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RESPONSE OF HEPA FILTERS TO SIMULATED ACCIDENT CONDITIONS

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Abstract

High-efficiency particulate air (HEPA) filters have been subjected to simulated accident conditions to determine their response to abnormal operating events. Both domestic and European standard and high-capacity filters have been evaluated to determine their response to simulated fire, explosion, and tornado conditions.

The HEPA filter structural limitations for tornado and explosive loadings are discussed. In addition, filtration efficiencies during these accident conditions are reported for the first time. Our data indicate efficiencies between 80% and 90% for shock loadings below the structural limit level. We describe two types of testing for ineffective filtration--clean filters exposed to pulse-entrained aerosol and dirty filters exposed to tornado and shock pulses. Efficiency and material loss data are described. Also, the response of standard HEPA filters to simulated fire conditions is presented. We describe a unique method of measuring accumulated combustion products on the filter. Additionally, data relating to pressure drop vs accumulated mass during plugging are reported for simulated combustion aerosols. The effects of concentration and moisture levels on filter plugging were evaluated. We are obtaining all of the above data so that mathematical models can be developed for fire, explosion, and tornado accident analysis computer codes. These computer codes can be used to assess the response of nuclear air cleaning systems to accident conditions.

I. Introduction

Most nuclear facilities depend on ventilation systems to bring air into, through, and out of the facility. Because the air passes through contaminated areas, most ventilation systems also contain air cleaning systems; the high-efficiency particulate air (HEPA) filter is a critical component in the air cleaning system. The system may consist of a series arrangement of these filters or banks containing several hundred filters. These filters typically exhibit cleaning efficiencies of 99.97% or better. They operate very effectively in most noncorrosive atmospheres at normal airflow conditions. However, there is concern about the degradation of performance or destruction of these units when they are subjected to accident conditions. The areas of concern are (1) the structural integrity of the HEPA filter media, (2) the influence of design and construction on structural integrity, (3) the filtration effectiveness, and (4) plugging or clogging by combustion products.

A standard HEPA filter consists of pleated filter material enclosed by a plywood or metal frame. The filter material (which is made up of a thin mat of fine, intertwined glass fibers) is folded back and forth around thin sheets of asbestos or aluminum materials, called separators. The nominal airflow capacity

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of this type of filter is $0.47 \text{ m}^3/\text{s}$. High-capacity HEPA filters usually do not contain separators, have a reduced folding depth, and are arranged in a V-type pattern within the frame. These filters have a normal operating airflow capacity of $0.85 \text{ m}^3/\text{s}$.

Under accident conditions, HEPA filters may have to respond to high airflows and pressure surges resulting from tornado depressurization or from internal explosions. In the case of fire, the filter may be exposed to high temperatures and large quantities of smoke (solid and liquid aerosol). In this investigation, we have simulated the effects of tornado, explosion, and fire accident conditions and evaluated the response of both standard and high-capacity filters.

We examine the structural limits of these units and also discuss their filtration efficiencies when they are subjected to simulated tornado and explosion transients. A unique device to evaluate the response of HEPA filters to fire conditions is described, and preliminary filter plugging data are presented. Finally, we discuss how and where these data may be used by an analyst in evaluating the response of nuclear facility air cleaning systems to accident conditions.

II. HEPA Filter Response to Simulated Tornado Transients

The response of HEPA filters to simulated tornado transients has been reported in several places.⁽¹⁾⁻⁽³⁾ In this paper, we wish to summarize the structural limit data reported elsewhere and report for the first time on the efficiency of HEPA filters subjected to simulated tornado transients.

Structural Limits

Structural limits are defined here as the pressure differential across the filter needed to just break the filter medium. We have determined the structural limits for standard HEPA filters (American or British design) and for high-capacity designs, including both European and American models.

Standard HEPA Filters. Table I summarizes the structural limit data we obtained for four manufacturers' filters. The highest limit we found was 20.1 kPa (2.91 psi), and the lowest limit was 9.1 kPa (1.32 psi). The mean break pressure was 16.4 kPa (2.37 psi).

Table I. Standard HEPA filter structural limits for simulated tornado transients.

<u>Manufacturer</u>	<u>Structural Limits</u>	
	<u>kPa</u>	<u>psi</u>
A	17.3	2.50
B	20.1	2.91
C	9.1	1.32
D	18.4	2.66
Average	16.4	2.37

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Table II. High-capacity HEPA filter structural limits for simulated tornado transients.

Manufacturer	Structural Limits	
	kPa	psi
E	11.0	1.6
F	9.0	1.3
G	15.9	2.3
H	9.0	1.3
Average	11.2	1.6

High-Capacity Filters. The structural limits for high-capacity HEPA filters were found to be lower than those for standard HEPA filters; that is, 11.2 kPa (1.6 psi) compared with 16.4 kPa (2.37 psi). The results of these tests are shown in Table II.

Filtration Response

Determining the structural limits of HEPA filters is important, but questions about the filter's capability to perform its function during tornado transients remain. Therefore, we subjected HEPA filters to two types of filtration tests: (1) entraining aerosol in the pulse upstream of a clean filter and determining its efficiency during a transient by measuring the amount of aerosol up and downstream of the filters and (2) preloading filters with aerosol and measuring the amount of aerosol dislodged when the filters were subjected to a simulated tornado transient. A description of the test method and other details can be found in Ref. (4).

Efficiency of Clean Filters. Polystyrene latex aerosol with a mean diameter of $0.46 \mu\text{m}$ was injected upstream of the test HEPA filter and downstream of the prefilters as shown in Fig. 1. After this operation, the tornado transient was

Figure 1. Schematic of apparatus used to determine the structural limits and efficiency of clean HEPA filters subjected to simulated tornado transients.

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Table III. Efficiency of standard HEPA filters subjected to simulated tornado transients.

<u>Manufacturer</u>	<u>Efficiency (%)</u>
A	99.0
B	98.9
C	98.4
D	<u>99.1</u>
Average	98.9

initiated, and upstream and downstream samples of particulate were collected on nuclepore filters. The particulate counts on the nuclepore filters were determined using an electron microscope. Table III shows the results of subjecting four manufacturers' standard HEPA filters to simulated tornado transients. The pressure transient was at a level below that required to cause structural failure. As shown in Table III, the filtration efficiency is degraded from 99.97% during normal operation to approximately 98.9%. No attempt has been made in our program to determine the effectiveness of high-capacity filters in this type of test.

Material Loss from Preloaded Filters. Standard HEPA filters were preloaded with 0.46- μ m-mean-diam polystyrene latex aerosol using a Laskin-type generator at a normal operating condition airflow rate. The filters were loaded to a normal pressure drop of 38.1 cm w.g. At this pressure drop, approximately 1 kg of material was deposited on a filter. The amount of material released from the test filters was determined by placing nuclepore filters downstream of the filter and applying a vacuum of 12 cm w.g. to the back of the nuclepore filters to assure that the released aerosol would collect on them. As in previous tests, the test filter was subjected to only one simulated tornado transient, which was at a pressure level below that required to cause structural failure. The results of this type of test for standard HEPA filters are listed in Table IV.

Only two filters (from the same manufacturer) were evaluated. Table IV shows that the amount released in the two tests differed considerably. Although the amount released is significant, the analyst should be cautious when using these results because of the limited amount of data.

Table IV. Material released from preloaded standard HEPA filters during a simulated tornado transient.

<u>Manufacturer</u>	<u>Particulate Mass Released (g)</u>
A	14.6
A	<u>7.1</u>
Average	9.35

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Figure 2. Test configuration used to determine structural limits and efficiencies of HEPA filters subjected to simulated explosive transients.

III. HEPA Filter Response to Simulated Explosion Transients

Data on HEPA filter response to simulated explosion transients can be found in several reports. (2), (5), (6) Here, we wish to summarize the data for structural limits, filtration efficiency, and material release that was obtained by subjecting HEPA filters to simulated explosion transients. These data contain values for both standard and high-capacity HEPA filters.

Structural Limits

The configuration used to determine structural limits is shown in Fig. 2. As discussed in the reports listed above, the break point or structural limit was determined photographically using the high-speed camera shown in Fig. 2. In the area of structural limits, we wish to compare our data with that obtained earlier by Anderson and Anderson and also determine structural limit data for high-capacity filters. (7) Our data for 47-ms-long simulated explosion waves are listed in Tables V and VI.

Table V. Structural limits of standard HEPA filters subjected to simulated explosion transients 47 ms long.

<u>Manufacturer</u>	<u>Structural Limits</u>	
	<u>kPa</u>	<u>psi</u>
A	17.2	2.50
B	17.4	2.53
C	7.2	1.04
D	<u>9.5</u>	<u>1.86</u>
Average	12.8	1.86

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Table VI. Structural limits of high-capacity HEPA filters subjected to simulated explosion transients 47 ms long.

Manufacturer	Structural Limits	
	kPa	psi
E	5.5	0.8
F	5.5	0.8
G	9.7	1.4
H	6.9	1.0
Average	6.9	1.9

The structural limits of high-capacity filters are lower than those found for standard HEPA filters (6.9 kPa or 1.9 psi compared with 12.8 kPa or 1.86 psi). Both of these values are lower than those reported earlier by Anderson and Anderson (22.0 kPa or 3.2 psi) for explosive waves of a 50-ms duration. We also noted that standard HEPA filters have different structural limits for tornado and explosive transients.

In our investigation of the structural limits of HEPA filters, we believed that identifying structural limits based on peak pressure alone was not sufficient. Therefore, we also evaluated the total impulse applied during the explosive transient. The impulse (I/A) was evaluated using Eq. 1 by including both peak pressure (p) at the structural limit and the time until the filter fails (Δt).

$$\frac{I}{A} = \int p \, t \, . \quad (1)$$

We used Fig. 3 to study the supposition that impulse causes structural failure in the filters. Figure 3 is a plot of impulse per unit area; $I/A = \int p \, \Delta t$ as a function of shock wave duration. If the impulse resulting from the shock overpressure is the cause of failure, then the plots in Fig. 3 would be horizontal. Obviously, this is not entirely true. At the longer shock wave duration, impulse seems to be the controlling parameter, but this does not seem to be true for the shorter durations (5 ms--20 ms). This caused us to examine our test data more thoroughly as outlined below.

Figure 3. Plot of impulse vs shock wave duration for four manufacturers' HEPA filters.

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Figure 4. Typical pressure for a 47-ms shock wave duration.

Figures 4 and 5 show typical pressures for 47-ms and 5-ms shock wave durations. Previous studies have shown that the reflected wave from the rim of the filter case that appears at the pressure transducer located about 20 ms after shock passage is not experienced on the face. Careful examination of the pressure records reveals that for all of the short shock waves, filter failure occurred after the shock impulse had passed through (or more probably, had been absorbed by) the filter. Compare the shock wave shown in Fig. 5 with the long-duration shock wave shown in Fig. 4. This result seems to imply that some other mechanism contributes to the failure of the filter at short shock wave durations; airflow rate could be the cause of this phenomenon. The passage of the shock wave through the air by the tube causes the air to move in the same direction as the shock wave.

The structural limit of the E-type filter at the 5-ms shock wave duration was 10 kPa (1.45 psi). The air velocity behind the shock wave with the overpressure was 28.77 m/s or a flow rate through the filter of 10.69 m³/s. Our tornado testing of this filter showed that flow rates through this filter reached a maximum value of 10.38 m³/s and that most filter failures occurred at flow rates below this value. Thus, because high residual airflow rates persist after passage of the shock impulse, it is probably the high flow rate with its attendant high stagnation pressure that causes filter failure at short shock wave durations.

Figure 5. Typical pressure for a 5-ms shock wave duration.

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Filtration Response. As in the response when filters are subjected to simulated tornado transients, we also are concerned about the response of the HEPA filters to simulated explosion transients. In these tests, only high-capacity HEPA filters were tested. Both efficiency testing of clean filters to shock-entrained aerosol and material loss testing were performed. The tests were very limited in number so the results should be viewed as somewhat qualitative and should be used with caution.

Efficiency of Clean Filters. The efficiency of high-capacity HEPA filters in simulated explosion transients was examined by first loading the driver section of the shock tube with polystyrene latex aerosol like that used in the tornado testing. Our use of nuclepore filters to make the measurement was similar to that described above for the tornado tests. A single high-capacity filter (type E) was chosen for this test. The maximum pressure was 6.89 kPa (1 psi), which was below the structural limit found in earlier testing. Our measurement of upstream and downstream particles for the test indicated an efficiency of 70%.

Material Loss From Preloaded Filters. To determine the material release from high-capacity HEPA filters, we preloaded several filters with polystyrene aerosol in the same manner as for the tornado testing. In these tests, two manufacturers' filters were tested at simulated explosive pressures below break values found in the structural limit tests. The results of the material loss tests are given in Table VII. The large amount of mass loss for the first filter listed in the table (341 g) apparently occurred because the filter medium was slightly creased during the test. Again, the analyst should view these results with caution because of the limited amount and variability of the data.

IV. HEPA Filter Response to Simulated Fire Accidents

Background

In this section we will describe the Los Alamos National Laboratory filter plugging program and present some preliminary experimental results. This program was initiated in 1981 when we realized that there were no known data for simultaneous measurements of pressure drop, flow rate, and combustion product mass accumulation on HEPA filters for realistic fire conditions. These data are needed to calculate the empirical coefficients in expressions relating filter pressure

Table VII. Material released from preloaded high-capacity HEPA filters subjected to simulated explosive transients.

<u>Manufacturer</u>	<u>Material Released</u>
	<u>(g)</u>
E	341.3
E	0.001
F	0.002

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drop to volumetric flow rate in the Los Alamos FIRAC accident analysis computer code.⁽⁸⁾ An example of a typical semi-empirical expression of this kind is⁽⁹⁾

$$\Delta p = \Delta p_0 (1 + \alpha m_p) \quad , \quad (2)$$

where

$$\Delta p_0 = K_L \mu \frac{Q}{A^{3/2}} + K_T \rho \frac{Q^2}{A^2} \quad . \quad (3)$$

In Eqs. (2) and (3), Δp_0 represents the clean filter pressure drop resulting from both laminar friction and turbulent dissipation in pascals, and

- α = filter plugging coefficient dependent on filter and material properties (kg^{-1}),
- m_p = accumulated mass of material on filter (kg),
- $Q = V_A$ = volumetric flow rate (m^3/s),
- $Q_0 = V_0 A$ = clean filter volumetric flow rate
- A = filter cross-sectional flow area (m^2),
- K_L, K_T = dimensionless laminar and turbulent coefficients, respectively,
- μ = air dynamic viscosity ($\text{Pa}\cdot\text{s}$), and
- ρ = air density (kg/m^3).

Equation (2) assumes that a linear relationship exists between $\Delta p/Q$ and m_p .

Other more complicated theoretical models of filter plugging are available in the literature, such as the dendrite model⁽¹⁰⁾ and the increasing fiber model.⁽¹⁰⁾ The models quantitatively predict filter plugging as idealized cases in which the loading particles either form fiber-like dendrite chains or increase the fiber diameter, respectively. (In actuality, both effects are probably occurring in the case of smoke.) These models are extensions of existing pressure drop theories for clean filters.

The dendrite model states that the loaded filter pressure drop may be predicted using

$$\Delta p = \Delta p_0 \left(1 + \frac{R\alpha}{r\alpha_F} \frac{p}{F} \right) \left(1 + \frac{R^2\alpha}{r^2\alpha_F} \frac{p}{F} \right)^{1/2} \left(\frac{Q}{Q_0} \right) \quad , \quad (4)$$

when the volumetric flow rate Q is a variable.

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In Eq. (4),

α_p = particle volume fraction = vol. particles/vol. media,

α_f = fiber volume fraction = vol./fibers/vol. media,

r = particle radius (m), and

R = fiber radius (m).

Because α_f can be derived from measurable quantities and the uniform fiber (media) density, the fiber radius R may be estimated using the clean filter pressure drop equation.

$$\Delta p_0 = \mu Q_0 T \frac{16 \alpha_f^{3/2}}{R^2}, \quad (5)$$

where T is the filter thickness (m).

Filter Plugging Facility.

To supply the needed filter plugging data, Los Alamos and New Mexico State University have constructed a unique filter plugging test facility. The purpose of this facility is to supply experimental data for 0.61- by 0.61-m HEPA filters under conditions simulating those postulated as credible for fires in nuclear facilities. Industrial fires such as these are expected to differ from other kinds of fires in the types of materials involved and the ventilation conditions (availability of oxygen). A typical fuel mixture may be composed of the materials listed in Table VIII. These materials are likely to burn under both oxygen-rich and oxygen-starved conditions (over- and under-ventilated conditions) to produce particulate material, water vapor, and gaseous combustion products.

Thus, some unique capabilities were required of the new facility. First, we needed the capability to determine the accumulated mass gain of a clean 16-kg HEPA filter because of smoke and moisture clogging. Previous tests using polystyrene latex spheres lead us to expect plugging (arbitrarily defined to be a 50% flow rate reduction from the design value) to occur from an accumulation of under 500 g of dry solid material. To resolve 2- to 3-g smoke accumulations out of 16 000 g, we designed and constructed a special null-balance filter-weighing apparatus. Second, we needed the capability to burn mixtures of materials selected from the

Table VIII. Typical fuel mixture composition.

<u>Component</u>	<u>Composition (%)</u>
1. Polymethylmethacrylate	45
2. Cellulosic	26
3. Elastomer	18
4. Polyvinyl Chloride	8
5. Hydraulic Fluids	2
6. Polystyrene	1

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above list with variable burning efficiencies. To do this, Pacific Northwest Laboratory designed and constructed a special combustor for Los Alamos. Finally, we needed the capability of adding varying amounts of heat and moisture to the airflow. Heat will be supplied by a commercial air heater, and water is sprayed into the air through a commercially available nozzle.

Idealized Tests Using Stearic Acid

A preliminary series of 19 plugging tests were conducted during the winter of 1981 to (1) prove out the null-balance filter-weighing system and (2) determine the effects of concentration and moisture addition. In these tests, dry stearic acid particles with a mean diameter of $0.488 \mu\text{m}$ were generated using a commercial condensation-type generator. Stearic acid was chosen because a fairly monodisperse, spherical, nontoxic, control aerosol could be generated for the approximate size and concentrations desired to simulate a fire. (We were able to generate stearic acid aerosol loadings of about 60 to 120 mg/m^3 ; full-scale forced ventilation fire tests at Lawrence Livermore National Laboratory have produced concentrations of real smoke in excess of 5 g/m^3 while burning porous cribs of solid fuels.) A spray nozzle was used to inject water at selected flow rates up to fully saturated conditions. The 19 tests, including dry particulate only, water only, and mixed conditions, are summarized in Table IX.

Reviewing Table IX, we observe that increasing the stearic acid concentration by increasing the generation rate from 0.105 to $2.05 \text{ cm}^3/\text{min}$ in the absence of water spray successively reduced plugging times from 32.2 to 4.87 h . Adding water spray at the higher flow rates (200 and 400 g/min) resulted in faster plugging (about 3 -- 6 h) with higher mass loadings (about 5.5 -- 8 kg). Dry stearic acid plugged the filters with significantly less mass loading (about 0.40 -- 0.55 kg).

Table IX. Summary of idealized filter plugging tests using stearic acid and water spray.

Test	Stearic Acid Volumetric Flow Rate (cm^3/min)	Water Mass Flow Rate (g/min)	Plugged Mass (kg)	Time to Plug (h)
17	0.0	100.0	3.447	27.0
18	0.0	200.0	7.729	9.52
19	0.0	400.0	6.996	5.27
4	0.105	0.0	0.415	32.2
7	0.105	100.0	6.481	32.9
6	0.105	200.0	8.060	5.787
5	0.105	400.0	6.583	4.93
1	0.241	0.0	0.401	20.7
10	0.241	100.0	6.179	31.5
9	0.241	200.0	6.941	4.53
8	0.241	400.0	6.336	4.13
2	0.941	0.0	0.550	13.4
13	0.941	100.0	3.796	6.22
12	0.941	200.0	5.429	6.23
11	0.941	400.0	5.450	3.90
3	2.05	0.0	0.454	4.87
16	2.05	100.0	4.251	5.97
15	2.05	200.0	5.345	6.05
14	2.05	400.0	6.449	3.00

Figure 6. HEPA filter plugging by simulated smoke aerosols showing the effect of moisture addition.

Figure 6 presents the results of the four filter tests conducted at the highest stearic acid mass generation rate with three water spray injection rates. These curves can be fitted with polynomials of the form $\Delta p/Q = f(m_p)$, where f is a polynomial and includes the linear form of Eq. (2). In this way the data could be used in a computer code to estimate pressure drops during filter plugging under fire conditions.

A comparison of the dendrite model prediction of Eq. (4) and the experimental data of test 2 has been made in Fig. 7. For Test 2, the pertinent parameters used in Eq. (4) were $\Delta P_0 = 2.3$ cm. w.g., $R = 1,428 \mu\text{m}$, $\alpha_F = 0.4292$, volume of filter media = 0.007267 m^3 , and $\rho_p = 0.9846 \text{ g/cm}^3$. The parameter p varied from 0 to 0.0767 as the filter was plugged with dry stearic acid. The flow rate Q dropped from 1695 to $878 \text{ m}^3/\text{h}$. Two values of particle (or dendrite) radius r were

Figure 7. Comparison of dendrite model and experimental data.

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used in Eq. (4) to produce the model curves shown in Fig. 7. The first value of $r = 0.244 \mu\text{m}$ was determined as an arithmetic average of stearic acid aerosol particle sizes measured using a Royco Model 225 Aerosol Particle Counter. The second value of $r = 0.16 \mu\text{m}$ was obtained by back-calculating with Eq. (4) to match the last or plugged data point shown. Figure 7 illustrates the sensitivity of the dendrite model to dendrite geometry and aging, that is, to the selection of r . However, the $r = 0.16 \mu\text{m}$ curve presents a conservative estimate of filter plugging for this case.

Future Testing

A more complicated series of filter plugging tests will be conducted during the fall of 1982. This series will use the same weighing technique but will also use the special combustors to burn two materials, polystyrene (PS) and polymethylmethacrylate (PMMA), at two mass-burning (or smoke-generation) rates, high and low. The mass-burning rates will be controlled by adjusting the inlet air supply rate. Each of these conditions will be repeated 3 times for a total of 12 tests. The repetitions are intended to allow us to assess the reproducibility of our test results. Because PS and PMMA represent extremes of smoke-producing materials, we should be able to derive filter plugging coefficients that bracket those expected in nuclear fuel cycle facility fires. Additional experiments are planned for 1983, and these will include using typical fuel mixtures, adding heat and moisture to the flow, and using improved gas analysis and particle-size measuring instrumentation. These tests are intended to simulate and measure more complex and more realistic filter plugging conditions.

The current filter plugging test series are part of a Los Alamos fire test plan to support development and verification of the FIRAC Computer code. Ultimately, we wish to model and predict transient combustion product generation and transport in nuclear fuel cycle facilities using FIRAC. To do this, we need to develop experimental fire simulation and measurement capabilities in the following areas.

1. Fire simulation and classification
2. Compartment fire behavior
3. Combustion product behavior during transport (deposition and modification by aerosol dynamic changes)
4. Filter plugging behavior
5. FIRAC code verification

The testing in these areas will include release rate oven, compartment fire, filter plugging, and ventilation system facility experiments.

V. Application of HEPA Filter Data to Accident Analysis

Experimental results from subjecting HEPA filters to simulated accident conditions are needed by analysts concerned with the design and safety of nuclear facilities. Typically, safety analyses require predicting the consequences of accidents occurring within nuclear facilities. In addition, the accident-induced challenge to the air cleaning system must be predicted. The analyst must know the structural limits, filtration efficiency, plugging effect, and possible material release from critical HEPA filters. We have obtained supportive HEPA filter experimental data that, when coupled with computer codes that can predict accident-induced loadings, will allow the analyst to determine the response of

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fuel cycle facilities to fire, explosion, and tornado accident conditions. In this section, we illustrate how and where HEPA filter experimental data can be used.

Evaluation of the effects of tornado depressurization on a nuclear facility air cleaning system can be accomplished using the Los Alamos computer code TORAC to predict the pressure and flow rates at all filter locations within the facility.⁽¹²⁾ Knowing the predicted pressures and flows, the analyst then can turn to the structural limit data to see if structural failure can occur. If structural failure occurs during the transient, the analyst has the capability to restart the problem with new flow conditions that simulate the failure mode when using the TORAC code. If the analyst has no knowledge of the type of filter used in the facility, the lowest structural limit of 9.0 kPa (1.3 psi) should give the most conservative analysis.

The structural limit data for explosive transients can be used in the same manner as discussed for tornado transients. However, in this case the analyst would use the Los Alamos computer code EXPAC to simulate the explosive wave propagation.⁽¹³⁾ Our data indicate that shock pressures should be less than 13.8 kPa (2 psi) for standard HEPA filters and less than 6.9 kPa (1 psi) for high-capacity HEPA filters to preclude HEPA filter destruction.

From our studies of high-capacity HEPA filters, we found that shock impulse per unit area (I/A) was related to structural failure. The filters seem to have a property that causes them to fail at a particular value of I/A. If this or a higher value of I/A is contained in an impinging shock pulse, the filters will fail during the shock over-pressure. The impulse present in any pressure wave can be calculated using the EXPAC computer program. If there is not sufficient I/A contained within the shock pulse, then the filter may still fail because of the magnitude of the airflow rate following the shock wave. Thus, the analyst must take great care when using I/A as a criterion. The safest approach would appear to be using the lowest I/A from Fig. 3 (that is, 100 kPa/ms) as the limiting I/A.

We believe that our material loss data from loaded filters (that is, filters that have seen significant service conditions) can be used by a safety analyst to estimate possible release when filters are subjected to tornado or explosive transients. However, we offer rather qualitative guidance because of the limited number of tests. Experiments show that at the initial point of failure, large amounts of particulate can be released. Further, even if structural failure does not occur and the peak pressure is 50% below the failure point, significant amounts of particulate will be released under explosive transients. In estimating possible releases from HEPA filter units, the safety analyst should consider using a pressure limit that is 50% below the structural limit. This area needs further investigation because of the limited amount of data.

The current generation of accident analysis codes also can predict transport and movement of particulate through a nuclear facility's ventilation system. If the analyst couples the experimental data for efficiency into the filter modules of these codes, an estimate of material release through the filter system can be made. If the analyst uses the results from our preliminary shock pulse study, he should allow 30% of the material to pass through the protective HEPA filter even if the impinging shock wave is below the filter's structural limit. However the data in this area are limited and should be used carefully.

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The filter plugging data being obtained by subjecting filters to simulated fire conditions are essential supportive data for a computer code to predict fire spread in a nuclear facility. The HEPA filter is very effective in trapping all smoke particulate generated from a nuclear facility fire. As smoke particulate accumulates on the filter, the pressure drop increases and the flow through the filter decreases. Therefore, a computer code that simulates smoke movement through a facility must have the capability to alter the flow dynamics in accordance with material accumulation on the filter. The FIRAC computer code discussed above will be capable of predicting temperature and smoke distribution throughout a nuclear facility ventilation system. As illustrated in Sec. IV, the data developed in this program will be transformed into a filter plugging relationship for the FIRAC code, which will automatically adjust the flow conditions in accordance with the mass of material on the filter. This simulation capability is essential if the analyst is to predict flow reversals and the effect of the changing ventilation conditions on the character of the fire. That is, the reduced airflow may create greater smoke production and flow reversals sending backflow to less less contaminated zones within the plant.

VI. Summary

Los Alamos is conducting multifaceted experimental studies funded by the U.S. Nuclear Regulatory Commission in which HEPA filters are being subjected to simulated accident conditions. The purpose of these studies is to obtain experimental data on filter performance and structural integrity during simulated accident conditions. The data will be used by analysts to formulate new or improve existing mathematical models of HEPA filter performance. Such models currently are being used, for example, in the Los Alamos family of nuclear fuel cycle facility accident analysis computer codes, FIRAC, EXPAC, and TORAC.

This paper presented test results for both domestic and European style HEPA filters of both standard and high-capacity design. These filters were exposed to simulated fire, explosion, and tornado conditions. Results showing filter explosion and tornado accident structural limitations and, for the first time, filtration efficiency were presented. Our HEPA filter plugging program and test facility are also reviewed. This program is yielding useful experimental data on HEPA filter performance during controlled loading with simulated combustion products. The effects of smoke concentration and moisture level were investigated.

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