weight loss begins at about 250 C and ends at about 420 C. The 4.5% weight loss is due to the binder. The derivative of the weight loss curve is also shown in Figure 1 as a single peak and is useful for identifying the beginning and end temperatures of the weight loss from a component. The sample in Figure 1 shows a single peak in the derivative curve and thus indicates only a single component, the binder, accounts for the lost weight.

Figure 1. TGA results for filter media taken from 17.5-year-old filter (Manuf. A) showing binder loss.

Figure 2 shows the TGA curve for the 2.7-year-old sample of Manufacturer A. We see two peaks in the derivative curve, one for the binder and one for the Nomex. In this case the binder begins to lose weight at about 320 C and is completely vaporized at 429 C. The second peak for the Nomex begins at 429 C and is through at about 580 C. The weight loss for the binder and Nomex peaks are 1.5% and 1.6% respectively.

Figure 2. TGA results for filter media taken from 2.7-year-old filter (Manuf. A) showing loss of binder and Nomex.

We encountered more complicated TGA curves as shown in Figure 3, where four derivative peaks are seen for the sample taken from a 12.1-year-old filter (Manuf. D). The four derivative peaks indicate four components are present, although not necessarily independent. The first peak is due to adsorbed water removal. Water adsorption on the filter media suggests that the organic waterproofing has degraded. The second and third peaks are due to loss of binder and Nomex respectively. The weight loss due to binder is 1.6% beginning at 290 C and ending at 424 C. The weight loss due to Nomex is 1.8% beginning at 424 C and ending at 581 C. We do not know what the fourth peak is due to.

Figure 3. TGA results for filter media taken from 12.1-year-old filter (Manuf. D) showing loss of water, binder, Nomex and an unknown component.

In order to relate the weight loss in the TGA curves to the weight percent of binder and Nomex fibers in the filter media, we conducted baseline TGA tests using pure acrylic binder and Nomex fibers (6). The results for the acrylic binder and Nomex fibers are shown in Figures 4 and 5 respectively. The baseline tests show the weight loss for acrylic binder is 81.2% in the temperature limits between 250 C and 420 C and 34.7% for Nomex fibers in the temperature limits between 420 C and 580 C. Since the pure samples do not show 100% weight loss in the temperature limits, the measured weight loss for binder and Nomex have to be corrected. For the acrylic binder, the measured weight loss has to be multiplied by 1.23 to obtain the percent of binder in the medium. For the Nomex fibers, an additional correction has to be made since a small portion of binder loses weight in the temperature region attributed to Nomex fibers. This overlap is corrected by subtracting 11% of the measured binder weight loss from the Nomex weight loss. The net measured weight loss for Nomex fibers is then multiplied by 2.67 to obtain the percent of Nomex fibers in the medium.

Figure 4. Baseline TGA curve for 100% acrylic binder.

Figure 5. Baseline TGA curve for 100% Nomex fibers.

The results from the laboratory tests are summarized in Table 1, where we have tabulated the percent by weight of binder and Nomex, the tensile strength of the unfolded and folded samples, the thickness, and the weight of the media samples. We computed the correlation of filter age to the binder composition, tensile strength, thickness and ream weight, but did not find any significant correlation. Figure 6 shows the least squares fit between the tensile strength of the unfolded media and the filter age. We expected to see a strong correlation in tensile strength with age based on previous studies on in-service aging (2,3).

Figure 6. Correlation of media tensile strength to filter age.

During our shelf life study, we learned that the filter medium in the 1990 and 1991 filters of Manufacturer A currently was developing cracks during transportation and installation. Since the problem seemed to be related to manufacturing and not age, we examined the effect of removing the questionable data from our correlations. We removed the 1990 and 1991 data on Manufacturer A and replotted the data in Figure 7. The data now show a strong correlation of decreasing tensile strength with age. The regression coefficient of the linear least squares fit is $R = 0.81$. A similar trend is seen for the tensile strength of the folded media in Figure 8, although the values are much smaller.

Table 1 Media Test Data

Age (Years)	Manu- facturers	Purchase Date	<u>Composition</u>		<u>Tensile Strength</u> (lb./in., Mach. dir.)		Thickness (in.)	Weight lb / 3000ft ²
			(% by wt.) Binder	(% by wt.) Nomex	Unfolded ¹	Folded		
18	A	1976	1.4	0.0	4.0	—	.019	42.7
17.5	B	Jan '76	5.5	0.0	4.8	1.1	.021	58.1
12.1	D	Aug '82	2.0	4.3	4.1	1.9	.022	59.3
9.8	C	Apr. '84	5.8	4.3	8.3	2.7	.024	58.6
9.9	A	Jun '84	3.0	2.4*	8.3	1.6	.023	48.0
9.3	E	Nov. '85	4.3	3.7	6.8	1.9	.020	53.8
8.2	A	Oct. '86	3.8	2.9	6.9	1.6	.025	56.6
4.8	E	May '89	4.7	4.0	7.1	2.7	.020	57.4
4	A	1990	2.0	2.9	3.9	—	.024	52.3
3.3	A	Mar '91	2.5	1.9*	4.0	0.9	.023	46.8
2.7	A	Oct '91	1.8	3.7	2.0	0.9	.020	43.7
0.2	A	May '94	3.0	3.2	9.3	2.3	.024	50.5

¹ Standard is 2.5 lbs. minimum

* Nomex not requested in LLNL purchase order

Figure 7. Correlation of media tensile strength to age with 1990 and 1991 data on Manufacturer A removed.

Figure 8. Correlation of tensile strength to age of folded media with 1990 and 1991 data on Manufacturer A removed.

The results from our media tests show that the tensile strength of the media decreases with age, but does not provide sufficient information to establish a shelf life for filters. All of the filter media tested in our study meet the requirements in MIL-F-51079 that specifies the tensile strength of unfolded media be greater than the minimum value of 2.5 lb./in.⁽⁴⁾. There is no requirement for the tensile strength of the folded media, although that is the critical parameter determining media failure. Note that the average tensile strength of the folded media is about 1/3 the strength of the unfolded media.

The media tests do suggest that the low, although acceptable, tensile strengths of the 1990 and 1991 media of Manufacturer A is due to insufficient binder to hold the glass fibers together in a sheet. We have plotted the tensile strength versus the percent of binder for all of the media samples of Manufacturer A in Figure 9 and show good correlation. The straight line correlation was obtained by least squares analysis. The correlation is not as good when the data of all the manufacturers are combined. This is not surprising since the manufacturers do not use the identical materials and processes.

Figure 9. Correlation between the percent of binder and the media tensile strength for Manufacturer A.

Filter Tests

We conducted a limited number of non-destructive quality assurance (QA) tests and destructive qualification tests on three different aged filters we had available. These tests were selected because they specify the minimum acceptable performance for new filters. We reasoned that aged filters should also meet these requirements. A previous study on in-service filter life used simulations of tornado pulses and shock wave overpressures to evaluate aged filters.

The quality assurance tests on assembled filters consist of visual inspection for damage, penetration, and resistance (7). Because all of the filters under study are Size 5, designated 24 by 24 by 11-1/2 inches, the latter two tests involve use of the Q107 penetrometer to measure penetration of dioctyl phthalate (DOP) particles through the filter and resistance to air flowing at 1000 cfm. A second penetration test is made with air flow reduced to 20% (200 cfm.) and is primarily targeted at identifying unwanted holes in the media and leakage at those seams where frame and gasket pieces are joined together. The upper limit for DOP penetration is 0.03% at either flow rate. The maximum allowed resistance (pressure drop) is 1.0 inch, water gauge, at the 1000-cfm. flow rate.

Qualification testing has reliability of the design of the assembled filter as its primary aim. Testing is abnormally severe and is so intended to ferret out any component weakness by which the filter might fail. This dictates that a filter not be used after a qualification test; therefore, qualification testing is classified as destructive. A detailed explanation of the tests was included in the Proceedings of the 22nd DOE-NRC Nuclear Air Cleaning conference (8) and listed below by function:

- a. Q160 overpressure apparatus. A 60-minute test which subjects a previously humidified filter to steam droplets in air flowing at an elevated resistance of 10.0 inches, water gauge. Post-test penetration must not exceed 0.03% at 20% air flow.
- b. Heated air device. Subjects a filter to air while heating to 700 degrees F. and operation at that temperature for five minutes. Post-test penetration must not exceed 3.0% at 100% flow.

c. Rough handling machine. The filter, in its shipping carton, is strapped to platform which subjects the packaged filter to an amplitude of 1/2 inch at a frequency of 200 cycles per minute. Post-test penetration must not exceed 0.03% at both 100% and 20% flow. No rough handling tests were conducted in this preliminary study.

We conducted QA and qualification tests on only three different ages filters in this preliminary study. The 0.2- and 2.7-year-old filters of Manufacturer A were selected to provide information on an immediate problem with filters used at RFP and other DOE facilities. The 9.8-year-old filter of Manufacturer C was selected at random. In a more comprehensive study, all of the filters we collected would be tested.

We conducted the heated air and pressure resistance tests using a different filter for each test as specified in MIL-F-51068 (7). We also conducted tests using the same filter in a test sequence consisting of a heated air test followed by a pressure resistance test. The latter test sequence was previously used to evaluate a high-strength HEPA filter to better simulate the multiple stresses placed on HEPA filters during accident conditions(8). Ruedinger et al (9) reported that nuclear reactors in Germany require filter qualification tests consisting of elevated temperature in still air, pressure resistance in high air flow, and humid air resistance.

Table 2 shows the test results for the pressure resistance tests. The 0.2-year-old filter of Manufacturer A and the 9.8-year-old filter of Manufacturer C passed the test and showed no structural damage. In contrast, the 2.7-year-old filter of Manufacturer A failed the test. Examination of the filter after the test showed a slit about 5 inches along a pleat (Figure 10) and small media tears near the housing (Figure 11), both defects on the downstream side.

Table 2. Pressure resistance tests.

Age (Years)	Manufa cturer	Purchase Date	ΔP in.	<u>Before</u>		ΔP in.	<u>After</u>	
				<u>Penetration</u> 100%	20%		<u>Penetration</u> 100%	20%
9.8	C	April '84	.86	.030%	.033%	.86	.026	.032
2.7	A	Oct '91	.80	.01%	.01%	.74	.51%	.81%
0.2	A	May '94	.80	.016%	.018%	.78	.005%	.011%

Figure 10. Slit in media pleat on the downstream side of a 2.7-year-old filter of Manufacturer A following the pressure test.

Figure 11. Small tears on downstream side of 2.7-year-old filter of Manufacturer A following the pressure test.

The failure of the 2.7-year-old filter in Table 2 can be attributed to the low tensile strength of the medium which resulted from insufficient binder. The other two filters show no deterioration after the pressure test despite the large age difference. Filter construction properties clearly have a much greater effect on resistance to pressure than filter age.

We then evaluated two additional filters in a test sequence consisting of a heated air test followed by a pressure test. Filter penetration measurements were made before and after each test. The test results are summarized in Table 3.

Table 3. Test results following heated air and pressure resistance.

Age (Years)	Manu- facturer	Purchase Date	Before			After Heated Air			After Heated Air and Pressure		
			ΔP in.	<u>Penetration</u>		ΔP in.	<u>Penetration</u>		ΔP in.	<u>Penetration</u>	
				100%	20%		100%	20%		100%	20%
2.7	A	Oct '91	.76	.018%	.023%	.74	1.24%	4.52%	0.64	5.86%	7.51%
0.2	A	May '94	.74	.008%	.008%	.76	0.77%	1.91%	.80	2.05%	4.12%

The two filters meet the requirements of less than 3% penetration at 100% flow after the heated air test. Since there are no standards for a sequence of tests on the same filter, there is no established penetration level defined as a failure.

During the heated air test on the 2.7-year-old filter, the sealant was burning and continued to burn even when the heat was removed. Examination of the filter after test showed the sealant had burned through the entire depth of the filter, leaving the filter pack loose in the wooden frame. Figure 12 shows a close up of the sealant on the exit side of the filter after the heated air test. The gap between the wooden frame and the filter pack is visible in the photograph. The filter pack also showed a slight buckling of the separators and media pleats into an "s" shape near the bottom frame of the filter. This buckling was presumably due to the softening of the media and the weight of the filter pack. No tears or holes were found in the filter media. The penetration at 100% flow is 1.24% and

is within the allowed 3% limit. Note that the filter would have failed if the penetration at 20% flow were used as done in the overpressure test.

Figure 12. Photograph of 2.7-year-old filter of Manufacturer A showing the crack where the sealant had burned away.

The damaged 2.7-year-old filter of Manufacturer A was then subjected to the overpressure test. During the test, a major portion of the filter pack was pushed out of the frame about one inch, but was not blown out. Figure 13 shows the exit side of the filter with portions of the filter pack pushed out. (Note that the gasketed side of the single gasket filter must be faced upstream in the heated air test and reversed to face downstream in the overpressure test.) The displacement of the filter pack can be seen by the extension of the aluminum separators beyond the gasket in the right side of the photograph in Figure 13. The central portion of the filter pack was pushed out even farther after the seventh aluminum separator from

the right. The step dislocation is seen by the exposed filter medium separating the two portions of the filter pack. The filter also showed more extensive buckling near the bottom frame and had media tears in that region as seen in Figure 14.

Figure 13. Photograph of the exit side of the 2.7-year-old filter of Manufacturer A showing filter pack pushed out of its frame after the overpressure test.

Penetration tests on the filter showed 5.86% and 7.51% at 100% and 20% flow respectively. Under slightly more severe conditions, the media pack would have completely blown out of its frame and resulted in 0% efficiency.

Figure 14. Photograph of the exit side of the 2.7-year-old filter of Manufacturer A showing media buckling and tearing after the overpressure test.

The 0.2-year-old filter of Manufacturer A had far less damage after the heated air and overpressure tests than the 2.7-year-old filter. The filter sealant had charred but held the media pack tight to the frame. There were four slits along the media pleats, about 3-4 inches long, on the exit side of the filter along with slight media buckling. During the heated air test, smoke was jetting out from the joints in the plywood frame. Bubbles were forming at the cracks indicating that the glue used to seal the frame was melting and burning.

Based on the limited filter tests summarized in Tables 2 and 3, we can conclude that filter age is not the primary factor affecting filter performance in the heated air and overpressure qualification tests. The 2.7-year-old filter of Manufacturer A had failed the overpressure test due to tears in the filter media. We have shown this filter has poor tensile strength due to insufficient binder. The filter also had severe structural damage during the heated air test,

although it met the maximum penetration requirements. The sealant was completely burned out around the filter pack, leaving it susceptible to blow-out. Thus, our preliminary conclusion is that the type of materials and the construction design used in HEPA filters have a greater effect of HEPA performance than age.

IV. Rocky Flats HEPA Failures

Our study to determine the shelf-life of HEPA filters coincided with a problem encountered at the Rocky Flats Plant with aged HEPA filters of Manufacturer A. The volume of filters purchased by Rocky Flats during 1990 and 1991 exceeded the capacity of the local storage facility. The filters were found acceptable upon quality assurance tests following delivery and were stored in containers which were outside and exposed to weather changes. During 1993 and 1994 many of these filters were withdrawn from containers, re-certified with quality assurance tests, and issued for installation. Some filters at the installation site were found with damaged medium; and following installation of others, in-place testing identified installed HEPAs with damage not prominently discernible to visual inspection.

Figure 15. Photograph of filter media tears encountered at the Rocky Flats Plant during the installation of 2- to 3-year-old filters of Manufacturer A.

An independent study by some of us (J.K.F. and F.R.) showed that the filter failures were due to small tears in the media that occurred during the transportation and installation of the filters. The mechanical stresses placed on the filter were evidently sufficient to damage the media. Figure 15 shows the typical damage that was seen with these filters. Our present study showed the damage was due to low tensile strength as a result of insufficient binder.

V. Conclusions

We have completed a preliminary study using filter media tests and filter qualification tests to investigate the effect of shelf-life on HEPA filter performance. The filter media was extracted from filters stored up to 18 years. Our media studies showed that the tensile strength decreased with age, but the data was not sufficient to establish a shelf-life. The media was also analyzed for the percent of binder and Nomex fibers using a TGA. These analyses demonstrated that the low tensile strength of the 1990 and 1991 media samples of Manufacturer A were due to insufficient binder.

The filter qualification tests (heated air and overpressure) conducted on different aged filters showed that filter age is not the primary factor affecting filter performance. The type of materials and the construction design have a greater effect on HEPA performance than age. We found that the 1991 filters of Manufacturer A had failed the overpressure test. The filter had passed the heated air test, but left the filter so structurally weak, it was prone to blow-out. The unsatisfactory performance of these filters is partially due to the lack of sufficient binder in the medium. The use of a combustible sealant that burns through the filter depth and leaves the filter pack loose inside the filter frame is also not acceptable.

This is a preliminary study of some of the factors involved in establishing a shelf-life for HEPA filters. The study was limited in both the type of parameters studied and the number of samples. Future studies should also include all of the filter components, e.g. sealants, gaskets, frame, in addition to the media. Other filter tests such as simulation of tornado pulses and smoke plugging should also be conducted in addition to the qualification tests to better differentiate the age effects.

The discovery that sub-standard HEPA filters have found their way into DOE facilities despite an existing system of regulations and quality control laboratories suggests that the present system must be improved. All HEPA filter manufacturers that sell their filters to DOE or NRC facilities must have every type of size 5 filter they sell pass the qualification tests (heated air, overpressure, and rough handling) every five years (7, 10). The enforcement of the requirements is typically left to a buyer in the individual DOE facilities. Some manufacturers do not requalify their filters every five years. Our present study has shown that even if a manufacturer qualifies their filters every five years as required, the manufacturing process or materials used may change and lead to sub-standard filters. We recommend that DOE initiate a filter qualification program to prevent this occurrence.

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Engineers, 345 East 47th Street, New York, N.Y. 10017, (1989)

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