SCANNING ELECTRON MICROSCOPY OF ULPA AND HEPA FILTERING PAPERS

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Abstract

The behaviour of newly developed ULPA and HEPA filtering papers has been examined in an abnormal condition due to overheating up to 400°C.

A noteworth failure in mechanical resistance has been observed, whereas efficiency was scarcely affected.

Scanning electron microscopy showed that observed anticipated failures were accompanied with ruptures of the glass microfibers of the papers.

I. Introduction

ULPA and HEPA filters have many applications in various fields, particularly where it is of prime importance to remove submicron particles from ambient air as in clean rooms, in nuclear facilities or where valuable electronic systems are to be protected. Ventilation systems shall be able to ensure an adequately safe environment for operators and population; that means strictly specified conditions have to be mantained in the process volumes and discharged air must be within prescribed limits.

Many events can cause perturbations to the conditions a ventilation system has to cope with; a lot of work has been carried out concerning accidents involving fires, explosions, attack of filters by chemicals and enough information is now available on the behaviour of filtering systems and related components in the above mentioned scenarios.[1- 11]

Nevertheless there are some abnormal situations where the response of the component would be worthy of further investigation. Attention was paid to the overheating of some newly developed ULPA and HEPA filtering papers, which are said to be capable to operate in continous up to 300°C and up tc 500°C for short periods; six ULPA and five HEPA paper types(*) were considered and their behaviour, change of "cleaning capacity" and mechanical resistance were experimentally studied.

(*) Main properties (manifacturers' data) are in Table 1.

II. Experimental procedure and apparatus

Paper specimens were heated up to the chosen temperature in an oven in 15 min about; they remained at steady temperature for one hour at least and then they were slowly cooled down to laboratory conditions.

The following inspections and measurements were carried out:

- weight loss: it was determined with a maximum error of + or - 0.1 mg;
- efficiency: in the rig of Fig. 1 circular paper specimens were tested at their operating velocities by a uranin aerosol, generated according to AFNOR Std NFX 44011 (a typical measured size distribution is shown in Table 2); particle concentration values were measured by a ROYCO 5200 laser spectrometer;
- mechanical resistance: air flow across circular specimens (flow area= 100 cm^2) was increased up to rupture and pressure drop on the paper was measured;
- visual: the aspect of the microfibers was examined by scanning electron microscopy.

III. Results

Weight loss

Data are summarized in Table 3: a weight loss only a little greater than the maximum combustible value reported by the manifacturers, was observed in some cases; most weight is lost at 300 C but the 20 % of the total loss is already experienced at 200°C. No relevant differences appear between the two classes of papers.

Penetration

When efficiency test procedure starts up and before test aerosol generation is operated, clean air flows through the specimen; in this phase, heated up papers "discharge" a noteworth amount of particles whose dimensions are in the range 0.1-2 microns; clearly they aren't test aerosol particles. The presence of particles in the flowing air continues 35-40 minutes about, depending on overheating and paper type. After this time only few particles in the size range 0.1-2 microns are detected (examples are shown in Tables 4,5 and Figs 2,3) and uranin tests show only small changes of the penetration values, surprisingly even at high overheatings (see Tables 6-11).

Mechanical resistance

Pressure drops measured at the paper rupture are reported in Table 12; data demonstrate that both ULPA and HEPA papers suffer not

negligeable diminuition of resistance also at 200°C. A 400°C heat up reduce rupture pressure drop at about less than a half of the initial value. In the aspect of the broken papers, no particular difference, to be related to different heatup process, was noted.

Structure

Samples of paper were examined by scanning electron microscopy to verify possible modifications of structure.

No meaningful alterations were observed at 100°C. At 200°C papers become brown and the microfibers appear covered with small lumps and deposits due to melting of the organic matter used to improve their flexibility; also a few ruptures of the fibers were found, particularly in the folds.

Raising up the temperatures (300 - 400°C) the microfibers become "clean", being the organic matter destroyed by heat and ruptures become more frequent, especially along the folds: their dimensions are small and look like cracks: the efficiency of the papers are slightly affected, being the area of the cracks very small, but the mechanical resistance fall down perhaps because of earlier crack propagation.

IV. Conclusions

ULPA and HEPA filtering papers, when subjected to abnormal conditions due to overheating, show only a small decrease of their "cleaning capacity" but loose their resistance to rupture: SEM shows organics in the papers are modified and finally disappear while the number of small cracks is growing up.

This phenomenology should not be neglected when ULPA and HEPA filters are claimed to operate at high temperature: it might be of major importance where joint occurrence of overheating and pressure pulses is expected.

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Table 1: Characteristics and properties of the papers.

PAPER	PENETRATION %	ΔP, mm H_2O at 32 l/m, 100cm^2	COMBUSTIBLES %	THICKNESS mm	TENSILE MD KN/m
ULPA 1	0.0001	63	5	0.38	1.35
ULPA 2	0.0001	50	5	0.38	1.04
ULPA 3	0.001	53	5	0.38	1.35
ULPA 4	0.001	50	5	0.38	1.35
ULPA 5	0.001	42	5	0.38	1.04
ULPA 6	0.001	44	5	0.38	1.35
HEPA 1	0.015	32	5	0.33	1.04
HEPA 2	0.015	36	5	0.46	1.47
HEPA 3	0.030	33	5	0.28	0.96
HEPA 4	0.090	28	5	0.38	1.15
HEPA 5	0.015	36	5	0.38	1.35

Table 2: Test aerosol size distribution.

SIZE RANGE	PARTICLES/CFT	%
01 - 0.2 µm	10687300	87
0.2 - 0.3 "	1282400	10
0.3 - 0.5 "	258800	2
0.5 - 1.0 "	10900	0.9
1.0 - 2.0 "	2000	0.1
> 2	< 10	=

Note: a TSI mod. 3302 diluter (dilution ratio 1/100) was used

Table 3 : Heat up of ULPA and HEPA papers - Weight loss.

PAPER TYPE	% WEIGHT LOSS AT:				
	100 °C	200 °C	300 °C	400 °C	500 °C
ULPA 1	0.20	1.70	6.50	7.00	7.20
ULPA 2	1.20	4.80	6.20	7.50	7.80
ULPA 3	0.18	1.10	4.20	5.00	5.30
ULPA 4	0.19	1.05	4.20	4.95	5.25
ULPA 5	0.29	2.27	4.11	5.00	==
ULPA 6	0.25	1.27	5.34	6.36	==
HEPA 1	0.38	0.96	1.92	2.30	2.68
HEPA 2	0.66	2.32	5.36	5.96	6.13
HEPA 3	0.68	2.03	4.73	5.41	5.74
HEPA 4	0.37	1.12	4.85	5.22	5.60
HEPA 5	0.18	1.10	4.34	5.43	==

Note: A brownish colour appears at 200 °C and completely disappears at 400 °C about. Colour intensities are different depending on the paper types.

Table 4 : Release of particles from ULPA 3 heated up to 200 °C.

PARTICLE SIZE (μ m)	PARTICLES/l (at the start)	PARTICLES/l after 30'
0.1	225	180
0.2	20	6
0.3	12	0
0.5	8	0
1.0	6	0
2.0	3	0

Table 5 : Release of particles from ULPA 3 heated up to 400 °C

PARTICLE SIZE (μ m)	PARTICLES/l (at the start)	PARTICLES/l after 30'	PARTICLES/l after 1 h
0.1	1625	223	170
0.2	828	65	31
0.3	506	38	15
0.5	315	26	9
1.0	145	13	4
2.0	79	7	3

Table 6 : Penetration (*) of ULPA papers, heated up to 200°C, against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION x 10^5 (0.1 - 0.2µm)	PENETRATION X 10^5 (0.2 - 0.3µm)	PARTICLES/l x 10^5 (0.1 - 0.2µm)	PARTICLES/l x 10^5 (0.2 - 0.3µm)
ULPA 1	0.24	0.53	7	n.d.
ULPA 2	1.4	0.4	68	4
ULPA 3	1.1	0.4	59	2
ULPA 4	1	0.2	43	2
ULPA 5	8.6	1.7	508	22
ULPA 6	10.9	2.4	647	28

(*) Values measured at the end of the release phase.

Table 7 : Penetration (*) of ULPA papers, heated up to 400°C, against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION X 10^5 (0.1 - 0.2μm)	PENETRATION x 10^5 (0.2 - 0.3μm)	PARTICLES/l (0.1 - 0.2μm)	PARTICLES/l (0.2 - 0.3μm)
ULPA 1	0.2	1	6	1
ULPA 2	1.2	0.45	48	4
ULPA 3	1.3	0.7	46	5
ULPA 4	1	0.6	27	2
ULPA 5	10.8	3.9	473	34
ULPA 6	9.6	2.4	438	24

(*) Values measured at the end of the release phase.

Table 8: Penetration of ULPA papers against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION X 10^5 (0.1 - 0.2μm)	PENETRATION x 10^5 (0.2 - 0.3μm)	PARTICLES/l (0.1 - 0.2μm)	PARTICLES/l (0.2 - 0.3μm)
ULPA 1	0.2	0.43	6	0.13
ULPA 2	0.2	0.1	7	0.15
ULPA 3	1.8	0.3	88	2
ULPA 4	1.9	0.4	97	3
ULPA 5	4.8	1.4	271	9
ULPA 6	7.7	1.8	371	19

Table 9: Penetration of HEPA papers against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION x 10^4 (0.1 - 0.2μm)	PENETRATION x 10^4 (0.2 - 0.3μm)	PARTICLES/l (0.1 - 0.2μm)	PARTICLES/l (0.2 - 0.3μm)
HEPA 1	1.5	0.3	650	80
HEPA 2	1.6	0.4	680	85
HEPA 3	3.2	0.7	1200	90
HEPA 4	12	5	4200	350
HEPA 5	11	4	4100	360

Table 10 : Penetration (*) of HEPA papers, heated up to 200°C, against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION x 10^4 (0.1 - 0.2μm)	PENETRATION X 10^4 (0.2 - 0.3μm)	PARTICLES/l (0.1 - 0.2μm)	PARTICLES/l (0.2 - 0.3μm)
HEPA 1	1.66	0.4	536	36
HEPA 2	1.85	0.6	630	45
HEPA 3	3.4	0.9	1160	74
HEPA 4	12.8	4.3	4337	370
HEPA 5	10.8	3.8	3573	323

(*) Values measured at the end of the release phase.

Table 11 : Penetration (*) of HEPA papers, heated up to 400 °C, against particle size (air velocity: 2 cm/sec).

PAPER TYPE	PENETRATION x 10^4 (0.1 - 0.2μm)	PENETRATION x 10^4 (0.2 - 0.3μm)	PARTICLES/l (0.1 - 0.2μm)	PARTICLES/l (0.2 - 0.3μm)
HEPA 1	2.1	0.5	853	31
HEPA 2	1.6	0.4	709	31
HEPA 3	4.5	1.4	1614	61
HEPA 4	12	5	4863	265
HEPA 5	12.2	4.5	4657	233

(*) Values measured at the end of the release phase.

Table 12 : Rupture pressure drop of ULPA and HEPA papers
(test on disks of 100 cm^2 surface)

PAPER TYPE	(1) THICKNESS (mm)	(1) TENSILE MD (KN/m)	(1) ΔP at 32 l/min (mm H_2O)	(2) ΔP (mm H_2O)	(3) ΔP (mm H_2O)	(4) ΔP (mm H_2O)
ULPA 1	0.38	1.35	63	85	51	22
ULPA 2	0.38	1.04	50	57	49	28
ULPA 3	0.38	1.35	53	71	45	29
ULPA 4	0.38	1.35	50	77	51	31
ULPA 5	0.38	1.04	42	46	37	30
ULPA 6	0.38	1.35	44	60	46	24
HEPA 1	0.38	1.04	32	54	38	30
HEPA 2	0.46	1.35	36	58	47	30
HEPA 3	0.28	0.96	33	53	28	12
HEPA 4	0.38	1.35	28	47	==	==
HEPA 5	0.38	1.35	36	61	38	19

(1) Manifacturers' values
(2) Paper as delivered
(3) Paper heated up to 200°C
(4) Paper heated up to 400°C

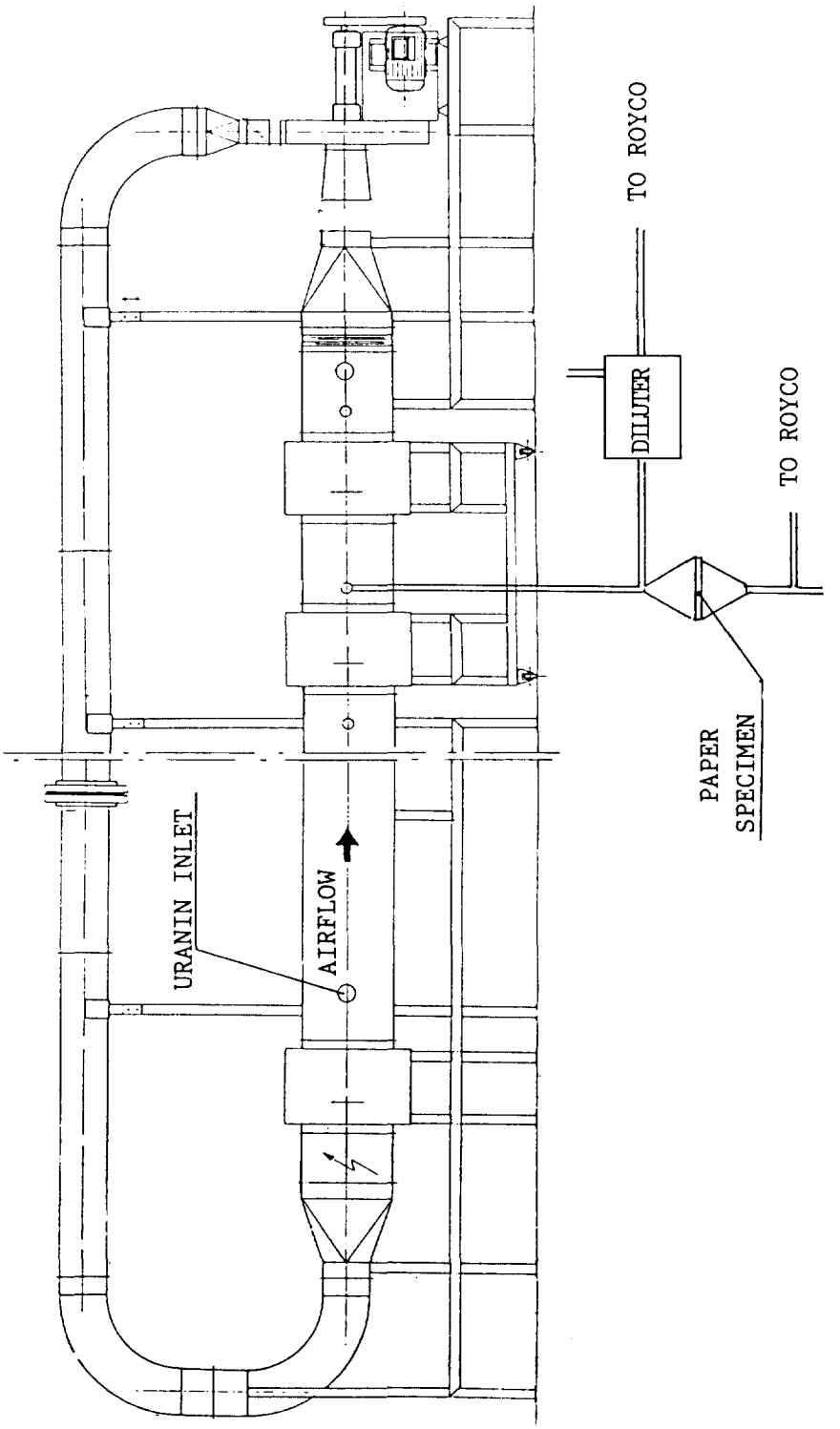

Fig. 1: EFFICIENCY TEST RIG

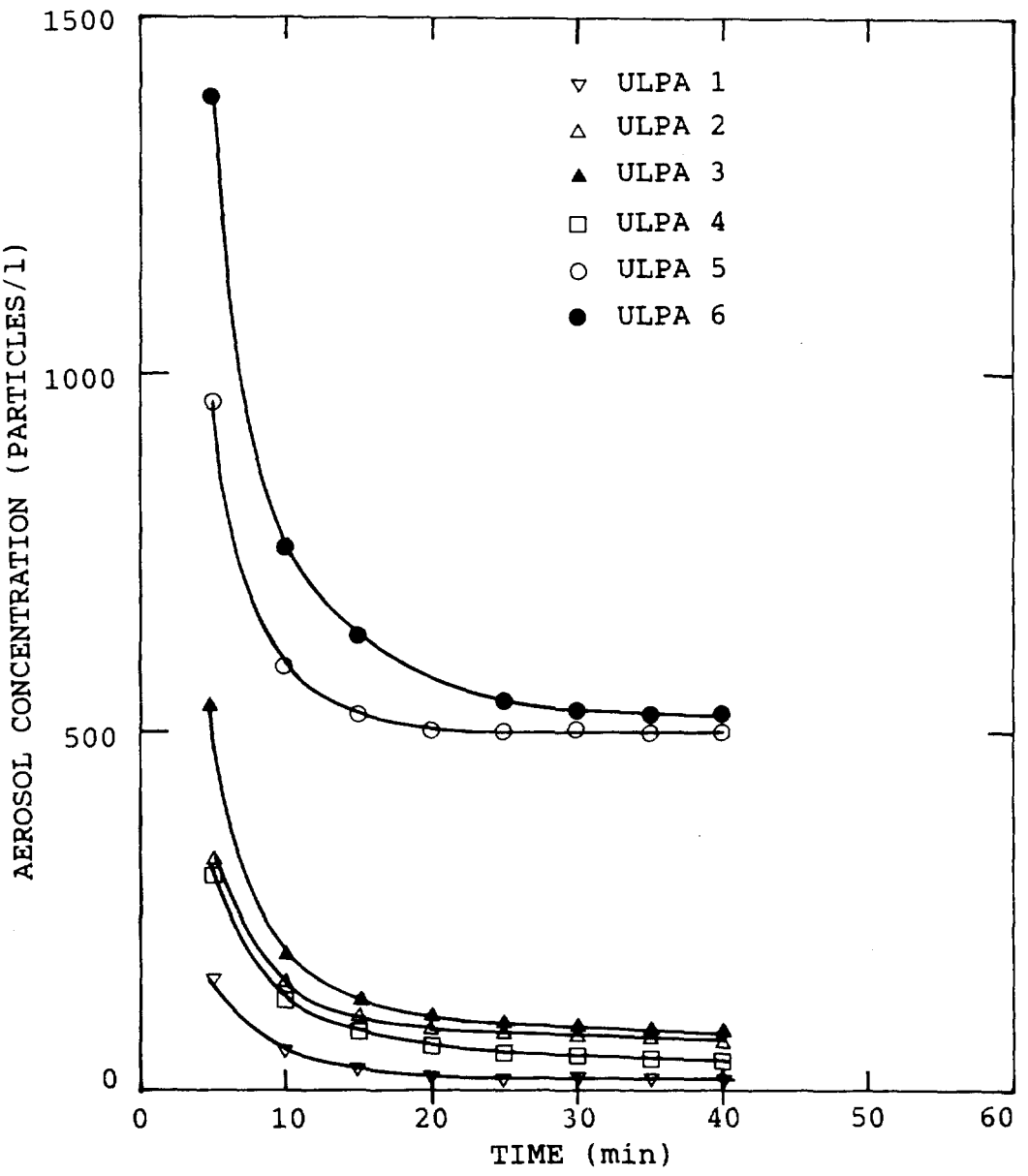

FIGURE 2
ULPA PAPERS HEATED UP TO 400 °C: RELEASE

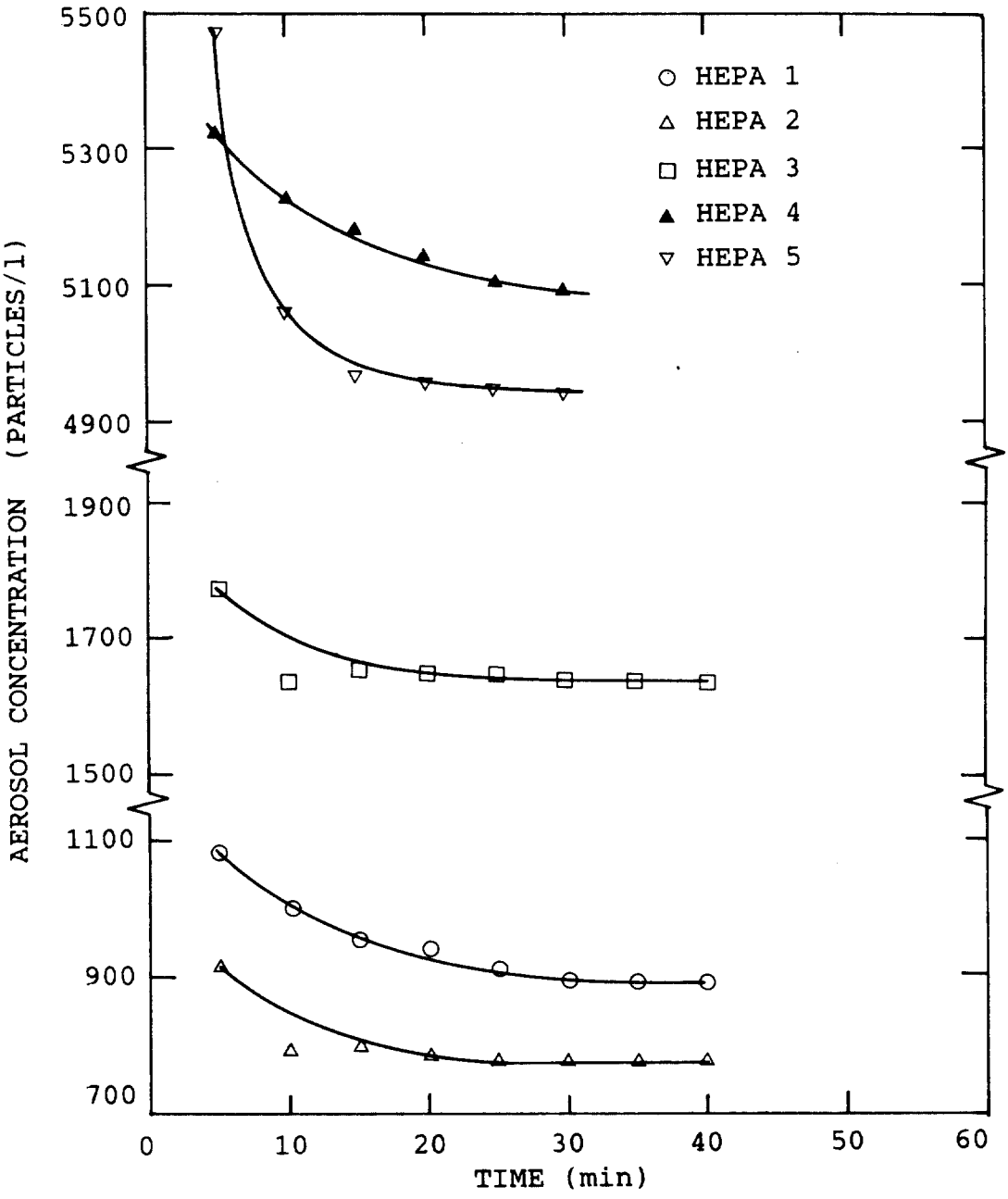

FIGURE 3
HEPA PAPERS HEATED UP TO 400 °C: RELEASE

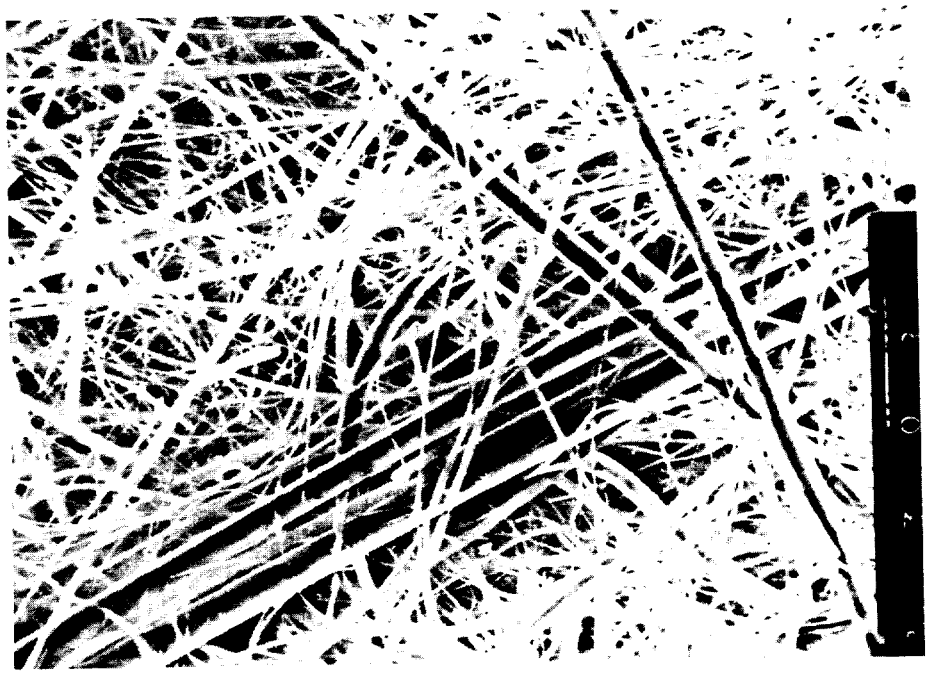

Fig. 4 - Reference Specimen ULPA 5. Magn. x 1,000

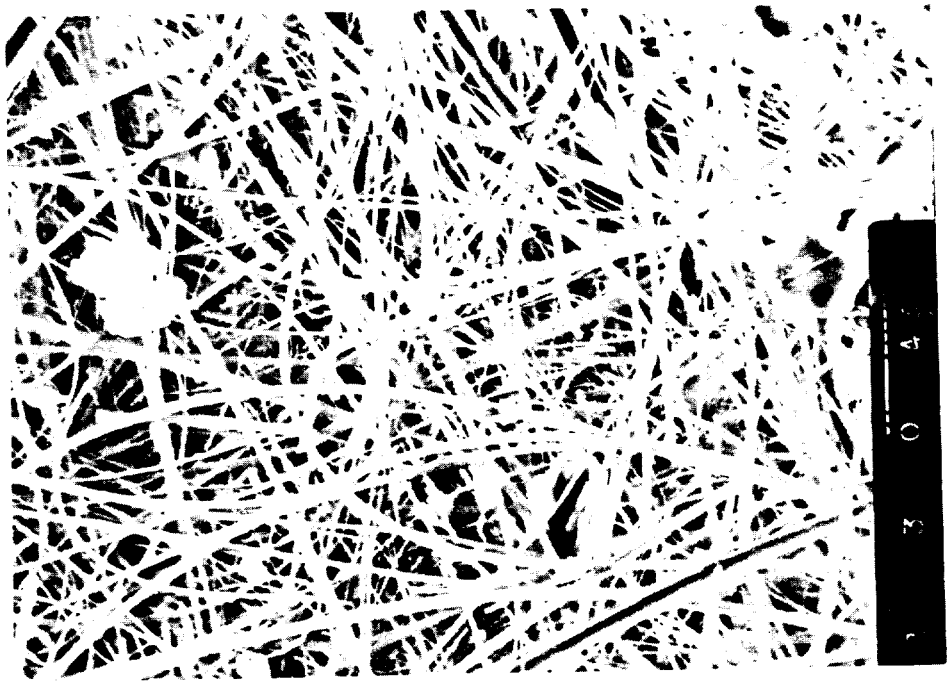

Fig. 5 - ULPA 5 heated up to 200 °C. Magn. x 1,000

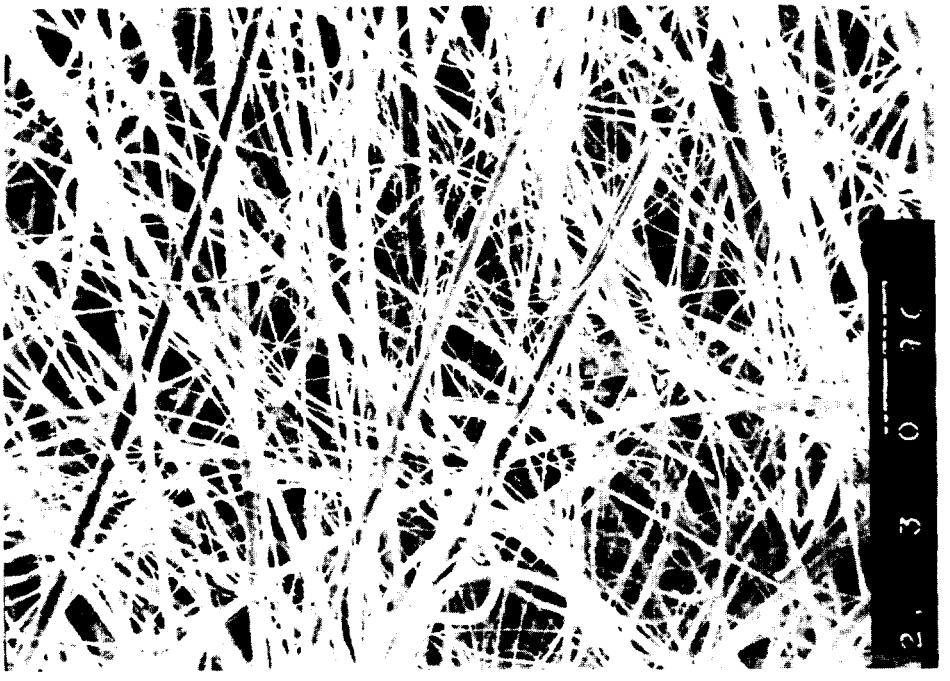

Fig. 6 - ULPA 5 heated up to 400 °C. Magn. x 1,000

Fig. 7 - ULPA 5 heated up to 200 °C Magn. x 200

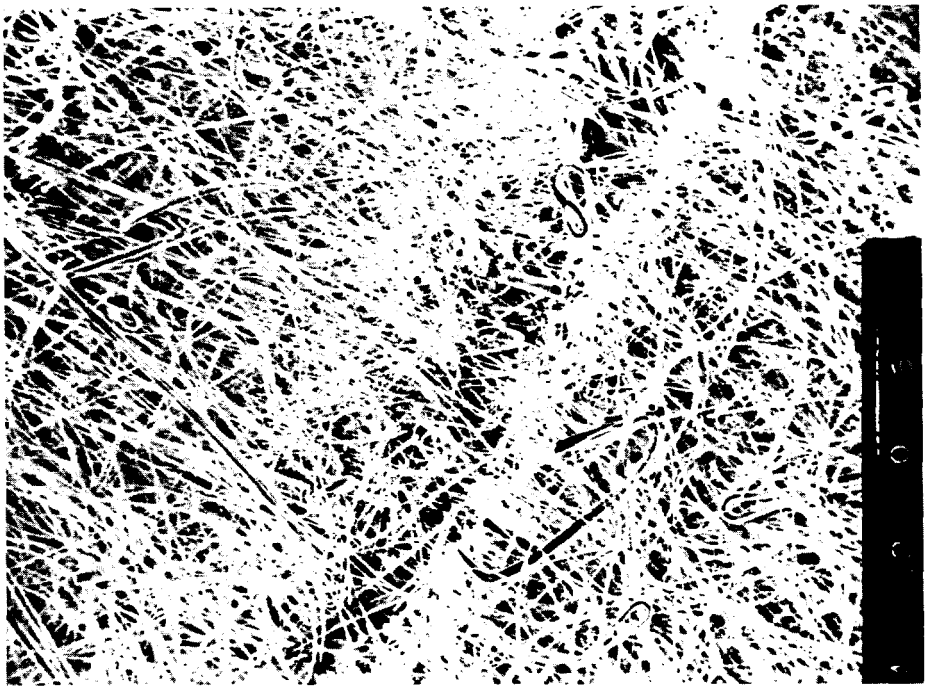

Fig. 8 - ULPA 3 heated up to 200 °C. Magn. x 300

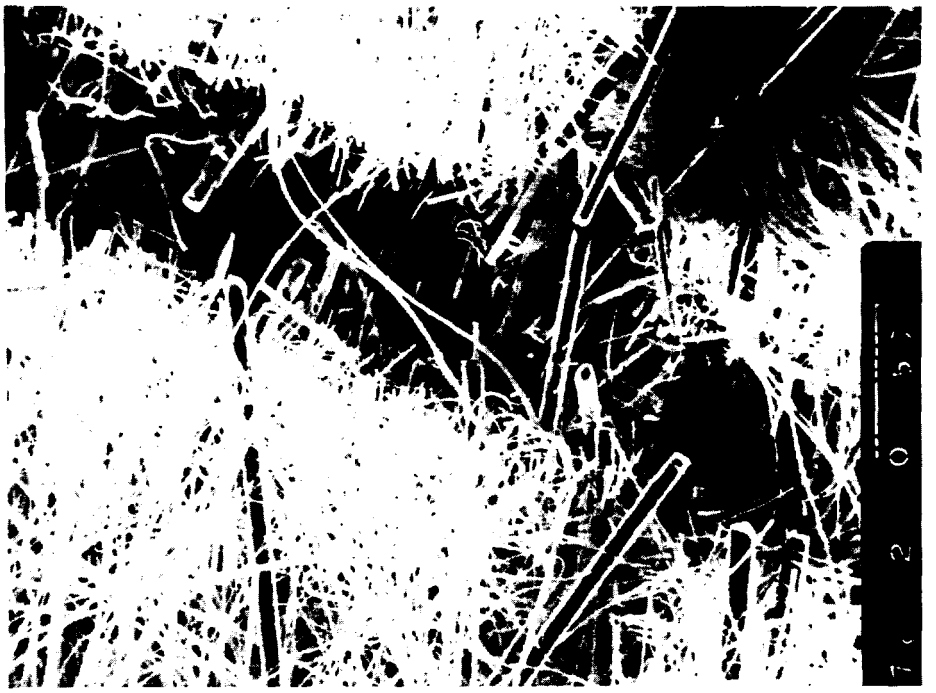

Fig. 9 - ULPA 3 heated up to 200 °C. Magn. x 600

PERFORMANCE LIMITATIONS OF HEPA FILTERS AT HIGH TEMPERATURES

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ABSTRACT

Over the last few years a number of studies have investigated the performance of High Efficiency Particulate Air (HEPA) filters under simulated accident conditions modelling a fire or high temperature airflow.

Earlier studies have concentrated on evaluating the insert performance when subjected to hot airflows at 500°C through the clean filter. This temperature was selected on the basis of a static oven test for flammability required by the purchasing specification. At these temperatures, the work showed that the filters could fail catastrophically. Calculations have shown that the temperature seen by main filter banks, distant from the source of a fire, would be of the order of 250°C[1].

The work has now extended to an investigation of the performance of loaded, as opposed to clean filters at temperatures up to 275°C thereby attempting to produce a more representative model of the real fire/accident condition. The work reported here has considered three filter designs and records their performance at temperatures of up to 275°C for periods of up to 24 hours. The filters all have an initial pressure differential of 750 Pa produced by loading with a test dust.

I. INTRODUCTION

High Efficiency Particulate Air (HEPA) filters are an essential part of the ventilation system of any nuclear facility. By providing an effective clean up of gaseous waste they ensure safe low level discharge of particulate to the environment. However, an unexpected high temperature excursion, such as that caused by a fire, must be allowed for in the plant design.

Current practice within the United Kingdom is to evaluate the performance, in terms of burst strength and efficiency to BS 3928[2], of a high temperature HEPA filter following a static oven test, 500°C for 10 minutes. It has been postulated that this is not a representative model of a true fire accident. Therefore, with a view to establishing the performance of HEPA filters using a more realistic model, the Hot Dynamic Filter Test Rig was built at Harwell (Fig. 1). This allows air, at flows of up to 3400 standard m^3/h and temperatures not exceeding 500°C, to pass through the filter and housing under evaluation whilst recording the state of the system, filter pressure differential, filter efficiency, flowrate, etc. Differential pressures of up to 400 mm water gauge across the test filter can be accommodated.

Previous work[3,4,5] investigated the performance under hot dynamic conditions of the three basic types of HEPA filters commonly used by the UKAEA and British Nuclear Fuels plc:

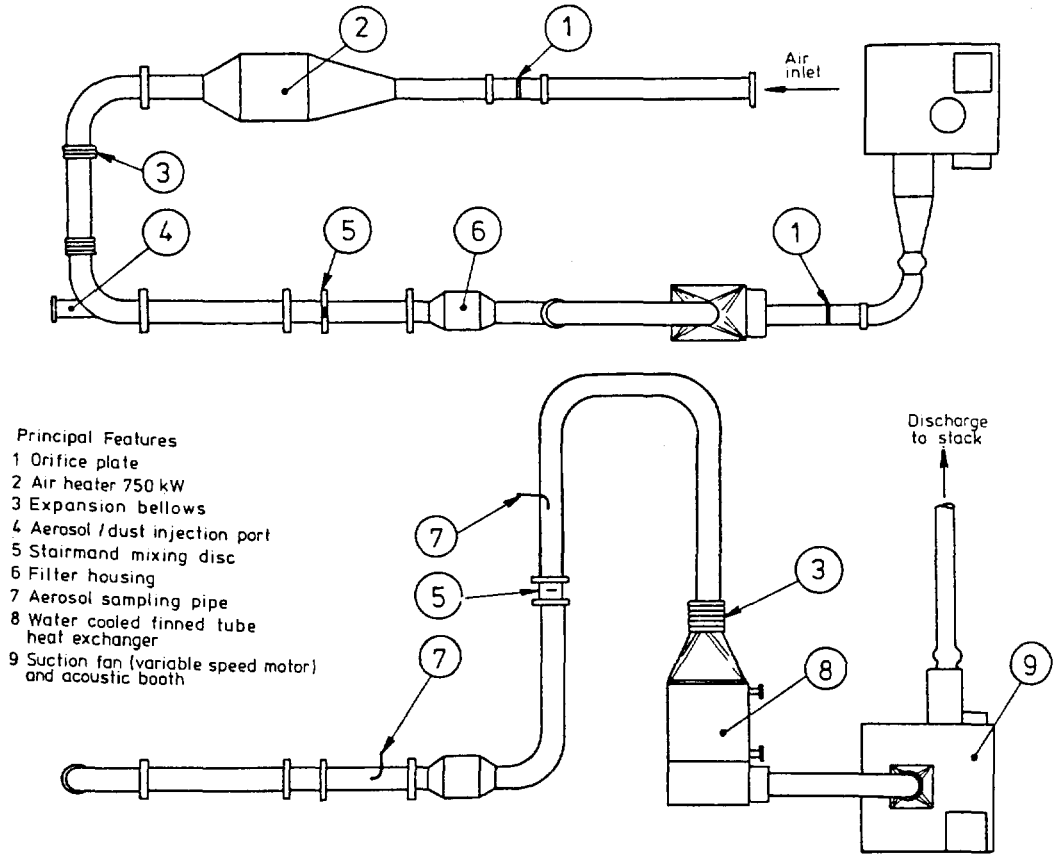

Figure 1 : Hot Dynamic Filter Test Facility

Type A - Conventional deep-pleat construction, incorporating aluminium spacers between folds of glass fibre medium. A compressed matt of glass fibre material or "dry seal" seals the filter pack into the steel case. The filter measures 609 x 609 x 292 mm and has a minimum efficiency of 99.95% (NaCl) at its rated flow of 1700 m^3/hr, (Fig. 2).

Type B - Conventional deep-pleat construction, with aluminium spacers separating the folds of glass fibre medium. A high temperature adhesive seals the filter pack into a steel case. The filter measures 609 x 609 x 292 mm and has a minimum efficiency of 99.95% (NaCl) at its rated flow of 1700 m^3/hr, (Fig. 2).

Type C - Mini-pleat construction, comprises panels of pleated medium laid up in vee formation within a steel filter case. The same high temperature adhesive used in the construction of the Type A filter seals the panels into case. The filter measures 609 x 609 x 292 mm and has a minimum efficiency of 99.95% (NaCl) at its rated flow of 3000 m^3/hr, (Fig. 3).

The preliminary studies concentrated on the effect of the high temperature excursion on clean rectangular HEPA filters and, in the light of the results,

have recommended certain design improvements, which are now incorporated in current designs. The work has now progressed to assessing the performance of loaded filters under hot dynamic conditions.

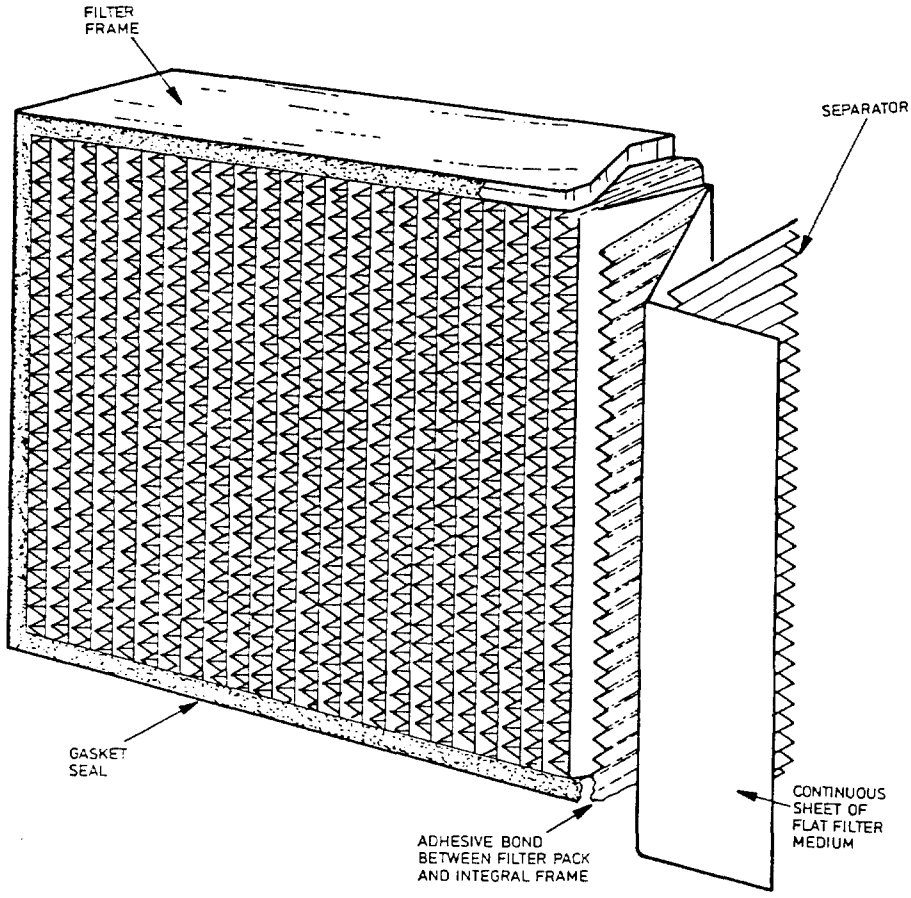

FIGURE 2 : Deep Pleat HEPA Filter (Type A and B)

The work reported here assesses the performance of the filters at temperatures of up to 275°C and at differential pressures of up to 3 kPa.

II. TEST PROGRAMME

Filters are initially loaded at ambient temperature with carbon black test dust to 750 Pa. They are then subjected to a hot dynamic test of up to 275°C at a constant mass flow rate and the dust loading continued at temperature until the filter reaches a pressure differential of 3 kPa; the test temperature is maintained for up to 24 hours. The results include measurements of the filter efficiency and pressure drop before, during and after the test. In addition, the filter is visually inspected.

In some cases the filters are subjected to a paraffin leak test to locate leak paths through the filter. This method is used when the efficiency of the filter is lower than expected and damage to the medium is suspected.

III. RESULTS

The results are summarised in Table 1.

Table 1
Summary of Results

Filter Reference	Type	Flow m^3/h	Max. Temp. °C	Penetration % (NaCL)								Comments
				At 20°C Clean	At 20°C 750 Pa	At. Temp. 750 Pa	At Temp. 3000 Pa	At Temp. 6 hours	At Temp. 12 hours	At Temp. 24 hrs	At 20°C	
1	A	1700	275	0.018	0.001	0.79	-	-	-	-	-	Leakage around drypack; medium shrunk from case; pleats opened up.
2	A	1700	275	0.008	0.001	0.11	0.37	0.68	-	-	0.49	Leakage around drypack; medium shrunk from case; pleat opened up.
3	A	1700	275	0.021	0.006	0.42	0.44	-	-	-	0.51	Medium shrunk from case; pleat opened up.
4	A	1700	200	0.001	0.004	0.17	0.09	0.20	0.14	-	0.08	Leakage around dry pack at top and bottom of filter.
5	A	1700	200	-	0.008	0.01	0.04	0.22	-	-	-	30mm tear down pleat.
6	A	1700	200	-	0.001	0.06	0.04	0.11	0.10	-	0.02	Paraffin check showed leakage around drypack; pleat opened up.
7	A	1700	200	0.012	0.001	0.01	0.02	0.45	1.06	-	1.71	30mm x 10mm long tear down pleat; medium pulling from sides; pleats opened up.
8	A	1700	200	0.021	0.001	0.06	0.56	0.91	-	-	0.70	Medium pulling away from sides of case; pleats opened up.
9	B	1700	275	0.008	0.001	0.01	0.01	0.05	-	-	0.04	Paraffin check showed small leak in corner through sealant; pleats opened up.
10	B	1700	275	0.006	0.001	0.07	0.94	-	-	-	0.36	Pleats opened up.
11	B	1700	275	-	0.023	0.41	-	-	-	-	0.37	Paraffin check showed leak at top of filter through sealant.
12	B	1700	275	0.052	0.049	FAIL	-	-	-	-	0.49	Poor initial efficiency; sealant cracked; pressure differential high.
13	B	1700	275	0.003	-	0.01	0.01	0.03	0.04	0.16	0.49	Paraffin check showed penetrations through sealant; pleats very swollen.
14	B	1700	250	0.007	0.004	0.01	0.01	0.02	0.01	0.01	0.03	Paraffin check showed small leak on edge of filter through sealant.
15	B	1700	250	-	0.007	0.05	0.48	0.39	0.52	0.48	0.35	Paraffin check showed leak on edge of filter through medium and sealant; pleats very swollen.
16	C	3040	250	-	0.001	0.01	0.06	0.02	0.06	0.40	0.40	Paraffin check showed leakage adjacent to case.
17	C	3040	250	-	0.001	0.01	0.01	0.04	-	-	-	Paraffin check showed leakage adjacent to case; pressure differential high; medium channels appear blocked.

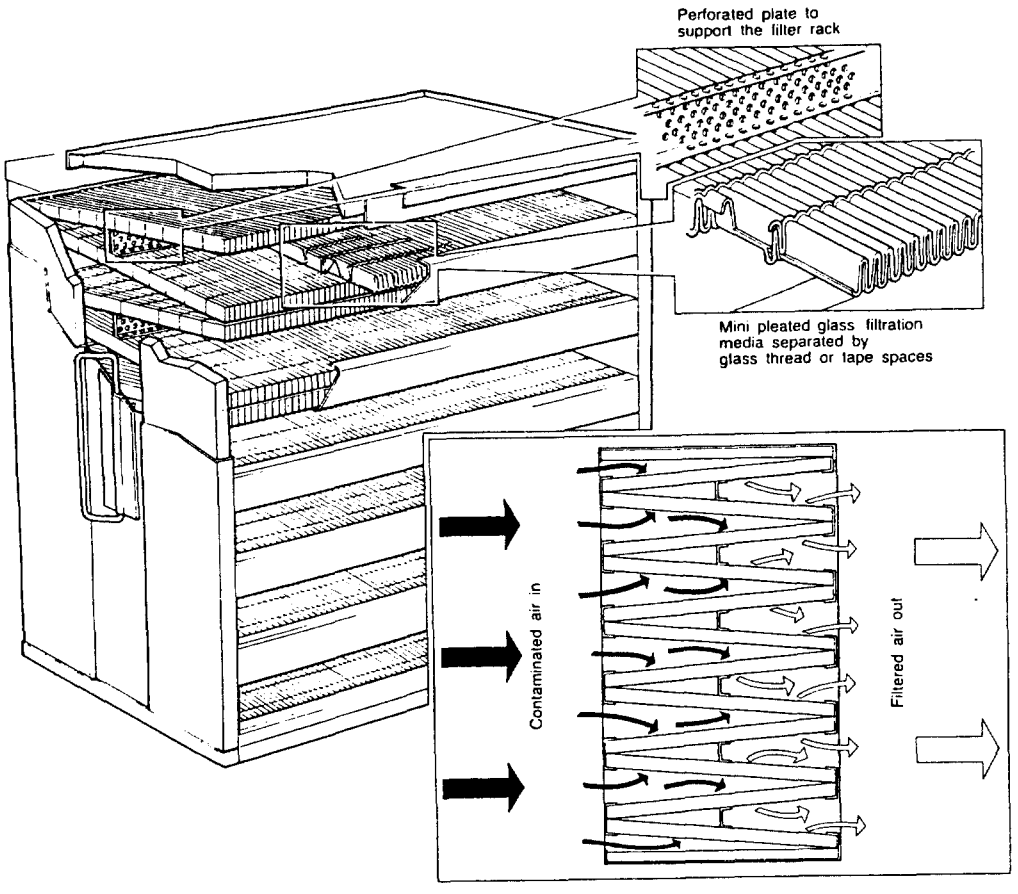

FIGURE 3 : Mini-Pleat HEPA Filter (Type C)

IV DISCUSSION OF RESULTS

i) Type A Filters - Dry Pack Sealant

Test Temperature - Ambient

The dry pack filters behaved at ambient temperature as would be expected for this design of filter having a penetration when clean of about 0.02%, this reduced to about 0.005% when loaded to 750 Pa with a test dust, in this case carbon black.

Test Temperature - 275°C

The results show that at temperature the efficiency of the filters deteriorated significantly. At 275°C the filter penetration increased by at least an order of magnitude. In one case, filter 1, the penetration had increased to 0.8%. The filter was removed from the rig and inspected for damage. The inspection revealed a large leak at the bottom of the filter caused by the dry pack starting to separate from the filter case. The tests continued on the two remaining filters 2 and 3; after dust loading at temperature to 3 kPa the penetration through both filters increased to about 0.4%. Both filters were inspected and filter 3 showed the same failure mechanism displayed by the earlier filter, i.e. a leak path between the dry pack and the filter case; filter 2 showed no obvious damage and no carbon black penetration. Tests continued on filter 2;

after running it for 6 hours at temperature (275°C) the penetration increased to 0.7%.

Test Temperature - 200°C

As a result of the above tests the test temperature for the remaining 5 drypack filters was restricted to 200°C. The tests on these filters consisted of dust loading to 3 kPa at 200°C followed by a period of operation at temperature for up to 12 hours.

Of the five filters tested, filter 8 had a penetration of 0.56% after dust loading at 200°C to 3kPa and the remaining four filters had penetration of less than 0.1%. However, with time at temperature the penetration through these four filters increased. For filter 7 the penetration increased to above 1%. For four out of the five filters tested, the dry pack shrunk away from the filter case allowing an unfiltered leak path through the filters.

ii) Type B Filters - Solid Sealant

Test Temperature - 275°C

Of the five filters tested at 275°C, two maintained a penetration of < 0.01% even after dust loading at temperature to 3 kPa, (filters 9 and 13). Extending the tests on these two filters over 6 hours caused their penetration to increase to about 0.05%.

Although the filters showed no visible signs of damage a paraffin leak test revealed a leak path on the edge of the filter possibly through the sealant or more likely through the medium adjacent to the sealant. In both cases, the pressure differential gradually increased throughout the test. An inspection after the tests revealed swollen pleats and flattened spacers between the pleats, (Fig. 4).

The three remaining filters all showed an increased penetration at 275°C, (filters 10, 11 and 12). The penetration of filter 10 increased at 275°C to 0.9% after loading at temperature to 3 kPa; there were no noticeable areas of carbon black penetration. Filters 11 and 12 had high initial penetrations, an order of magnitude higher than expected for this filter design. The filter penetrations increased markedly from the beginning of the tests.

An inspection of filter 12 showed a patch of carbon black penetration adjacent to an area of cracked sealant. The filter probably had a defect prior to the test and the combination of increased volumetric air flow (constant mass flowrate) and temperature probably caused the defect to open up. Filter 11 showed no noticeable carbon black penetration, however, a paraffin leak test revealed a large leak at the top of the filter adjacent to the sealant. Leakage via the gasket had been ruled out as the cause of the high penetration by rechecking the efficiency with a new silicone gasket replacing the glass gasket.

Test Temperature - 250°C

Filters 14 and 15 were tested at a reduced temperature of 250°C. For filter 14 the penetration increased to 0.01% after dust loading at temperature to

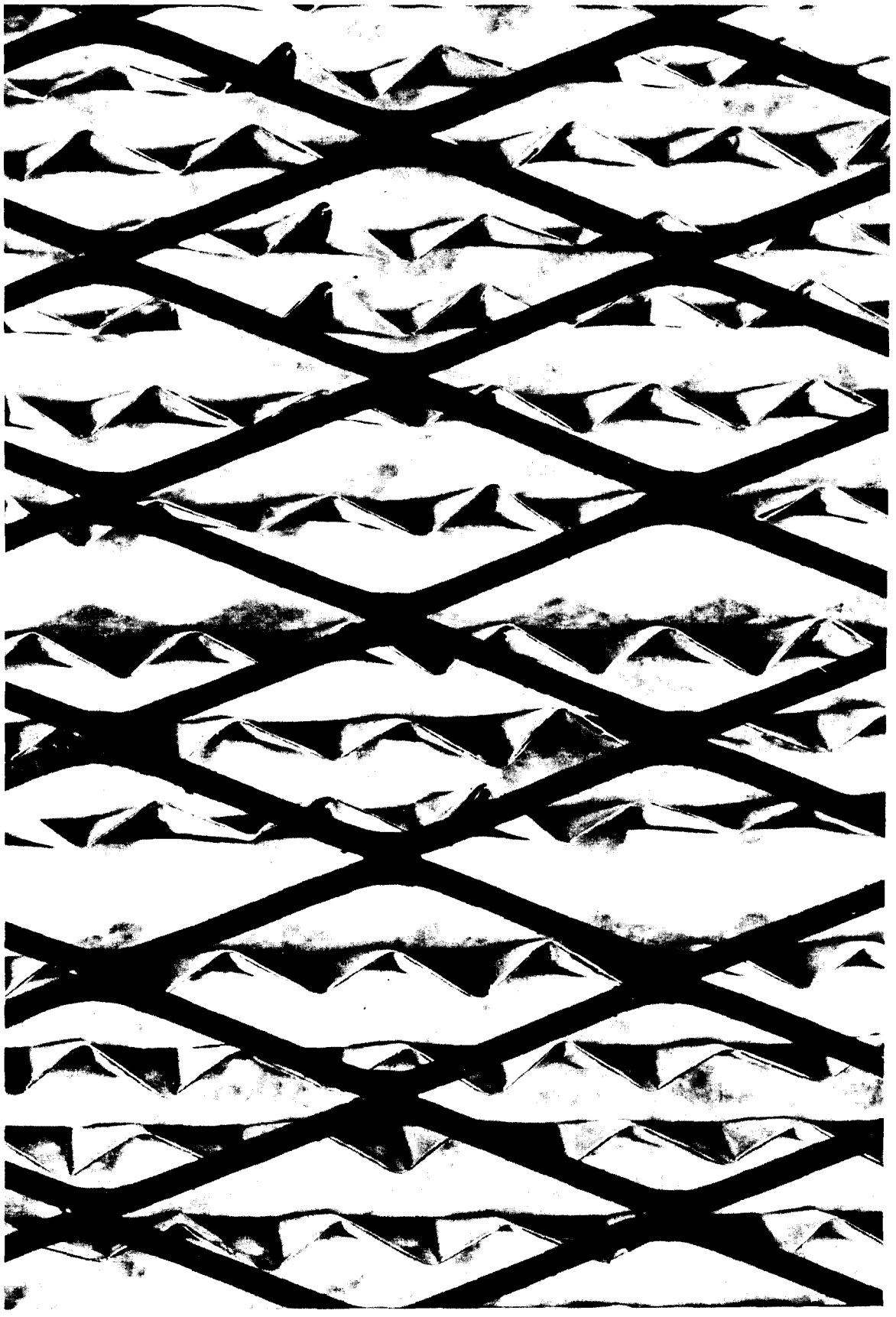

FIGURE 5: SWOLLEN PLEATS OF TYPE B FILTER AFTER 250°C TEST

3 kPa and, after a run for 24 hours at 250°C, maintained a low penetration of 0.03%. A paraffin leak test showed one small area of leakage adjacent to the sealant.

The penetration of filter 15 increased to 0.05% at 250°C and after testing for 24 hours to 0.4%. No obvious areas of carbon black were visible, however, the paraffin leak test revealed penetration over all of the filter face, i.e. through the medium.

In both cases the pressure drop increased throughout the 24 hour test due to the swelling of the pleats, especially filter 15, see Fig. 4.

Type C Filters - High Capacity

Filters 17 and 18 were subjected to a testing at 250°C. After testing for about 6 hours their penetrations had increased from 0.001% to 0.05%. During this period of time the pressure differential had shown a tendency to increase continuously due to the closing up of individual mini-pleat channels. The high pressures prevented further tests on filter 18, although tests on filter 17 continued. The efficiency remained good but decreased suddenly between 18 and 24 hours. A visual examination revealed no obvius areas of penetration.

Gaskets

For filter 14 after 12 hours of testing at 250°C the filter had a recorded penetration of 0.01%. However, when retested at ambient temperature, the penetration increased to 0.39%. The cause was traced to the glass gasket; with a silicone gasket fitted the penetration returned to 0.01%.

Filters 17 and 18 both used silicone gaskets. The tests on filter 17 extended over 24 hours at 250°C, the gasket remained in good condition.

V. CONCLUSIONS

From these results it appears that:

Type A Filters - Dry Pack

(i) Above 200°C the medium and drypack shrinks away from the filter case allowing an unfiltered leak through the filter.

(ii) Because of the mode of failure this filter design is not recommended for use in plant which may be subjected to a temperature excursion of > 200°C. Further work is required to establish the maximum operating temperature of these filters.

Type B and C Filters - Solid Sealant

(iii) Above 250°C leakage tends to occur adjacent to the filter case possibly through cracks in the sealant or small tears in the medium, however, usually no visible leak path can be seen.

(iv) This work indicates that if used at temperatures of 250°C or less for periods up to 24 hours, these filter designs will achieve penetrations of less than 1%.

Gaskets

(v) Glass gaskets perform well at temperatures of up to 275°C for periods up to 24 hours. However, they may not remain fully effective when the temperature returns to ambient.

(vi) Silicone gaskets work well at temperatures of up to 275°C for 24 hours, they appear to seal well at ambient conditions even after such an excursion.

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DISCUSSION

PORCO: On your solid sealant, can you identify the type used in the filters under test? There are various types that can be used. Did you evaluate others?

PRATT (for Stewart): I can not identify it, it is a proprietary brand of sealant developed by a European filter manufacturer. I guess that is all I can say about it. It is a mineral-based sealant.

EFFICIENCY OF HEPA FILTERS AT ELEVATED TEMPERATURES: INVESTIGATIONS WITH THE TiO_2 TEST METHOD*

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Abstract

Knowledge of the variations in HEPA filter efficiency at elevated temperatures is an important prerequisite for estimating the release of particulate radioactivity in the case of an accident in a nuclear power plant. The experimental data available up to now cannot be considered sufficient for reliable estimates.

Efficiency measurements were carried out with the TiO_2-test method, specially suited for use under extreme conditions. Standard size deep-pleat HEPA filters from four different manufacturers were tested at temperatures up to 250 °C under static and at rated airflow of 1700 m^3/h.

The experimental results in partial contradiction to filtration theory showed both increases and decreases in efficiency with rising temperature. This may be explained by structural changes observed in the filter medium of the filter units tested. All units tested under airflow showed a loosening of the filter pack. In some cases kinks in the filter pleats near the bottom close to the frame were observed. Local damages resulting from such structural changes may have caused reductions in filtration efficiency, apparently supported by partial decomposition of the organic binder. This was confirmed by additional efficiency measurements carried out at room temperature on filter units after repeated exposure to 250 °C in an oven.

The findings show that the efficiency of filter units at elevated temperatures is governed not only by the effects of temperature on the filtration mechanisms but can also be influenced by filter mechanical alterations resulting from thermal stress of the temperature sensitive construction materials, especially at longer exposure times.

I. Introduction

HEPA filters are installed in nuclear power plant ventilation systems as passive containment devices to prevent the discharge of particu-

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late radioactivity under both normal and accident conditions. To fulfill this task the performance of filter units commonly used must be known for extreme conditions.

For filter operation at elevated temperatures the data available up to now are not sufficient to assess whether proper particulate removal is assured. Theoretical analysis of the probable effects of elevated temperatures provide a guide to performance only when there are no internal changes within the filter medium or to the components which seal the filter medium to the frame. The commonly used standard filtration efficiency test methods developed for use under ambient conditions are not suited for measurements under extreme conditions.

Therefore, the variation in HEPA-filter efficiency for standard size units was studied with the TiO_2 test method which was specially developed for investigations under accident conditions. Results obtained at temperatures up to 250 °C are reported here.

II. Literature Survey

Mechanisms of Particle Removal

Theoretically, the effects of temperature on the filtration efficiency of HEPA filters depend upon the dominant removal mechanisms for the particle sizes involved. For small particles of diameters < 0.2 µm, an improvement in the predominantly diffusion controlled removal can be expected from an increase in temperature. Larger particles, for which primarily inertia forces dominate are removed less efficiently at elevated temperatures than under ambient conditions /1, 2/.

However, for elevated temperatures it is difficult to make reliable predictions of changes in the removal efficiency of HEPA filters. On one hand, the particles already collected in the filter matrix will improve the decontamination factor /3/. This is an effect to be taken into account principally for filters with extended service lives. On the other hand, the adhesive forces acting between the particles and the filter medium are not of significant magnitude /4/. If during thermal challenges the particles became detached again, this would result in a deterioration in filter efficiency. In the filter elements used in nuclear power plants particle removal can also be influenced by the thermal stability of the filter medium organic binders, the gasket material, and the adhesive sealant. Therefore, theoretical analysis alone will not lead to reliable estimates on the removal behavior of HEPA filters at elevated temperatures. This is the reason why experimental studies are necessary.

Investigation of Removal Efficiencies on Samples of Filter Media

The results of investigation into changes in filtration efficiency of filter samples at elevated temperatures usually agree with the theoretical predictions. For example, First /5/ observed a decrease of the decontamination factor for CuO particles of 8.5 µm median diameter after an increase in temperature up to 760 °C. This behavior could be expected from the removal of particles by forces of inertia.

Investigations with particles of diameters of ≤ 0.3 µm, for which

diffusion controlled removal should predominate, have shown that the removal efficiency increases with increasing temperature to a maximum of about 300 °C. The test aerosols used for these studies were NaCl /6/, uranine /7/, and tracered noble metal oxides /8/.

Investigation of Removal Efficiencies on Filter Units

In contrast with the above findings, the investigation of removal efficiencies performed with NaCl and uranine aerosols on HEPA filters of the 610x610x292-mm standard size up to temperatures of 500 °C, have yielded rather contradictory results.

Dillmann and Pasler, e.g., observed a distinct increase in removal efficiency with increasing temperature for deep bed metal fiber filters /9/ and Briand et al. made the same observation for glass fiber filters /10/. The investigation by Pratt and Green did not yield results indicating a clear tendency /11/. First found a reduction in removal efficiency with increasing temperature /12/.

According to Briand et al. the duration of the thermal challenge seems to be of major importance /13/. For some filter types the removal efficiency at constant temperature sometimes deteriorated substantially within one hour; presumably this was due to damage to the adhesive sealant and the beginning of decomposition of the binder. In all filters investigated smoke was observed to develop at or above 175 °C.

According to Pratt the loss of binder is accompanied by decreases of up to 60% in the filter medium tensile strength /11/. The influence of the duration of thermal challenge is evident also from the investigations by Dyment in which standard filter elements were repeatedly exposed to different, but constant temperatures. The removal efficiency was measured with NaCl under ambient conditions between heating cycles. At 300 °C and above, the removal efficiency deteriorated with increasing duration of the thermal challenge /14/.

III. Thermal Stability of the Test Aerosols

The applications of the NaCl and uranine test aerosols previously used in investigations of the removal efficiency are limited by the thermal stability of these tracer substances. Because of the increasing vapor pressure, NaCl should not be used at temperatures > 350 °C /15/. Uranine has been used at temperatures up to 200 °C /9/; in rare cases even up to 250°C /7/. However, if thermal loading lasts for an extended period, it is recommended to use the tracer only up to a temperature of 120 °C because of possible decomposition at higher temperatures /16/. A recently developed test method employs a stable compound, namely TiO_2. The method is explained below.

IV. Description of the TiO_2 Method for Removal Efficiency Testing

The test procedure /17/ specially developed for investigating the removal efficiencies of HEPA filters under accident conditions is represented schematically in Fig. 1. Fine grained TiO_2 powder is dispersed by a brush dispenser into an argon carrier gas stream which is fed to a commer-

cial 20-kW plasma burner. The powder vaporizes instantaneously and during subsequent cooling a solid condensation aerosol is formed. To prevent chemical reactions from taking place, argon is used as the plasma gas to which a few volume percent of helium or hydrogen has been mixed in order to increase the thermal power of the plasma burner.

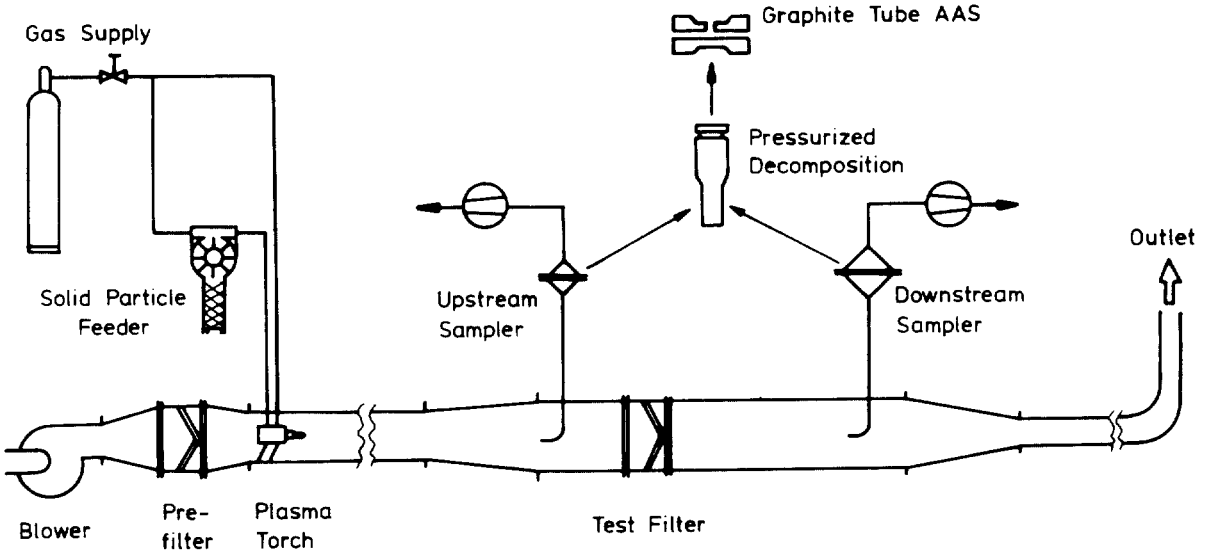


Fig. 1: Schematic of the TiO_2 Plasma Aerosol Test Method.

The determination of the removal efficiency is a discontinuous process. For this, aerosol samples are collected isokinetically from upstream and downstream of the test filter onto Nuclepore sampling filters. The samples are then dissolved under pressure at 200 °C in a mixture of concentrated nitric acid and concentrated hydrofluoric acid. After dilution of the resulting aqueous solutions to an acid content < 1 mole/l, the titanium content is determined by flameless atomic absorption spectroscopy.

The aerosol particles are nearly spherical in shape. The particle size distribution of Fig. 2 was assessed using a scanning electron microscope. The mean geometric diameter is 0.04 μm, with a standard deviation of 1.2. Other characteristic parameters of the TiO_2 method of removal efficiency testing have been compiled in Tab. 1. The test method is specific for the compound under test and allows decontamination factors on the order of 5×10^4 to be determined reliably.

Table 1: Characteristics of the TiO_2 filter efficiency test method.

Mass concentration	1-3 mg/m³
Sampling time	10-30 min
Sampling volume flow	0.5-8 m³/h
Detection limit	0.1 µg/m³
Temperature limit	500 °C
Air humidity limit	100% r.h.

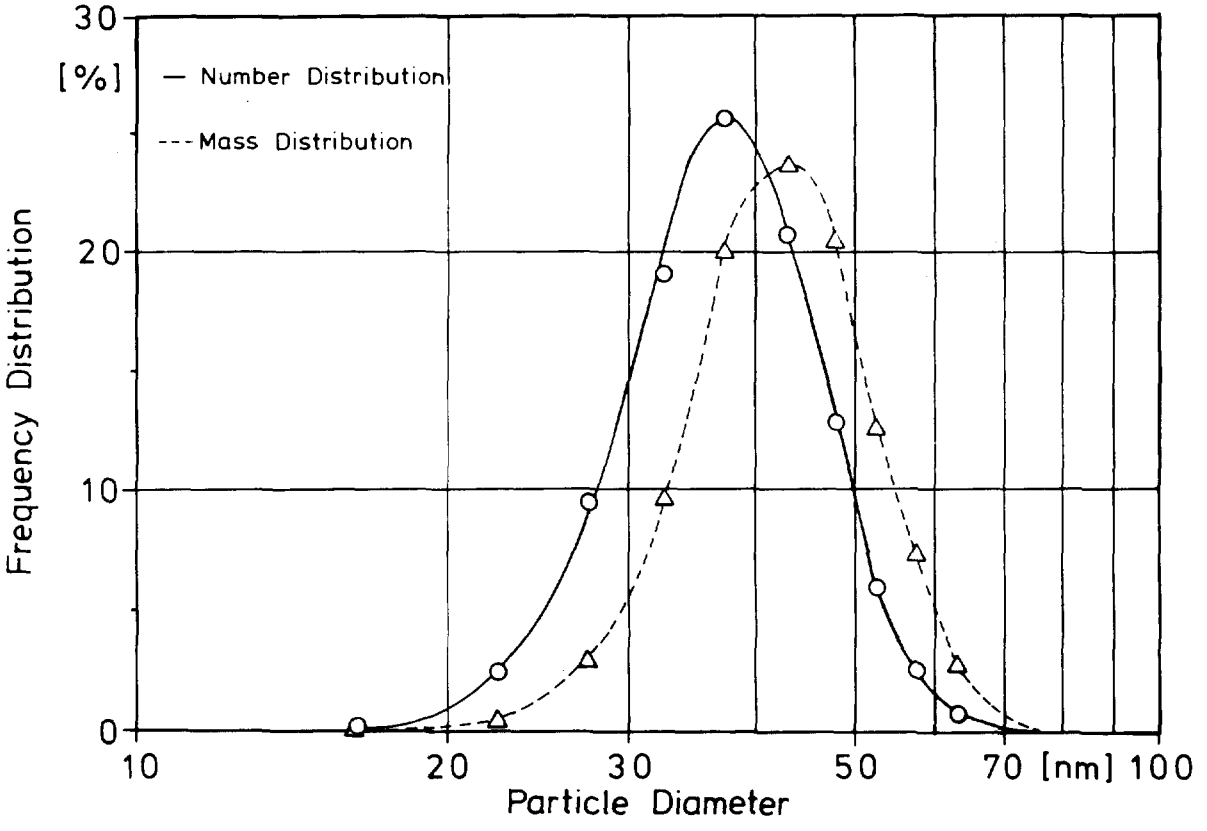


Fig. 2: Number and Mass Distributions of TiO_2 Condensation Aerosol.

Comparative filtration efficiency measurements using standard test methods yielded good agreement. The other methods included the US DOP in-place test with pneumatically generated aerosols /18/, the British sodium chloride test using collision generated aerosols /19/, and the French standard test with uranine as the tracer /20/. On account of the small particle sizes, the decontamination factors determined with the TiO_2 aerosol are slightly higher than the corresponding values determined with DOP, sodium chloride and uranine, although, on the average, not higher than by a factor of about two /21/.

V. Experimental Investigations

Measurements of Removal Efficiencies with TiO_2 at Elevated Temperatures and Design Airflow

Test Facility. Filtration efficiency tests with TiO_2 at elevated temperatures were performed in the BORA test rig, a facility built for investigation of HEPA filters under the individual or combined challenges of high differential pressure, high humidity or elevated temperature /22/. With the two speed-controlled blowers, tests can be carried out with airflows of up to 100,000 m^3/h or differential pressures of up to 70 kPa. Air humidities up to 100% r.h. and temperatures up to 350 °C can be attained. Both steady-state and transient test conditions can be implemented.

The test facility was modified as shown in Fig. 3 to provide for aerosol generation and representative sampling so as to perform removal efficiency measurements. The aerosol generator, consisting of a powder metering device and a plasma generator, was installed in a bypass duct of the facility. The solid condensation aerosol was pneumatically supplied to the test airstream.

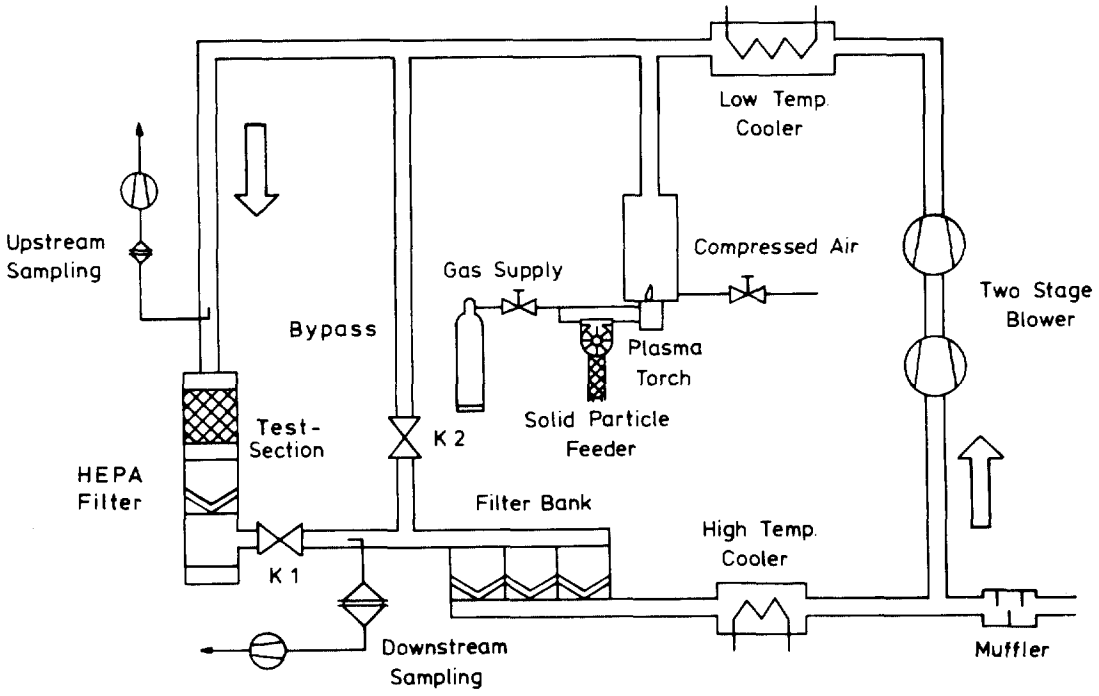


Fig. 3: Schematic of the Filtration Efficiency Test Set-Up in BORA.

Experimental. For determination of the removal efficiency the test facility was operated in a closed loop. The compression heat delivered by the blowers was used to raise the air temperature to the desired level for the test. Up until constant test conditions were obtained, the volumetric flow of 1700 m^3/h was routed through the bypass. As also indicated in Fig. 3, by closure of the valve K2 and opening of the valve K1 the air was then directed through the test filter. The downstream face of the test filter was monitored by a video camera system.

The temperature was increased in increments of about 70 ^0C and kept constant during the efficiency measurements. The removal efficiencies were measured up to 250 ^0C. This value is given by most manufacturers as the upper limit for continuous operation of HEPA filters. Two measurements of the removal efficiency were made at each temperature level. Each efficiency measurement lasted about a total of one hour.

Test Filters. In the investigation commercial deep-pleat high temperature HEPA filters of the size 610x610x292 mm from four manufacturers were tested. The design characteristics of the different filter types have been compiled in Table 2.

Table 2: Characteristics of the 610x610x292-mm deep-pleat HEPA filters used for efficiency tests at elevated temperatures.

Filter type	Frame	Sealant/ Gasket	Service Temperatures (°C) short term	continuous
AM	Aluminium	Silicone	-	260
CM	Stainless steel	Ceramic/ Silicone	-	250
DM	Stainless steel	Silicone	300	250
VM	Carbon steel	Glass fiber	500	250

Removal Efficiency. Figures 4 and 5 show some typical test results. The decontamination factors of the filters with an aluminium frame, type AM, clearly decreased with increasing temperature. At 220 °C, The DF for AM 11 was only about 30% and for AM 10 less than 10% of the initial value obtained under ambient conditions. A similar reduction of the decontamination factor was observed for the DM type filters equipped with stainless steel frames. With these filters the decontamination factor decreased to values between 50% for DM 02 and 20% for DM 05 with increasing temperature as seen in Fig. 4.

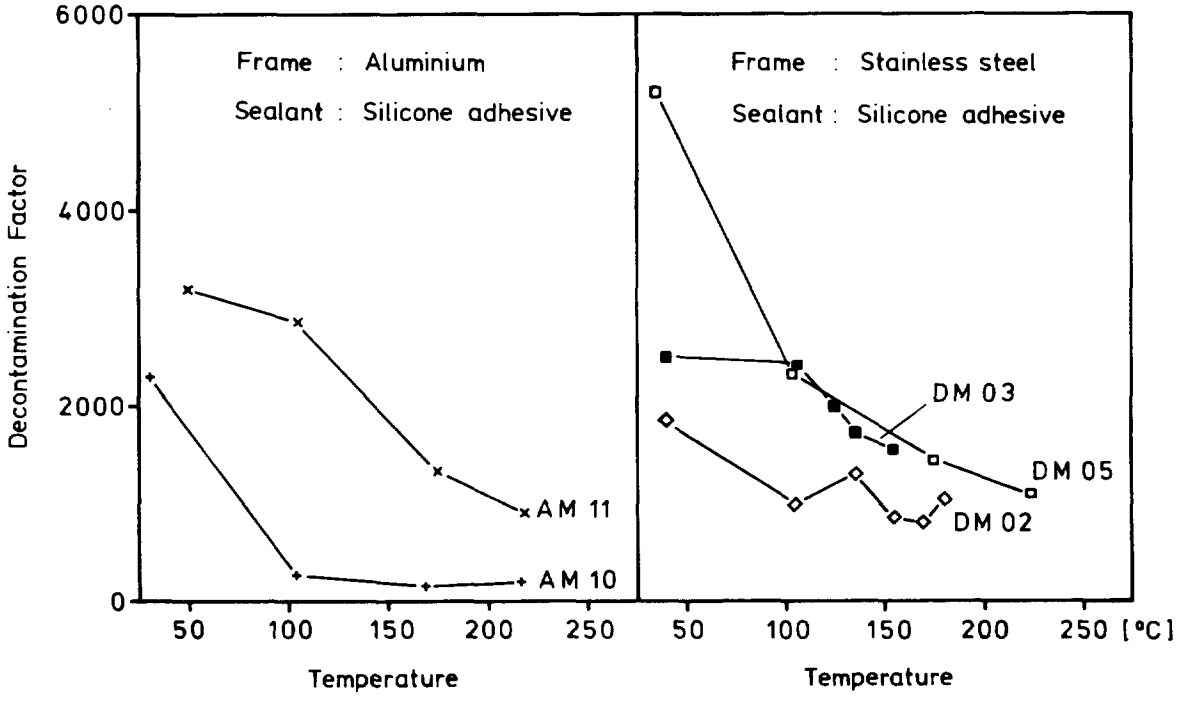


Fig. 4: Decreases in the DFs of Type AM and DM Filters at Elevated Temperatures and 1700 m³/h.

Fig. 5 indicates that for the CM and VM type filter units, the variation of removal efficiency was not as uniform. As the temperature increased, both a reduction in the decontamination factor, for filter CM 03 and VM 08, and an increase in the DF for filter CM 04, were found. In the case of the filter unit VM 12 the decontamination factor initially dropped while the temperature increased to 100 °C, but it increased again, when the temperature further rose to 170 °C. On the whole, the changes in removal efficiency were less pronounced for the filter types CM and VM.

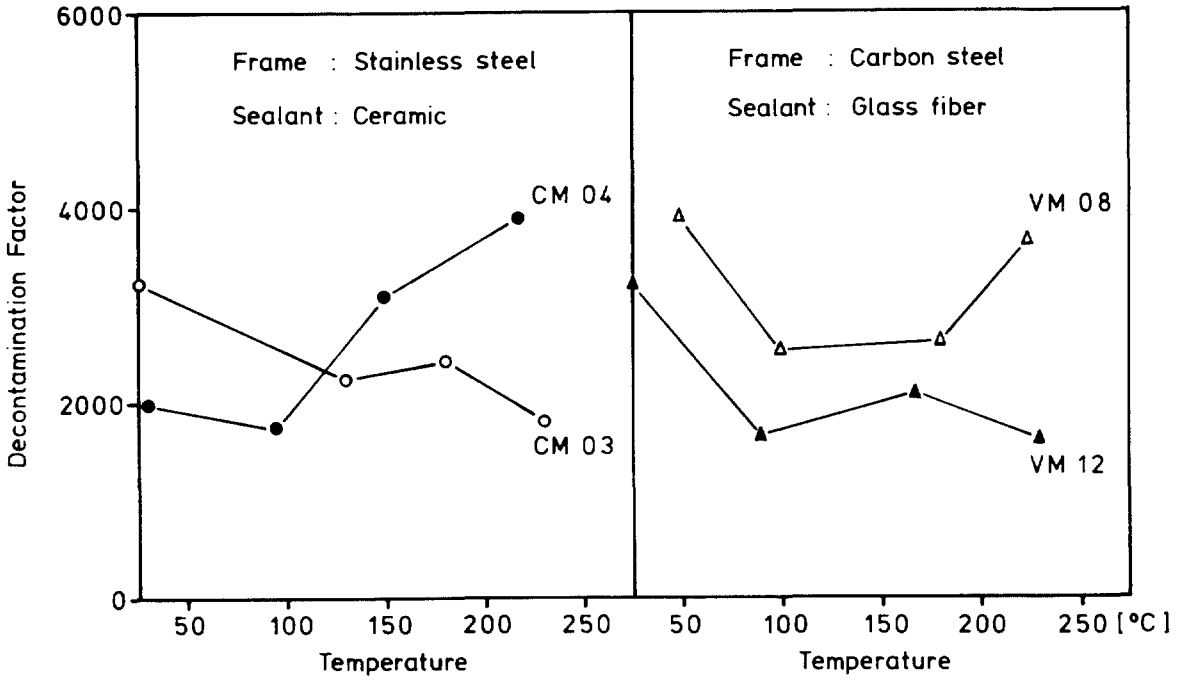
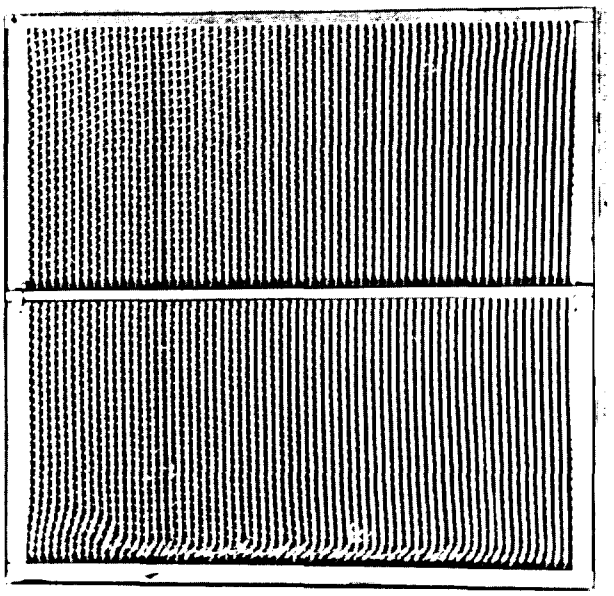


Fig. 5: Changes in the DFs of Type CM and VM Filters at Elevated Temperatures and 1700 m^3/h.

Changes at the Filter Pack. After the dynamic tests, the packs of all tested filters had distinctly loosened and the filter medium had changed color and become brownish. In locations close to the bottom of the pack, kinks in some pleats were observed for the filters sealed into stainless steel frames with a silicone or ceramic adhesive. This phenomenon was particularly distinct on the downstream face of the filter, as illustrated in Figs. 6 and 7, and first appeared at temperatures between 160 °C and 180 °C.

The filter packs sealed to aluminum frames did not exhibit such changes. It can be seen from Fig. 8 that in the type AM filters a gap formed between the pack and the frame on the upstream side due to the loosening of the filter pack. In the VM type filters with a sealant of glass fiber matting, no significant changes were observed on the pack.



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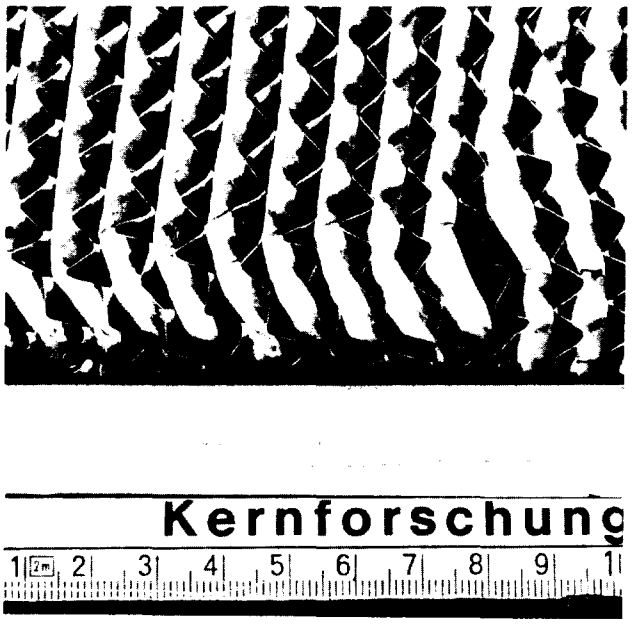

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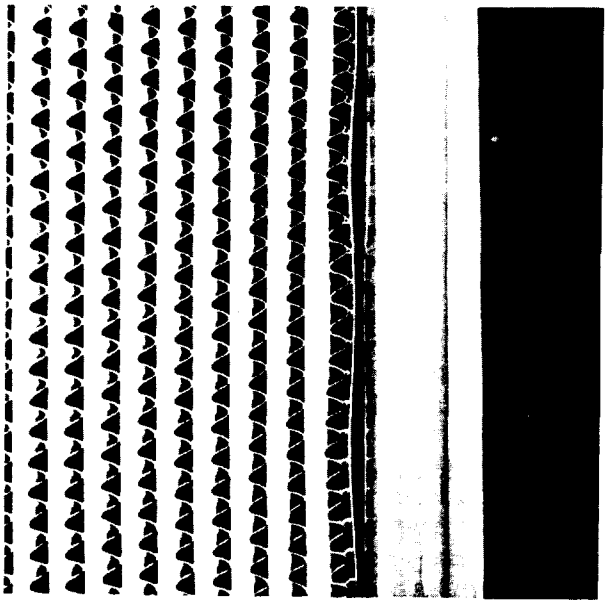

(8)

Alterations in filter pack after exposure to elevated temperatures at design airflow.

Fig. 6: Kinked Pleats on Downstream Side of Filter.

Fig. 7: Close-Up Photo of Kinked Pleats.

Fig. 8: Gap Between Filter Pack and Frame.

Additional Measurements of Removal Efficiencies After Exposure to Elevated Temperatures Under Static Conditions.

To supplement the studies of changes in removal efficiency at elevated temperatures at the BORA test rig, tests were performed in which HEPA filter units were first heated to 250 °C in a laboratory oven in the absence of air flow. The removal efficiencies were subsequently measured at room temperature after allowing the filters to cool. The removal efficiency was first determined after two hours of exposure to elevated temperature and at 24 hours intervals thereafter.

In order to avoid errors in the results due to filters loading with test aerosol particles in the course of as many as 10 measurements per filter, the uranine test was used as the method of testing at minimum mass concentration in the air. The results have been plotted in Fig. 9. In four of the six filter elements investigated, which included types AM, CM, and VM, the decontamination factors clearly decreased as the duration of thermal exposure increased. In the AM type filters a drastic reduction in the DF was found after only two hours of heating to 250 °C. For only two HEPA filters, one each of types CM and VM, did the removal efficiency remain unchanged, even after 82 hours of exposure. Except for a discoloration of the filter medium, no changes in the pleated medium were visible as a result of these tests.

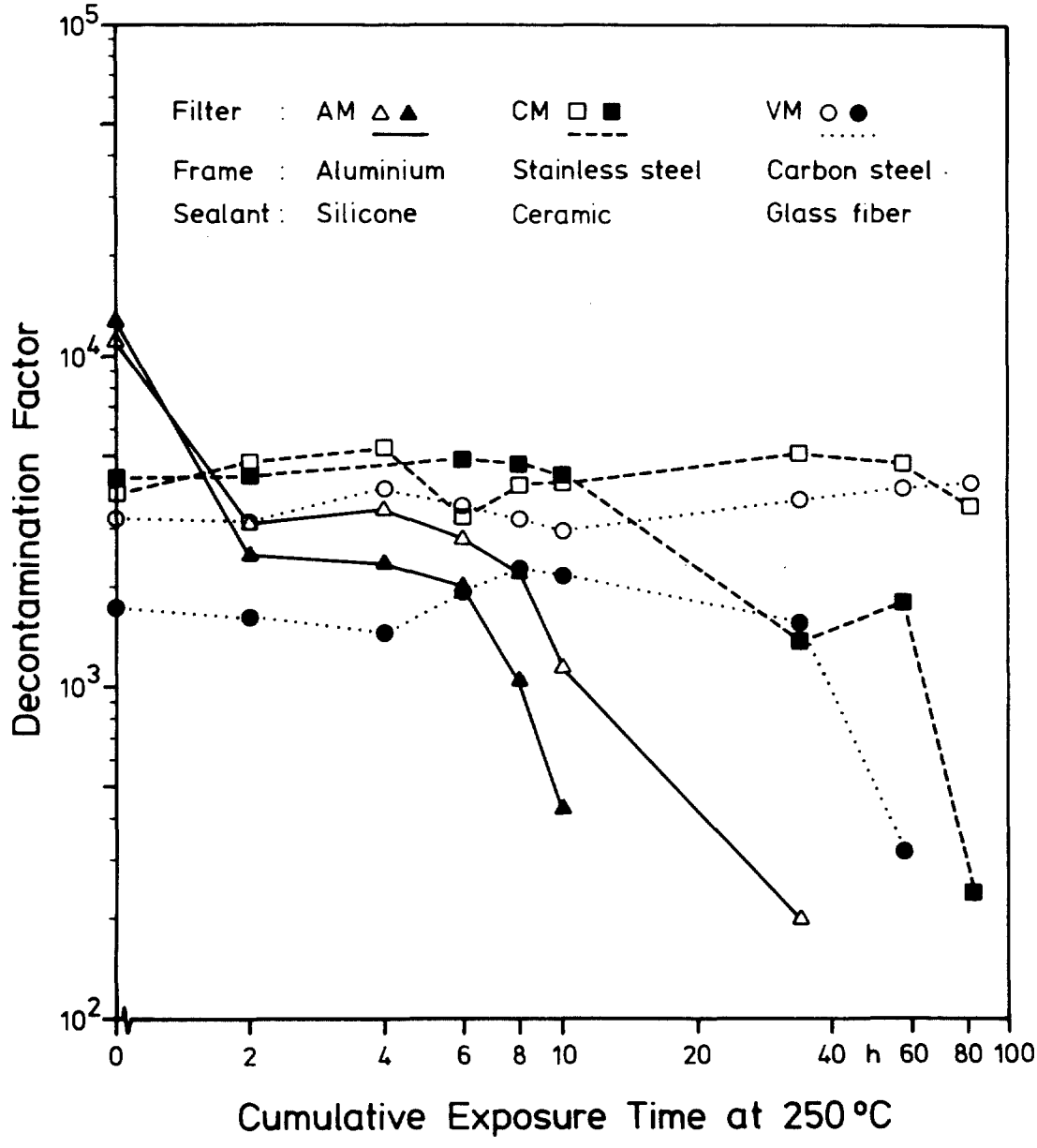

Fig. 9: Changes in the DFs of HEPA Filters at 20 °C After Repeated Exposure to 250 °C Under Static Conditions.

VI. Discussion

Filter Damage

The discolorations observed in the filter medium are indications of a partial decomposition of the organic binder which has been reported by other authors /11, 13/. Mechanical changes in the pack as a result of the thermal challenge apparently occurred only when the filters were simultaneously exposed to an air flow.

This could be the result of the mechanical loading of the filter medium by the differential pressure due to the airflow, together with the pack construction characteristics. Fig. 10 shows two possible arrangements of the adjacent separators in a filter pack /23/. In case (a) the peak to peak pattern permits mechanical loads to be transferred between separators without producing significant additional tensile stresses in the filter medium or play in the filter pack. This is not true for case (b). The arrangement of the separators in commercial HEPA filters is a random distribution between these cases.

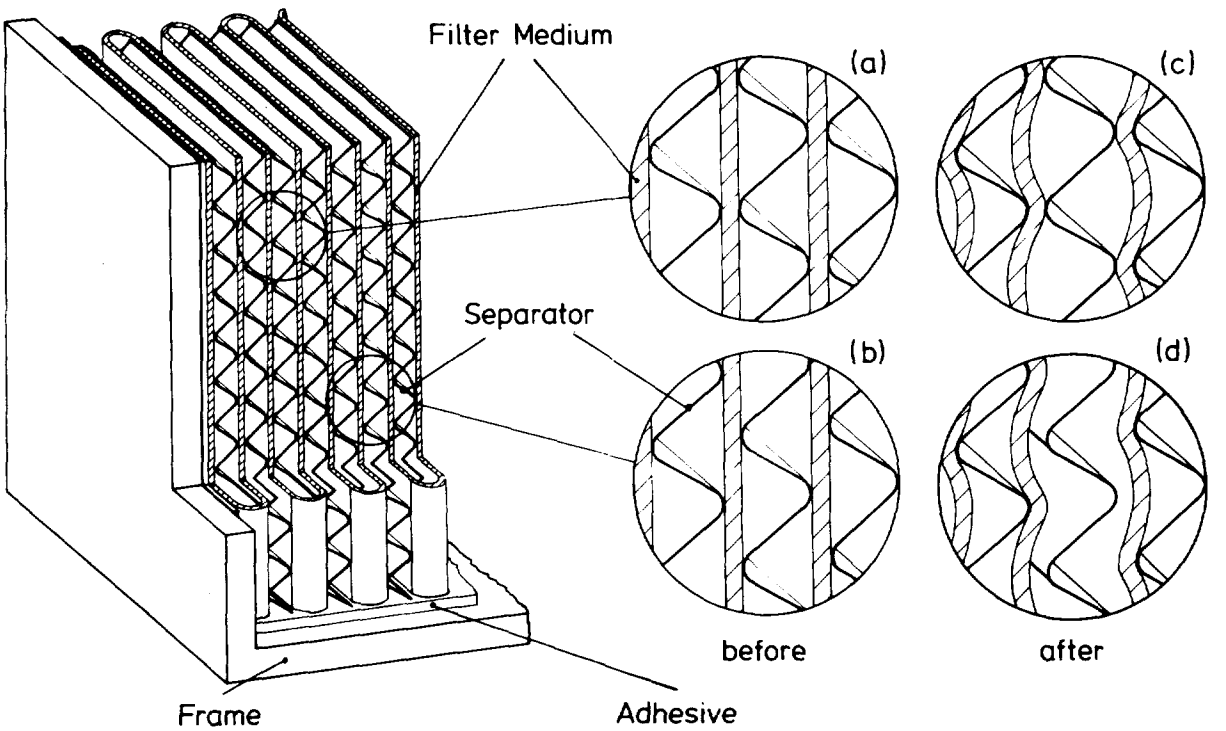

Fig. 10: Two Arrangements of Adjacent Separators in a Filter Pack Before and After Exposure to Elevated Temperature Airflow.

If HEPA filters are operated at elevated temperatures, the lateral thermal expansion of the aluminum separators and the pressure drop in case (a) cause only some deformation of the filter medium and the filter medium between the separator peaks to be squeezed together (c). However, in case (b) the separators can exert lateral forces on the filter medium, which lead to increased stresses and deformation in the filter medium and subsequent loosening of the filter pack (d).

Pleats in filters with a steel frame and a silicone or ceramic sealant that were tested at design airflow showed a tendency to kink at the bottom, partially as a result of the loosened pack. However, other factors probably also contribute to this phenomenon since filters with an aluminum frame or a glass fiber sealant also exhibited loosened packs but no kinks. The differences in the coefficients of thermal expansion for the various filter construction materials could play an important role here. This is a topic for further study.

Removal Efficiency

Due to the low mean particle diameter of about 0.04 μm, capture of the TiO_2 tracer aerosol is primarily diffusion controlled. According to theory, an improved filter efficiency should be expected from a rise in temperature; an effect which was confirmed by some of the tests performed. The changes observed in the filter pack are a potential cause of decreases obtained in the measurements of removal efficiency at elevated temperatures. If due to increased mechanical loading of the pleats, tears develop in the filter medium, the removal efficiency can also deteriorate at elevated temperature. The extent to which a higher particle loading in the filter medium could counteract this tendency depends on the degree of damage and on the amount of particle loading.

In the case of extended thermal challenge, filter damage will progress, due to decomposition of the organic binder and possibly the adhesive sealant. The results of the experiments conducted under static conditions in an oven are an indication of this effect. Briand and coworkers, in their studies of V-type HEPA filters, obtained similar results /13/.

The AM type filter with aluminum frame proved to be least capable of sustaining specified performance at elevated temperatures as indicated by the steep decrease in the removal efficiency.

VII. Conclusions

At elevated temperature, the removal behavior of commercial filter units with deep pleats is determined less by the removal mechanisms than by the thermal stability of heat sensitive filter components such as the gasket, the adhesive sealant, and the organic binder in the filter medium. This is evident above all when the filter is exposed to thermal challenge for extended periods. In the filter types with steel frames and silicone or ceramic sealant the thermal expansion of the separator, the frame, and possibly the filter medium can play a considerable role.

In order to clarify the influences which cause the decrease in filtration efficiency, further tests of both complete filter units and samples of filter media are necessary. The TiO_2 method offers the possibility to further evaluate the performance of HEPA filters under accident conditions and also to establish the limits of thermal resistance for conventional filter units. Thus, it can contribute to better estimations of and further reductions in possible radiation releases to the environment during accident situations.

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DISCUSSION

GREWAL: Did you have time to test separatorless filters for high temperature performance?

EINSINGER: We are able to do that, but we haven't up to this time. It would be interesting to do that.

LABORDE: What is the effect of your TiO_2 aerosol on the pressure drop and so on clogging of HEPA filters?

ENSINGER: The smaller the aerosol sizes the greater the influence of the loading on the pressure drop. This is also a result of an investigation we did in parallel at room temperature.

CONTAMINATION RELEASES FROM HEPA FILTERS UNDER HIGH TEMPERATURE OPERATING CONDITIONS

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Abstract

The High Efficiency Particulate Air (HEPA) filters installed in the air cleaning systems of nuclear facilities could, in the case of an accident, be exposed to operating conditions extremely different from those typical for normal operation. One of these is high air temperature in case of fires.

An experimental program was initiated on the test facility SIMOUN to evaluate the hazard of a contamination release from radioactive aerosols deposited on a filter submitted to thermal stresses. The radioactive release rate is determined using aerosols of soda fluorescein (up to temperatures of 175°C) or sodium chloride (up to temperatures of 400°C) both tagged with technetium (^{99m}Tc).

The influence of temperature according to different parameters such as design and initial state of the filters (new filters from the manufacturer, loaded filters recovered after several years of operation on a nuclear facility) has been studied.

The paper first describes the system of measuring the radioactive release rate and the associated experimental program. The preliminary results are then discussed. Contamination releases are observed from 175°C and cannot be disassociated from a smoke emission phenomenon resulting from thermal degradations.

I. Introduction

The acquisition of experimental data relative to the behavior of air cleaning systems, in particular for HEPA filters, coming under possible accident conditions (e.g. fires) in nuclear plants is necessary in order to determine the consequences of such accidents from the safety standpoint.

Several studies carried out have made it possible to enrich knowledge regarding the real behavior of HEPA filters exposed to thermal stresses included by an increase, in the dynamic state, of the temperature of the air to be filtered (1), (2), (3), (4), (5).

These studies have led to the determination, as a function of the temperature and exposure time, of the main characteristic magnitudes of HEPA filters : pressure drop, efficiency, mechanical strength. A complementary experimental program has been initiated at the SACLAY Nuclear Studies Center in order to evaluate the influence of temperature on the risks of contamination releases due to radioactive particles deposited on HEPA filters.

The tests are being carried out on the SIMOUN facility, making it possible to simulate temperature and flow profiles representative of fire conditions. An experimental method has been established in order to determine the contamination release rate ; soda fluorescein (up to temperatures of 175°C) or sodium chloride (up to temperature of 400°C) aerosols both tagged with technetium (^{99m}Tc) are used and produced from an ultrasonic spraying generator. The measurements of the amounts of radioactivity released from the filter are made by gamma spectrometry.

The first tests performed were on HEPA filters of the type currently used in French nuclear plants ; some of these tested filters are new and therefore have not been clogged. Others were recovered after several years of operation on a nuclear installation and are therefore clogged. Accordingly, the influence of the filter type and of its initial state was studied.

II. Experimental Device

II.1. SIMOUN Test Rig

A schematic diagram of the SIMOUN test rig is shown in figure 1.

Main Features

- Air
  - quality : filtered atmospheric air
  - temperature : between 20°C and 400°C
  - volumetric flow rate :
    - up to 4,000 m³/h at 400°C
    - up to 10,000 m³/h at ambient temperature
- Test aerosols
  - low temperature : soda fluorescein (up to 175°C)
  - high temperature : sodium chloride (up to 400°C)

The different thermal conditions to which the filter can be subjected are the following :

- filter submitted to the ambient temperature
- high temperature with filter by-pass to submit the filter to a thermal shock
- progressive rise in the temperature of the air flowing through the filter

Starting, regulation and stopping of the facility are obtained by a control system (control automaton + micro-processor) which also defines and displays a time dependent cycle with respect to flow rate and temperature.

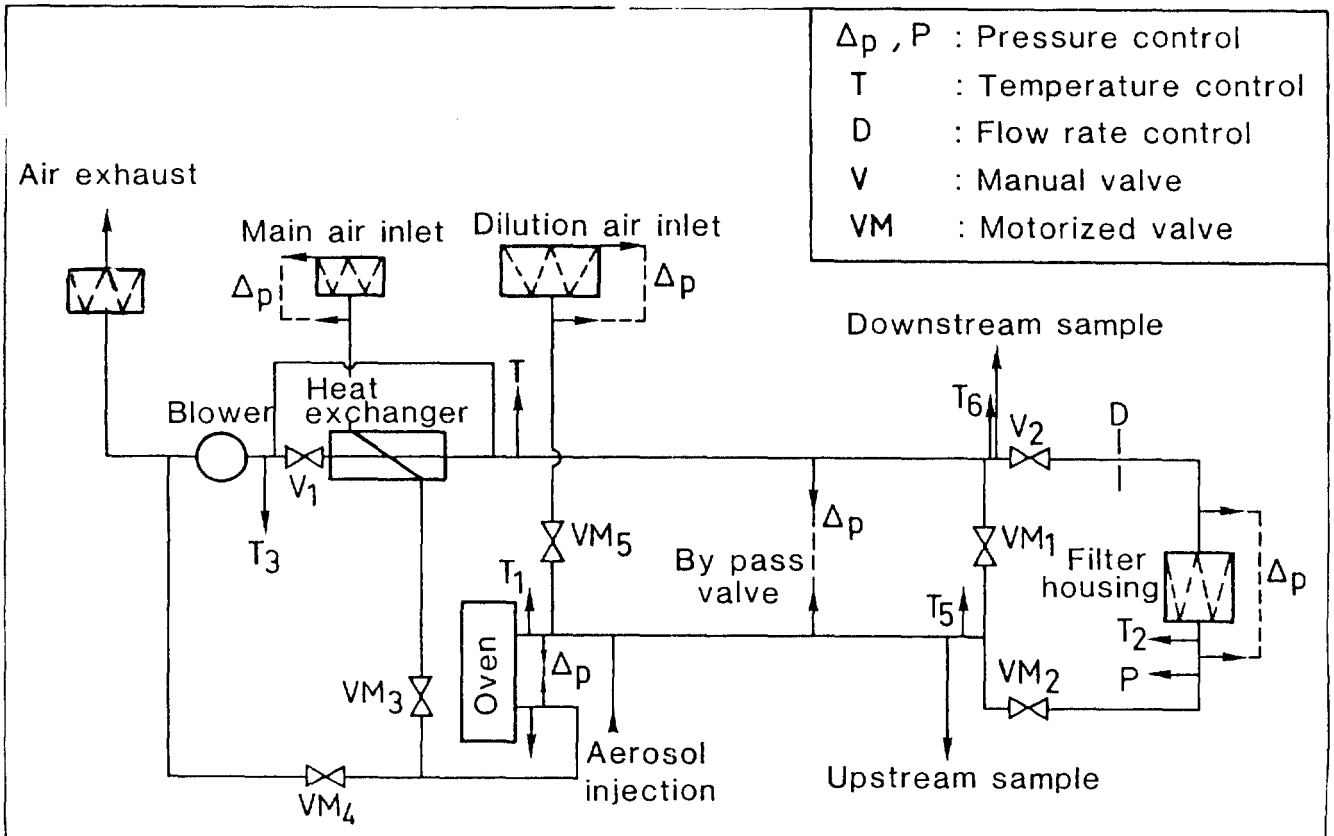


Fig. 1. Schematic diagram of the SIMOUN test rig

II.2. The released radioactivity measurement system

The phenomenon of radioactivity release is highlighted by the measurement, at a given moment, of the release rate T_R defined by the ratio :

$$T_R = \frac{\text{activity released between t and t + dt}}{\text{(activity deposited on HEPA filter) dt}}$$

Production of aerosol

Based on the principle of ultrasonic spraying, the production is insured by an environemental humidifier. An ultrasonic high frequency wave beam is directed from the bottom of the solution towards the surface. Under the effect of acoustic vibration, an ultrasonic fountain is created at the surface of the liquid, the upper part of which is pulverized in the form of very fine droplets. To obtain the wave beam a small metal disk is used, oscillating at a given frequency. The diameter of the droplets so formed is related to the acoustic frequency by the equation :

$$dg = kf^{-2/3} \qquad (1)$$

where :

dg : diameter of the droplets (µm)

f : vibration frequency (Hz)

k : calibration constant

The droplets derived from the fountain thus formed are removed and dried by dry compressed air. Complementary drying takes place during injection into the SIMOUN test rig whose air temperature during the aerosol emission phase is set at 60°C.

The diameter of the dry residue can be calculated by the relation :

$$d_p = d_g \left(\frac{C_o}{\rho_p} \right)^{1/3} \qquad (2)$$

where :

d_p : dry particle diameter (µm)

d_g : droplet diameter (µm)

C_o : solution concentration (g/cm^3)

ρ_p : particle density (g/cm^3)

Taking account of the amount of radioactive material involved ($20\ mCi \leqslant A \leqslant 35\ mCi$) the aerosol production system had to be put into a glove box maintained at a negative pressure of 30 daPa. The assembly is shown in Figure 2.

Aerosol detection

The radioactivity measurements are carried out by means of sampling filters ; each sampling filter is then analyzed by gamma spectrometry. The detection limit is approximately 10^{-11} Ci per sample.

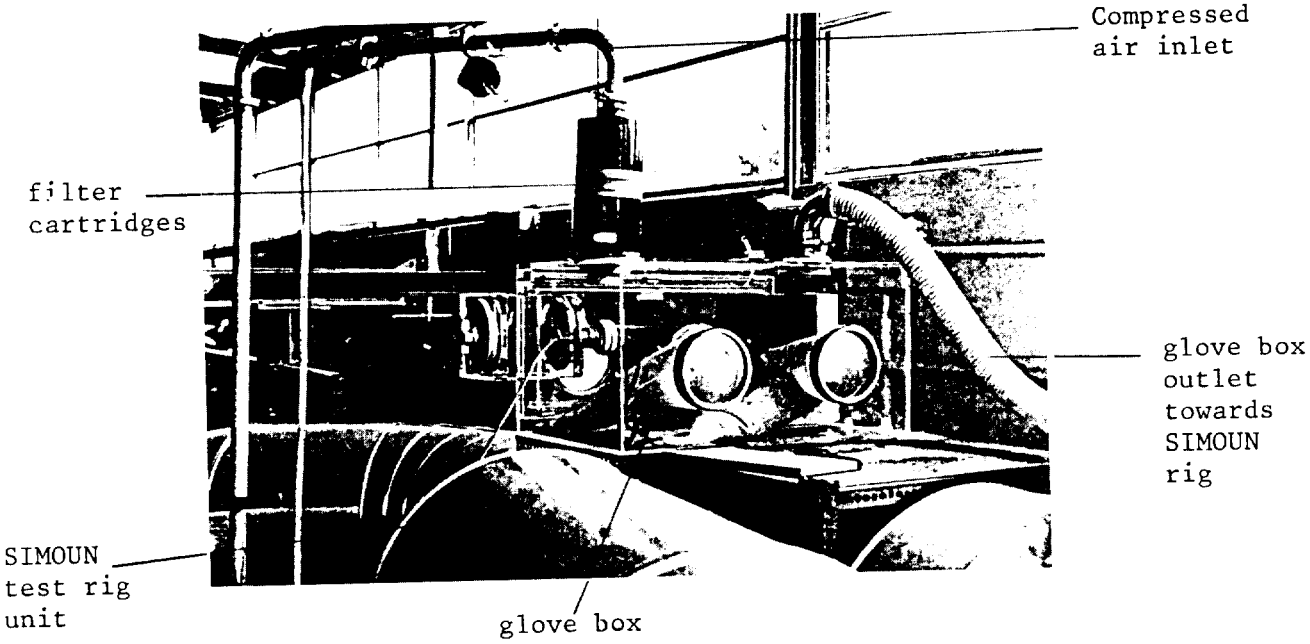


Figure 2
System of production of the aerosol tagged with technetium

III. Test Conditions

Characteristics of the tested HEPA filters

The tested filters are either new filters obtained directly from the manufacturers or used and non-contaminated filters obtained from nuclear installations after several years of use and, for the most part, exchanged because of the high value of their pressure drop. The main characteristics of the filters used are as follows :

. type 1 :
- size : 610 x 610 x 292 mm
- design : deep pleats
- filter medium : glass fiber
- sealant : polyurethane
- gasket : silicone
- volumetric rated flow rate : 1700 m^3/h
- filter clogged by atmospheric aerosol ($\Delta P \cong 100$ daPa for 1700 m^3/h).

. type 2 :
- size : 610 x 610 x 292 mm
- design : mini-pleats
- filter medium : glass fiber
- sealant : PVC
- gasket : neoprene
- volumetric rated flow rate : 3400 m^3/h
- filter clogged by atmospheric aerosol ($\Delta P \cong 40$ daPa for 3400 m^3/h).

. type 3 :
- size : 610 x 610 x 292 mm
- design : mini-pleats
- filter medium : glass fiber
- sealant : mineral
- gasket : silicone
- volumetric rated flow rate : 3400 m^3/h
- clean filter

Procedure

The tests are run in two successive phases :

- Phase 1 : production of aerosol

The test aerosol produced by the ultrasonic generator is brought into the SIMOUN rig, the flow rate of which is equal to the rated flow of the filter tested, at a temperature of 60°C. The aerosol production phase lasts 1 h. During this phase, samples are made in order to determine the radioactivity deposited upon the HEPA filter to be tested and the efficiency of this filter with respect to the produced aerosol.

- Phase 2 : release of contamination

When the aerosol emission phase is over, the temperature of the air at the level of the HEPA filter to be tested is brought to a predetermined value. The thermal stress applied to the HEPA filters and the temperature profiles obtained being different

according to the nature of the fire (structure fires, solvent fires, ...), the filter is submitted to a standard type of perturbation used during the study of physical systems : thermal amplitude degree corresponding to the temperature at which the release of contamination is to be studied ; the air flow is maintained at the nominal flow of the filter. Sequential (lasting 15 min) and continuous (for 1 h) sampling downstream from the tested filter allow "instantaneous" and average released activity to be measured. Sampling also makes it possible to determine the concentrations of the smoke derived from the HEPA filter the temperature of which is raised.

IV. Characteristics of Test Aerosol

The flow rate of the solution pulverized by means of the ultrasonic generator is approximately 200 cm^3/h. The diameter of the droplets obtained is 6 µm ; this has been determined by means of an Aerodynamic Particle Sizer (APS 33) which, by laser velocimetry, makes it possible to perform a size classification of aerosol particles whose diameters are ranging between 0.5 and 15 µm. Bearing in mind the soda fluorescein concentration (or the sodium chloride concentration), by relation (2), it is possible to calculate the theoretical diameter of the dry particles. During this study, the test aerosol diameter is set at 2 µm.

In order to characterize the real size distribution of the aerosol during production, as well as the emitted activity flow rate, measurements were made using an Andersen impactor. The results obtained are shown in figure 3.

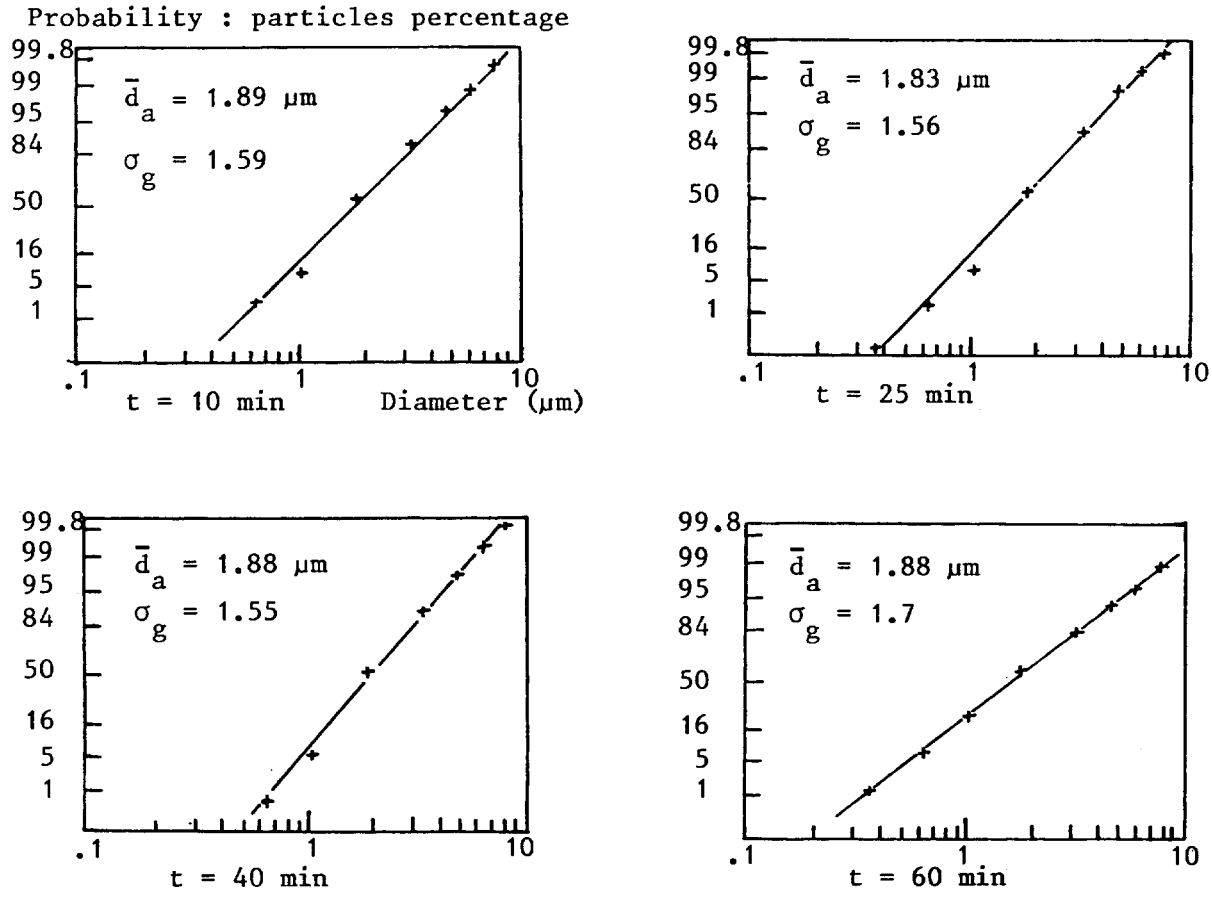
It is found that there is good stability in terms of size distribution as a function of production time. The average distribution characteristics are :

- aerodynamic mass median diameter : $\overline{d}_a = 1.87$ µm
- geometric standard deviation : $\sigma_g = 1.6$

The emitted activity flow rate is constant following a balancing phase of approximately 10 minutes. This time corresponds to the speed at which the chosen humidity level is reached by the generator. Taking account of the initial activity of the solution, the average activity rate is 7.8 mCi/h.

Because of the short technetium decay period (6 h), all of the activity values are corrected as a function of the measurement time and are transferred to correspond to a given origin time.

Size distribution



Emitted activity rate

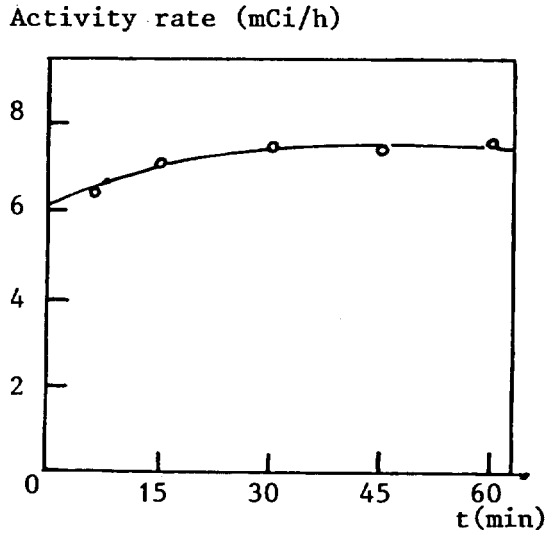


Figure 3
Evolution during the aerosol emission phase for size distribution and emitted activity rate

V. Release Rate of Contamination Fixed on HEPA Filters

For the same type of filter, several tests have been performed at various temperature values T. The pressure drop of the filter (ΔP) and the release rate of the contamination (T_R) have been measured at temperature T as a function of the exposure time. In addition, the Decontamination Factor (DF) of the filter is determined during the aerosol emission phase at 60°C.

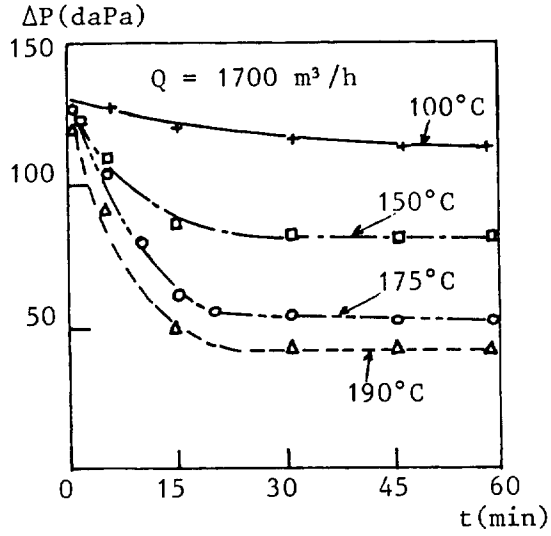
The set of results obtained is shown in table 1.

Table 1. Decontamination Factor of tested filters and imposed temperature

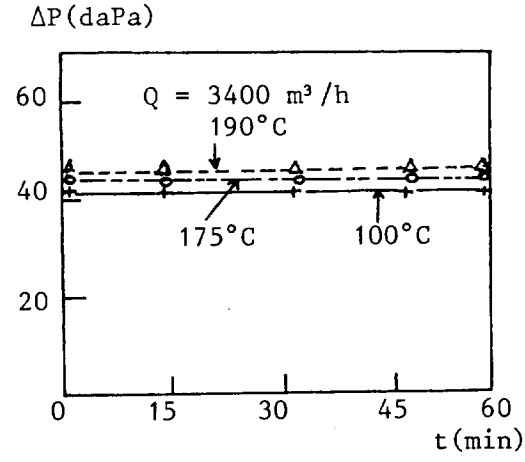
Filter type rated flow rate	Filter number	DF at 60°C aerosol : 1.8 µm	Imposed release temperature (°C)
	1	$3.1.10^5$	80
	1	$3.3.10^5$	100
1	2	$6.3.10^5$	150
1700m³/h	2	$3.3.10^5$	175
*	3	$4.4.10^5$	175
	4	2.10^5	190
	5	$1.2.10^5$	190
	6	$8.8.10^5$	100
	7	$1.1.10^5$	175
	7	$1.3.10^4$	175
2	8	$5.6.10^4$	190
3400 m³/h	9	$2.9.10^3$	190
*	10	8.10^5	190
	11	$5.8.10^5$	200
	12	$3.8.10^5$	150
	12	$3.8.10^5$	175
	13	$2.9.10^4$	190
3	13	$1.4.10^5$	190
3400 m³/h	14	$2.8.10^4$	250
	15	$9.4.10^3$	250 after exposure in an oven at 350°C
	15	$5.1.10^3$	350 after exposure in an oven at 350°C

*Remark : taking account of their design (polymer sealant), the filters type 1 and 2 have not been exposed to temperatures of more than 200°C (maximum operating conditions).

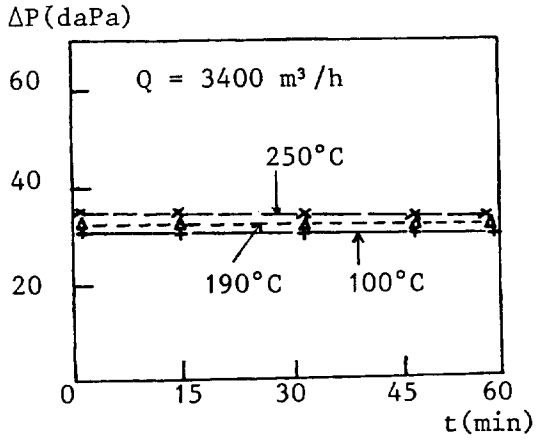
The evolution of pressure drop and release rate is shown in figures 4, 5, 6, 7.



(a) filters type 1



(b) filters type 2



(c) filters type 3

Figure 4
Evolution of pressure drop of HEPA filters tested during the release phase at given temperatures T

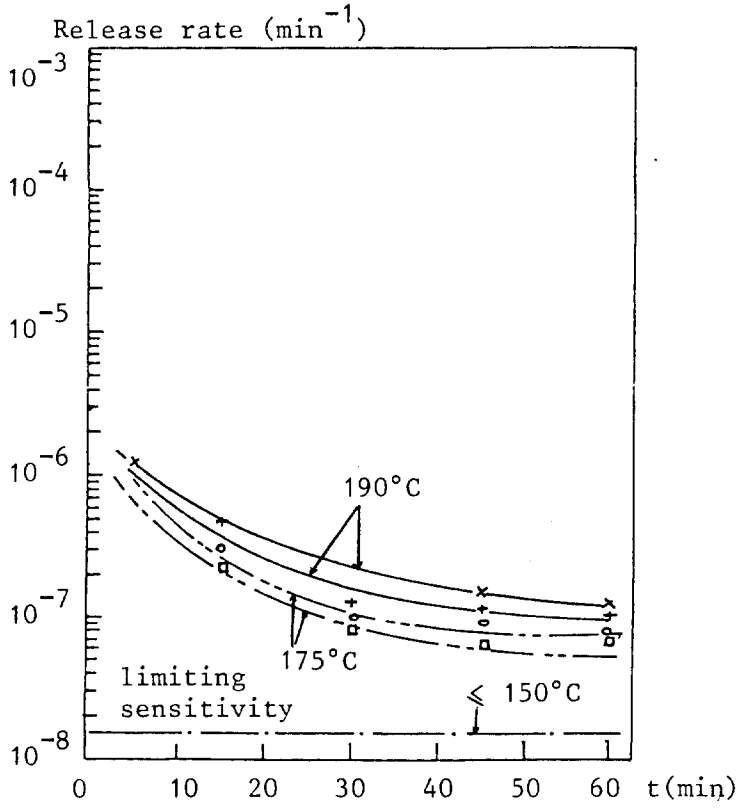


Figure 5
Evolution of release rate as a function of time at different temperatures (clogged filters type 1)

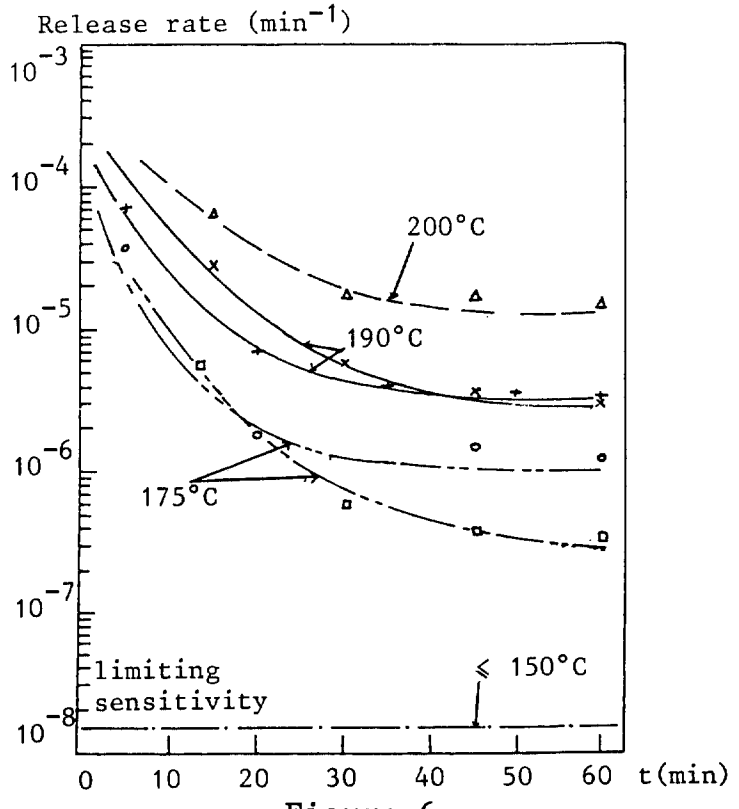


Figure 6
Evolution of release rate as a function of time at different temperatures (clogged filters type 2)

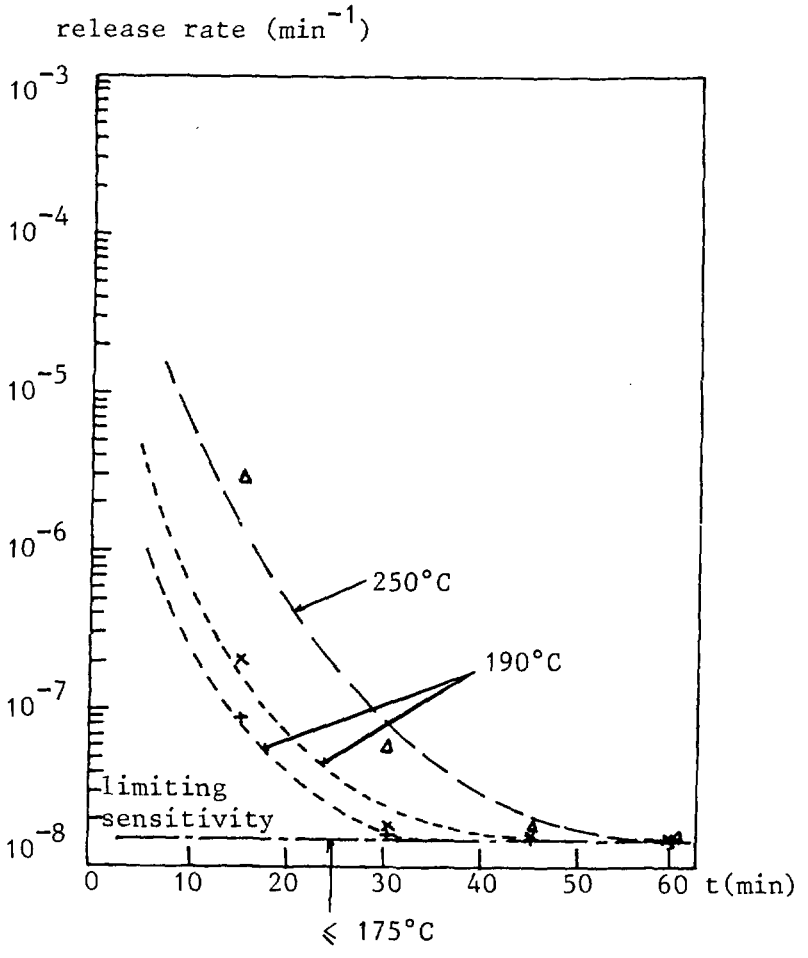


Figure 7
Evolution of release rate as a function of time at different temperatures (clean filters type 3)

All of the tests performed lead to the following comments :

- whatever the type of filter tested, there is no release of contamination at temperatures less than 150°C,

- when release is revealed, the release rate at a given temperature decreases with time,

- in most cases, the release rate increases with temperature,

- even at temperatures of 350°C, there is no release of contamination in the case of a mineral sealant filter which is not clogged (type 3) once it has been oven-fired previously,

- for all types of non oven-fired filters, an emission of smoke is observed as from about 175°C and beyond, as soon as the temperature of the filter builds up ; the intensity of the emission decreases with time as shown figure 8.

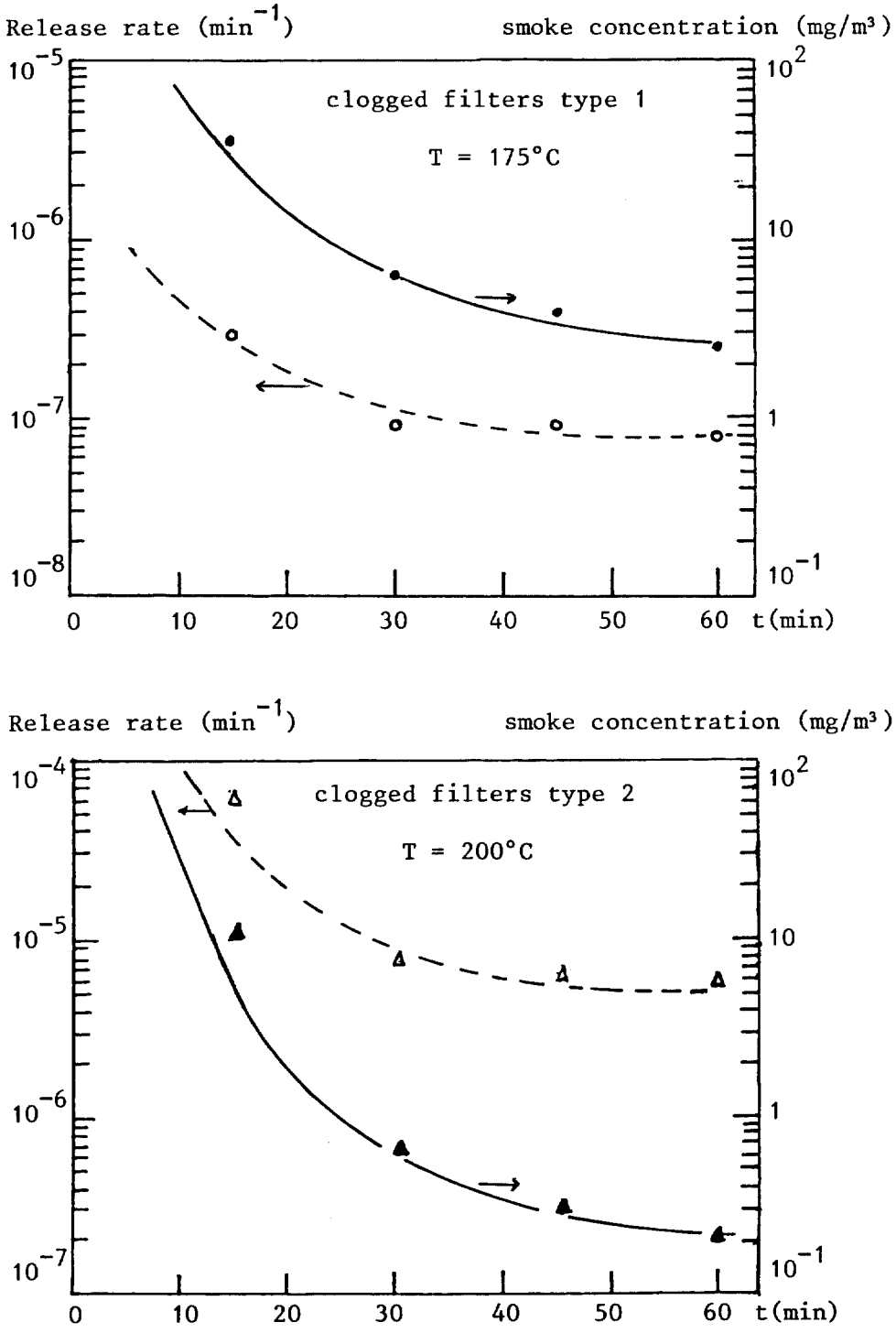


Figure 8
Compared evolution of the release rate and the concentration of smoke as a function of time

These results demonstrate that the release phenomenon of contamination cannot be disassociated from the smoke emission phenomenon which can have several origins :

- on filters type 1, it is due to the pyrolysis of the binders contained in the glass fiber filter medium and to the thermal degradation of the atmospheric dust fixed on the upstream face of the filter. This dust causes extensive clogging of the filters (initial pressure drop $\Delta P \cong 100$ daPa) ; a temperature rise at values of more than 150°C leads to thermal degradation of dusts, resulting in the decreasing of the pressure drop (figure 4 (a)),

- on filters type 2, it originates not only from the pyrolysis of the binders contained in the paper and the thermal degradation of the atmospheric dust but also from the pyrolysis of the adhesive fastening the threads maintaining the intervals between the paper layers and from the degradation of the PVC sealant. Because clogging is low (initial pressure drop $\Delta P < 40$ daPa), there is no significant decrease in the pressure drop,

- on filters type 3, it is obtained simply from the pyrolysis of the binders and the adhesive of the spacers threads. In some tests this type of filter is put previously through an oven in order to condition it and to eliminate the risk of smoke emission before the test in dynamic conditions ; in this case, there is no release of contamination.

During the aerosol production phase, part of the particles is deposited directly on the glass fibers while the other part fixes on the paper binder, the particles forming the atmospheric dust and the sealant. One of the plausible hypothesis to explain the phenomenon of release downstream from the filter consists in admitting that the filter, through pyrolysis of the binder and/or of the dust and/or of the sealant, behaves like an "aerosol generator". Taking account of the efficiency of the filter during the release phase, it is possible to measure, downstream from the filter, a contamination release rate. The complexity of the phenomenon of the formation of smoke, and of their different origins (binder, atmospheric dust, sealant, spacers threads adhesive) makes it difficult on the basis of the tests performed to date, to make any quantitive interpretation or to evaluate accurately the parts played by each of the components responsible for smoke emissions.

It is simply possible, in a qualitative manner, to establish a parallel between the decreased release rate and the decreased concentration in smoke with time, as shown in the curves of figure 8.

The measured release rates never exceed a value of 10^{-4}/min and overall low value. The higher release rates are obtained with PVC sealant filters. Filters of type 2 are only differentiated from filters of type 3 by the nature of their sealant (the difference of the initial state due to the low clogging of filters type 2 does not appear to be taken into account) ; it can be assumed that the high values of the release rate is essentially due to the thermal degradation of the PVC sealant.

VI. Conclusion

This study has made possible the development of a method for evaluating, in the event of a temperature rise, the risk of release of contamination due to the radioactive particles fixed on the HEPA filters. The test aerosol used is a soda fluorescein or sodium chloride aerosol (carrier aerosol) tagged with technetium ^{99m}Tc (tracer aerosol). It is produced from an ambient humidifier the principle of operation of which is ultrasonic spraying.

This method has been used in order to determine the contamination release rate derived from different types of HEPA filters, clean or clogged by atmospheric aerosol after several years of use on nuclear plants . Release of the contamination has been revealed for temperatures greater than 175°C. The release rate decreases as a function of the exposure time of the HEPA filter at a given temperature and is linked with the emission of smoke resulting from the pyrolysis of certain filter elements (binder, spacer threads, sealant, deposited dust, as applicable).

At the current stage the study is continuing in order to determine the part played by each of the elements effected by thermal degradation. In addition, the influence of the activity initially fixed on the filter as well as the effect of the deposited particle diameter must be evaluated.

Acknowledgements

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DISCUSSION

SCHMIDT: I am just wondering after seeing your slides whether you advocate heat treatment as a means of rejuvenating used HEPA filters? Assuming that a HEPA filter is not contaminated with radioactivity, would you advise or advocate using heat treatment to make it new again?

LABORDE: I do not advise using heat treatment to rejuvenate or make a filter new again because HEPA filters submitted to thermal stresses can suffer damages (thermal degradation of polymer sealant, pyrolysis of filter medium binders,...) involving a decrease of the decontamination factor and of the mechanical strength; so they can not be used again.

SCHMIDT: If your filter is contaminated, certainly that would be very dangerous and undesirable.

LABORDE: The study carried out shows that a contaminated filter, by the emission of smoke resulting from the degradation of certain elements, behaves like a generator of radioactive particles. With the tests performed to date it is premature to say if this phenomenon is dangerous because the values of release rate observed are low. The studies are following to determine whether the radioactivity released is proportional to the radioactivity deposited on the HEPA filter.

SCHMIDT: You know that there are a lot of HEPA filters used in clean rooms for electronic production of solid state circuits, and that sort of thing, where there is no radioactivity at all. Do you think that this thermal treatment could be used to rejuvenate those filters and perhaps save money?

LABORDE: As I said previously, I don't think that a thermal treatment could be used to rejunevate filters.

PRATT: I would like to make an observation rather than a question. We heard this afternoon a paper from Pisa University, which suggests that the reduction in the strength of the filter is linked to the loss of binder. We have had previous papers at other conferences which also suggest the same phenomenon. And here we have a paper from you which suggests that with the loss of binder one gets a resuspension of some of the contamination that is collected on the filter. My observation is this, should we not be looking for development of higher temperature binders so we can get over the problem of loss of strength of filters during temperature excursions? And also to get over the problem that you have now highlighted, i.e., resuspension of contamination.

LABORDE: I agree with you, Mr. Pratt. We should be looking for development of higher temperature brinders in order to get over the problem of loss of mechanical strength. Nevertheless, the problem of resuspension of contamination is more complex because it originates not only from the thermal degradation of binders but also from the thermal degradation of other elements (polymers sealant, dust deposited for clogged filter,...). Perhaps we should be looking also for the development of filters with metallic fiber media.

THE EFFECT OF AGE ON THE STRUCTURAL INTEGRITY OF HEPA FILTERS*

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Abstract

All of the controls on high-efficiency particulate air (HEPA) filters are based on rigid manufacturing standards with regard to filtration efficiency, temperature performance, pressure integrity, and strength. Third-party inspection and testing by the U. S. Department of Energy increases the reliability of new HEPA filters, but only routine in-place testing is used to assure that an aging filter performs adequately. In 1980 the Lawrence Livermore National Laboratory initiated a small evaluation to determine if age has a significant effect on the structural integrity of HEPA filters. A series of used uncontaminated filters dating back to 1965 was obtained for these tests. Tensile strength tests on the old media indicated a decrease in strength. To provide additional measurement of the filters' overall strength, several of these aged filters were subjected to pressure pulses equivalent to the NRC Region I tornado pulses and shock wave over pressures. Data from these tests indicate a decrease in breaking pressure of from 25-50%. A large increase in complete filter pack blow-out during the simulated NRC Region I tornado tests was also observed. The preliminary results indicate the need for an administrative lifetime for HEPA filters used in critical nuclear facilities. Due to the unique conditions in each facility, different administrative lifetimes may be necessary.

I. Introduction

High-efficiency particulate air (HEPA) filters have been used by the nuclear industry since the mid 1940s to filter contaminated exhaust air.[1] Over this period of time the general design concept has been fiberglass filter paper folded and separated with asbestos or aluminum spacers, cut to size, and glued into a plywood or metal box. Several new approaches have been developed to separate the filter media; i.e., the separatorless and the minipleat HEPA filters. Throughout the four-decade history, however, no detailed analysis has been carried out to determine the effect of aging on the service life of these various HEPA filter designs. It is the general rule that as long as a HEPA filter passes the aerosol in-place filter efficiency test and is operating within an accepted pressure drop range, the filter has an indefinite lifetime. In many facilities that exhaust

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corrosive chemicals or high particulate concentrations, the filters are changed frequently due to failure or high pressure drops, thus eliminating the concern for an administrative lifetime for HEPA filters. Many other users, however, use prefilters or a second stage of HEPA filters to provide a higher filter efficiency or a redundant system. These systems create a "forgotten" group of HEPA filters that can operate indefinitely if the aerosol in-place filter efficiency test and the pressure-drop range is the only criteria used to dictate a changeout. Such a system was in operation at the Lawrence Livermore National Laboratory (LLNL) until 1980 and provided the filters evaluated in this study.

Carbough reported the results of a survey of HEPA filter applications and experience at the Department of Energy (DOE).[2] Figure 1 summarizes the findings of this study with reference to service life. Data was summarized on the service life of 231 filter banks. Indefinite service life responses accounted for 53 (23%) of these banks. Of the remaining 178 banks, a mean life of 3.0 years with a standard deviation of 2.0 years was calculated. Carbough also reported a HEPA filter failure incidence of 12% for this three-year period. Table 1 summarizes the filter failure modes reported in this study. If one examines the categories reported for filter failure, it is evident that the effects of aging could contribute to 81% of these failures, except for the 19% resulting from handling or installation damage.

Additional information supporting the effects of HEPA filter aging were briefly reported by Marshal at the 16th DOE Nuclear Air Cleaning Conference.[3] In a summary paper describing advances in the field of nuclear air cleaning technology in the U. K., he described a technique developed at Harwell for dismantling and separating the components of HEPA filters. The technique was based on simply unfolding the pack and rerolling the media. The technique worked well on new HEPA filters but became impractical on used filters because of the weakness of the filter paper. This report stimulated our initial premise that aging could be an unrecognized but significant consideration in assuring the reliability of HEPA filter systems.

Robinson and coworkers reported, in 1985, on the in-service aging effects of unused and used cleanroom, chemical, and radioactive contaminated HEPA filters.[4] Aluminum spacer deterioration was observed in all used filters examined with the most significant levels observed when high humidities and acid gases were present. The variations in the measured test parameters of unused filter media made it difficult to utilize these parameters as quantitative indicators of aging effects. They did note however, that the aging effects measured were greatest for non-water repellent papers and the level of radioactive contamination did not appear to increase the aging effects of the filter paper. The results from this study are not sufficient to quantify HEPA filter aging, but they do indicate a deterioration with age.

To determine the significance of HEPA filter aging, LLNL initiated this preliminary internally funded project. The project was separated into two parts: a micro scale/static test evaluation to determine how the aged media has changed with reference to the Military Specification for Filter Medium, Fire-Resistance, and High Efficiency Filtration, MIL-F-51079. These tests were carried out by DOE's Filter Certification Laboratory at the Rocky Flats Plant, Golden, CO. The second part of the project was a macro scale/dynamic test series consisting of the NRC Region I tornado as interpreted by Los Alamos National Laboratory (LANL) and a shock test that simulated the effects of explosive transients. The two macro scale tests were carried out at the LANL Fluid Dynamics Test Facility located on the main campus of New Mexico State University in Las Cruces, NM.

II. Description of Test Apparatus

The test equipment and procedures specified in MIL-F-51079 was used to evaluate the flat sheets of aged media we removed from the old filters.[5] Figure 2 shows how the HEPA filters were disassembled to obtain the flat sheets used in these tests.

The wind tunnel that simulates the standard NRC Region I design basis tornado pressure pulse is shown schematically in Fig. 3. Air supplied from two large tanks flows into the system through 12 solenoid valves, which are timed to open in sequence. The timing was adjusted to provide the desired pressure pulse at the test filter located at the end of a 2' x 2' (0.61 m x 0.61 m) duct 30 feet (9.14 m) long. A typical pressure pulse across a 2' x 2' x 0.96' HEPA filter is shown in Fig. 4. The shock tube used to carry out the tests for structural strength to shock impulse is shown schematically in Fig. 5. The tube is 160 feet (48.77 m) long and 3 feet (0.914 m) in inside diameter. The high-pressure driven section of the tube can be varied in length, but for these tests, was held constant at 10 feet (3.05 m). Plastic diaphragms placed between the flanges separating the high-pressure driven portion of the shock tube from the low-pressure driven portion were ruptured using a steel knife blade on the end of a plunger, when the desired driver pressure was attained. Figure 6 illustrates a typical pressure pulse just upstream of the filter face from a shock wave passing a flush-mounted wall pressure transducer. Due to the small number of filters available for shock testing, an increasing series of shock over pressure experiments were carried out on each filter until structural damage of the filter media just barely occurred. This testing protocol resulted in each filter being subjected to three or four tests. The testing procedures developed by Smith were followed in carrying out both of these tests.[6-7]

Each of the eight aged LLNL filters was tested initially for flow resistance at 1000 cfm. The pressure drop across the filter was measured by eight taps averaging static pressure, one at the centerline of each wall of the duct, just upstream and downstream of the filter.

III. Results and Discussion

A total of seven old HEPA filters were dismantled to obtain flat sheet media for the MIL-F-51079 testing. Five of the filters were in service for 14 years and two of the filters were in service for 13 years. Two commercial brands of HEPA filters were available from our pool of aged filters. Tables 2 and 3 present the results from our testing of filters from these two brands. Table 4 presents a summary of the results listed in Tables 2 and 3.

In reviewing this summary data we see that 42% of the filter sheets tested failed either the tensile MD or the tensile CD tests. Due to the brittleness of the bend area of the pleat, a sample could not be obtained for testing. There is no doubt, however, that this area of the aged HEPA filter media represents the weakest part and it should have even lower tensile strength value. This is indicative of reduced media strength as the result of aging. Seventy-one percent of the filter sheets failed the pressure drop test, which indicates -- as expected -- some loading of the media due to use. All of the filters passed the DOP efficiency tests. This indicates that the DOP test is not indicative of structural changes, which is not surprising to anyone who understands the principles upon which the test is based. On the other hand, 100% of the filter sheets failed the water repellent top test but only 57% of the filter sheets

failed the water repellent bottom test. Since organic material additives are used to create the water repellent nature of the media, it is not surprising that over time these additives will either volatilize or be chemically changed.

To carry out the macro tests, a total of eight aged filters were tested. Six filters were subjected to the NRC Region I Tornado Pulse and two filters were subjected to additive shock overpressure tests. The filters subjected to the tornado pulse were in service for 15 - 19 years, and the service life of the filters tested in the shock overpressure was 14 years.

Results from the six tornado pulse tests are listed in Table 5. The average breaking pressure of the six aged filters was 1.38 psi ± 0.95 psi. The comparable breaking pressure of a new unused HEPA filter is 2.89 psi which when compared to the aged filter's results indicates ~52% decrease in breaking pressure.

Results from the two shock overpressure tests are listed in Table 6. The average breaking pressure of the two aged filters utilizing small incremental pressure increases is 1.8 psi. The comparable breaking pressure of a new unused HEPA filter is 2.5 psi which when compared to the aged filter's results indicates a 28% decrease in breaking pressure.

Figures 7 and 8 show the downstream face of the HEPA filter at initial breaking pressure for several tornado tests. Note that a chunk of the edge of the filter pleat blew out upon failure. Figures 9-14 show the filter frames after completion of the tornado test. In most of these tests the entire filter pack was blown from the frame. Of the six aged filters tested in the tornado test, five of the filter packs were completely blown out of the frame, and the remaining pack was badly damaged. This type of catastrophic HEPA filter failure was also observed during the testing of new filters as well, but only at a rate of about 1 out of 10 filters tested.

IV. Conclusions

A series of preliminary evaluations have been carried out to determine if the aging of HEPA filters can affect their structural integrity. The results from the micro scale/static tests and macro scale/dynamic tests indicate aging effects could be significant. These results are summarized below.

- A 42% failure of sheet filter paper tensile strength, either MD or CD to the requirements of MIL-F-51079.
- A significant loss in the water repellant character of the sheet filter paper (57 - 100% loss).
- A 48% decrease in the breaking pressure of the complete filter in simulated NRC Region I tornado tests.
- A 28% decrease in the breaking pressure of the complete filter during shock overpressure tests.
- A large increase in complete filter pack blow-out during simulated NRC Region I tornado tests.

These preliminary observations, although not conclusive, emphasize the need to formally address the subject of the effect of age on the structural integrity of HEPA filters. They also indicate the need to establish a HEPA filter performance

database related to aging effects so that administrative lifetimes for HEPA filters used in critical nuclear facilities can be established. The need for regulatory activity in this area is obvious, so that consistent and acceptable risk levels are chosen by the various organizations operating critical nuclear facilities.

V. References

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Figure Captions

Table 1. HEPA Filter Failure Modes from "A Survey of HEPA Filter Experience" by Carbough

Filter Failure Modes

Failure Mode	Number	% of Total
Failure Mode Unknown	702	64%
Handling or Installation Damage	213	19%
Frame Failure	65	6%
Gasket or Seal Failure	62	6%
Media Rupture	54	5%
Filter Construction	6	<1%
Media to Frame Sealant Failure	3	<1%
TOTAL	1105	100%

Table 2. Used Filter Media From LLNL Tested by DOE's Filter Certification Laboratory at Rocky Flats, November 1983

Filter No.	1	2	3	MIL-F-51079 for new filter media
Thickness	0.026"	0.026"	0.021"	0.015 to 0.040"
Tensile MD	5.83#	7.18#	4.50#	>2.5#
Tensile CD	3.43#	4.01#	1.95#	>2.0#
Air Flow P/D	231.6 mm	130.7 mm	124.0 mm	<40 mm
DOP Efficiency	0.017%	0.010%	0.012%	<0.03%
Water Repel. top	2.75"	4.0"	10.0"	>20"
Water Repel. bottom	17.5"	8.0"	18.75"	>2.0"

NOTE: MD = machine direction
CD = cross direction
P/D = pressure drop
top = dirty side of filter media
bottom - clean side of filter media

Table 3. Used Filter Media From LLNL Tested by DOE's Filter Certification Laboratory at Rocky Flats, November 1983

Filter No.	4	5	6	7	MIL-F-51079 for new filter media
Thickness	0.017"	0.020"	0.019"	0.017"	0.015 to 0.040"
Tensile MD	1.90#	1.95#	3.19#	1.92#	>2.5#
Tensile CD	1.05#	2.03#	3.15#	1.41#	>2.0#
Air Flow P/D	37.3 mm	43.3 mm	40.3 mm	37.3 mm	<40 mm
DOP Efficiency	0.006%	0.005%	0.007%	0.004%	<0.03%
Water Repel. top	0.0"	0.0"	0.0"	0.0"	>20"
Water Repel. bottom	0.0"	0.0"	0.0"	0.0"	>2.0"

NOTE: MD = machine direction
CD = cross direction
P/D = pressure drop
top = dirty side of filter media
bottom = clean side of filter media

Table 4. Variation of Used Filters from LLNL Tested by DOE's Filter Certification Laboratory at Rocky Flats, November 1983

Filters 1-3	Filter 4-7	MIL-F-51079 for New Filters
All filters pass	All filters pass	Thickness
All filters pass	3 filters fail	Tensile MD
1 filter fails	2 filters fail	Tensile CD
All filters fail	2 filters fail	Air flow P/D
All filters pass	All filters pass	DOP efficiency
All filters fail	All filters fail	Water repel. top
All filters pass	All filters fail	Water repel. bottom

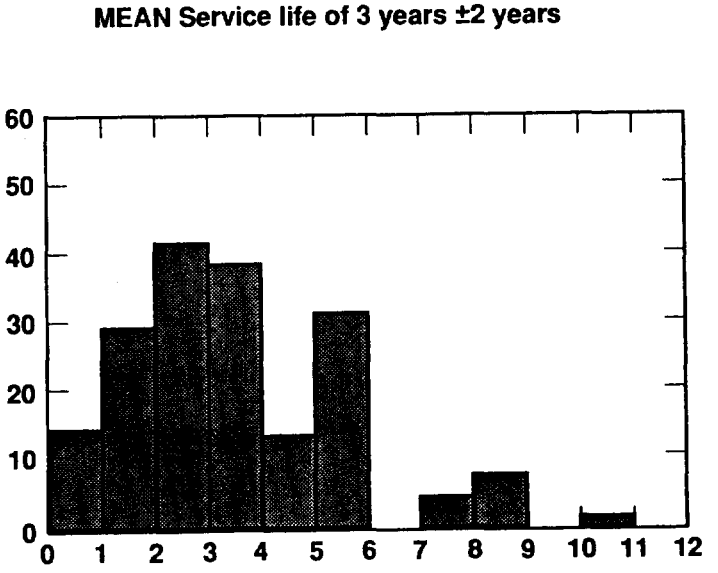
NOTE: MD = machine direction
CD = cross direction
P/D = pressure drop
top = dirty side of filter media
bottom = clean side of filter media

Table 5. Results from the Region I Tornado Tests

Test #	Time (Sec) Debris	Break	P,(psi) Debris	Break
17	0.75	2.77	0.92	2.81
18		0.57		0.56
19	0.22	0.60	0.14	0.68
21	0.16	1.19	0.12	2.05
22	0.14	0.47	0.12	0.49
23	0.13	1.02	0.10	1.65
Average				1.38 ± 0.95

Table 6. Results from the Shock Overpressure Test

Test #	Break Pressure (psi)	
1	1.5	aged filters
2	2.1	
Average	1.8	
3	2.5	new filters



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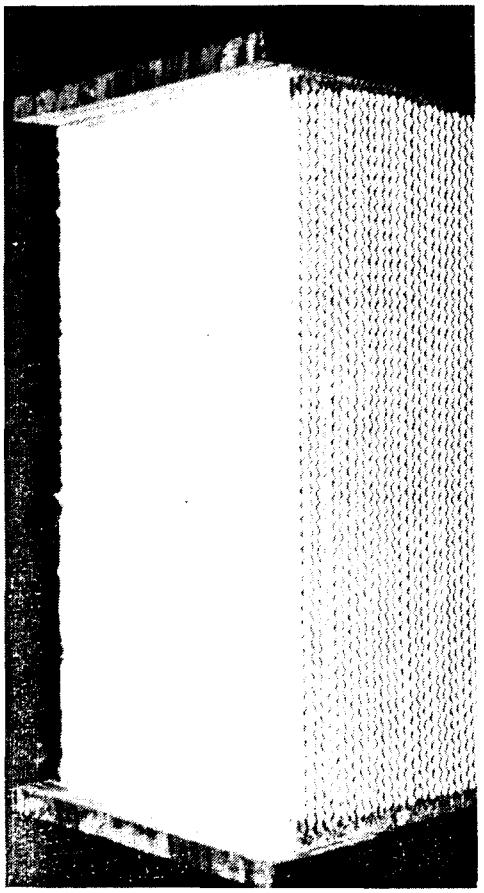

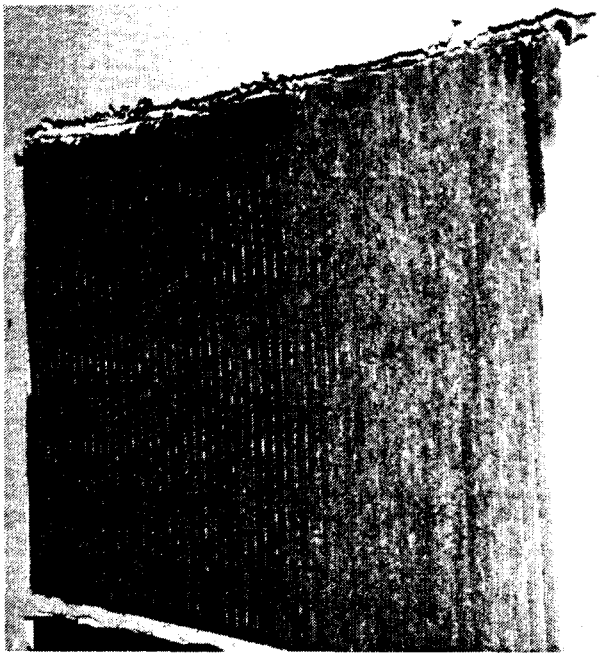

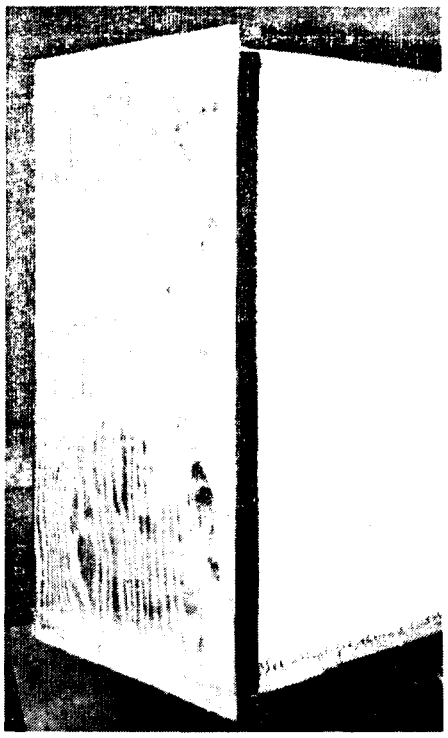

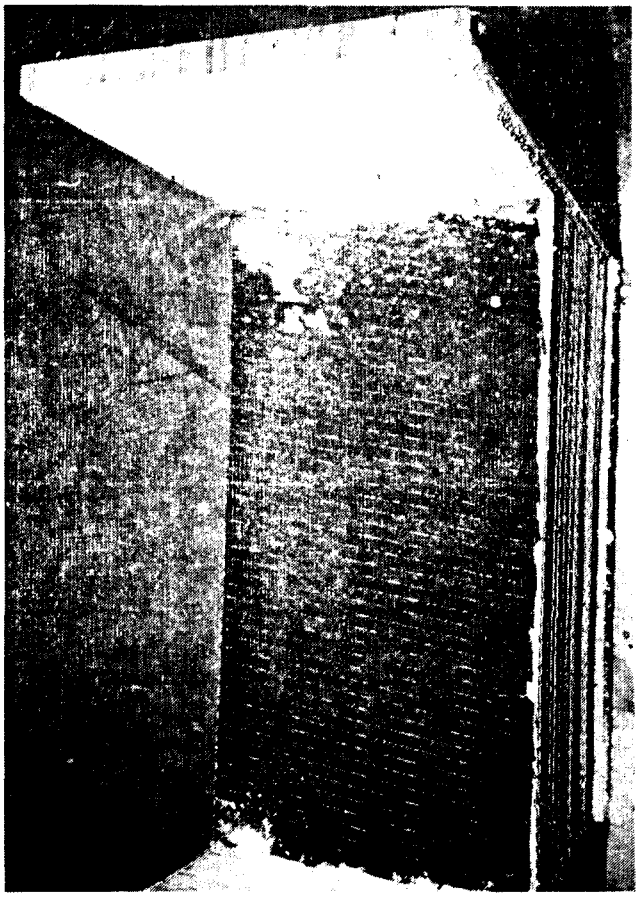

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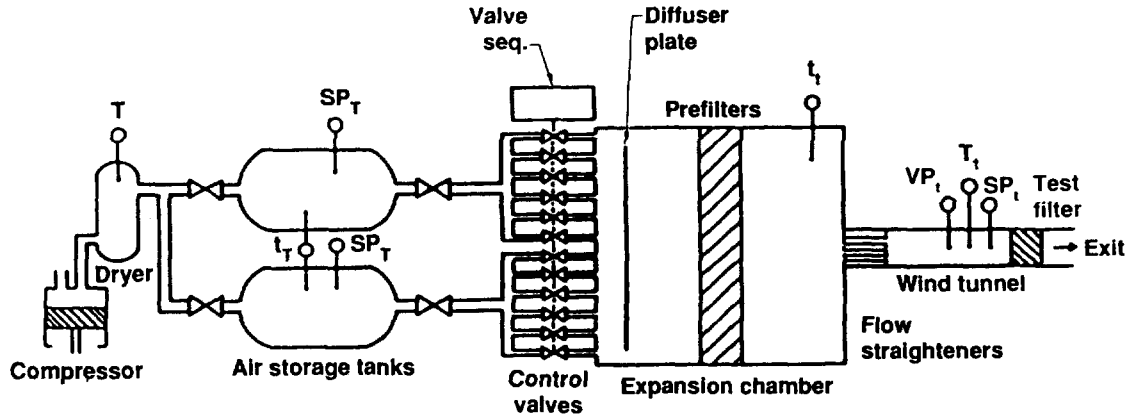

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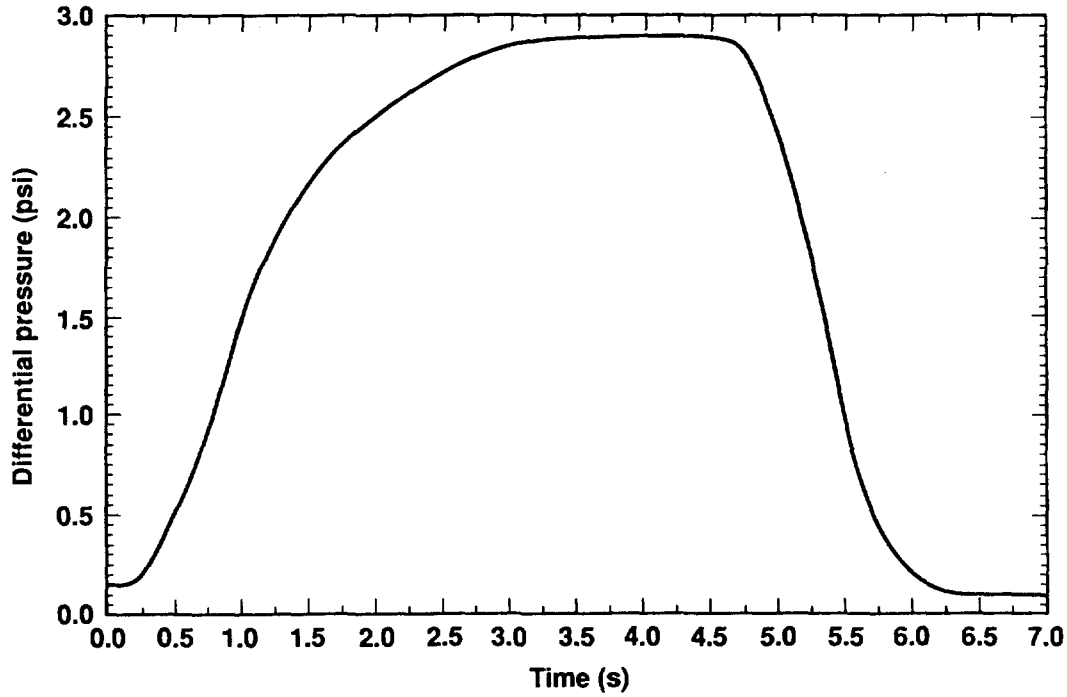

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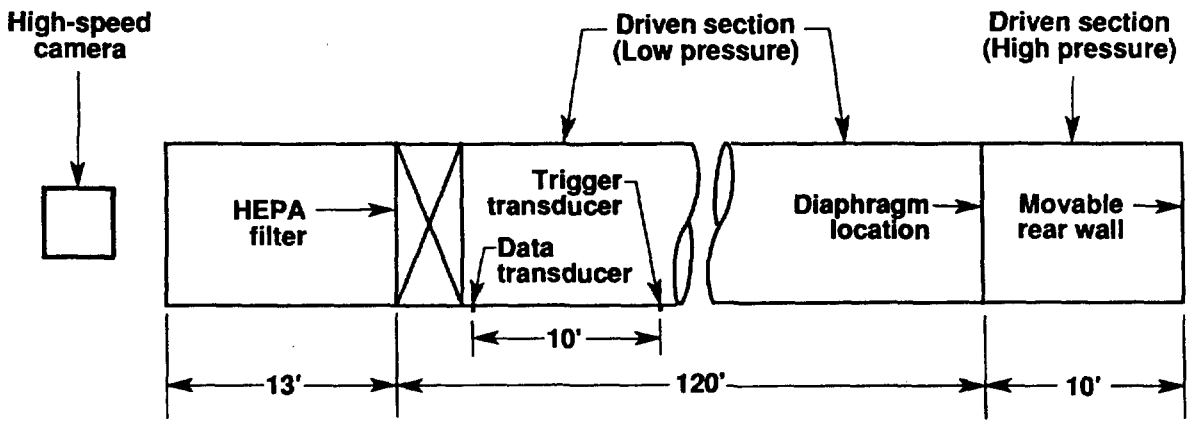

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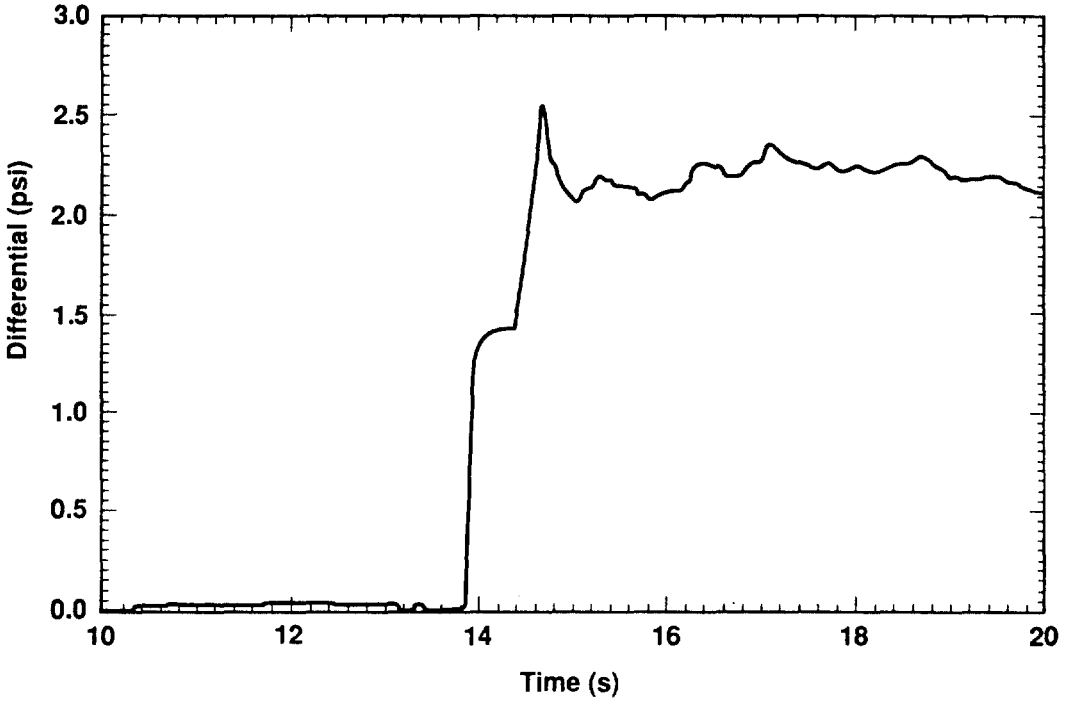

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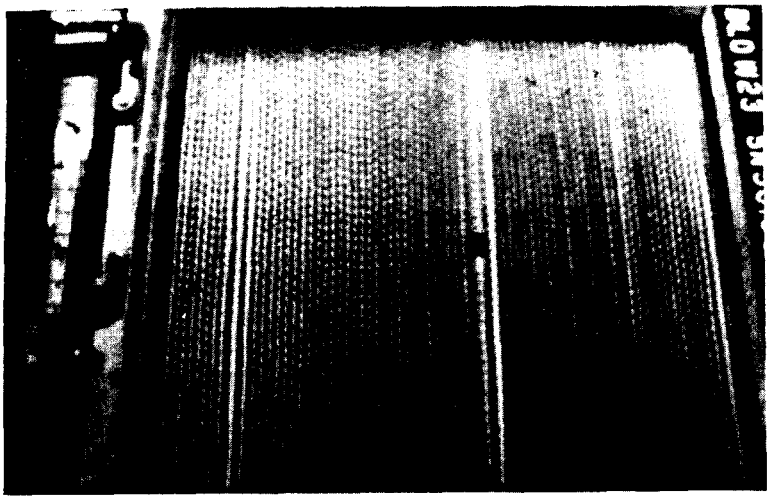

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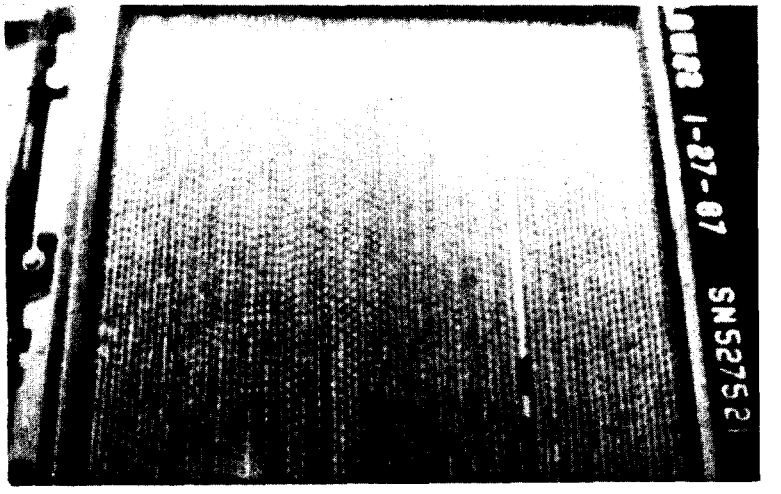

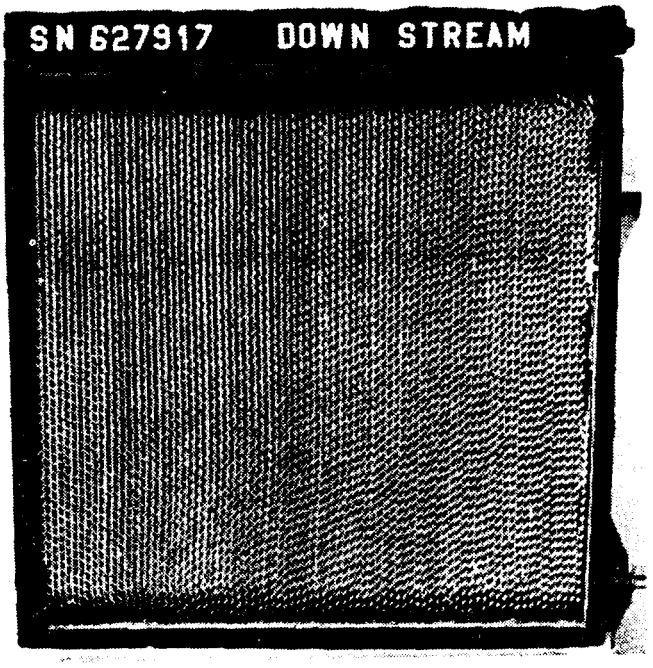

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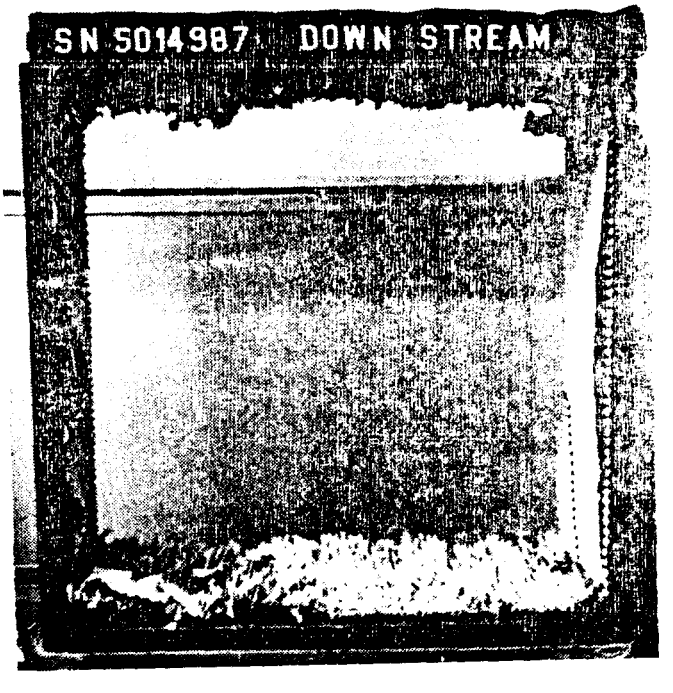

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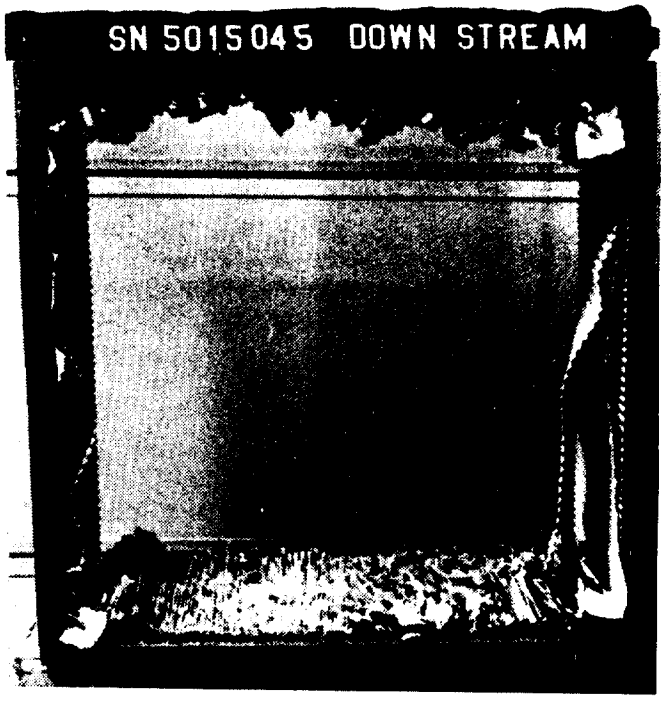

Figure 14.

DISCUSSION

FRANKLIN: I really wonder about the few filters you ted after 12, 13, 15, and 19 years; had those filters been used at 2-3 inches or at something way beyond their original requirements. They may have been subjected to extraordinary stress during their life. If you took a filter at one inch, it might not have been stressed.

JOHNSON: If you recall, the initial testing showed that they were not overly loaded and I can tell you the history of where they came from. They were pre-filtered and very clean air went through them in a nondisturbing way. In other words, they would not have seen high pressure pulses and they also had a good set of pre-filters in front of them. So the idea of large pulses or something like that is not very probable with these old filters. It is certainly something to think about, but a point to keep in perspective; they were not abused filters. It is hard to find an unabused filter but these were not abused as best I can determine.

FRANKLIN: It might suggest an experiment with a lot more filters.

JOHNSON: I do not disagree with that.

SCRIPSICK: I have a suggestion I want to get your comment on. Possibly one way of getting at the service life of these filters would be to use the high temperature and high pressure facility at Rocky Flats where they can take filters up to 10 in.w.g. It could do two things: help evaluate what would be a conservative estimate of service life, and help determine if it is a realistic test for certifying filter models.

JOHNSON: I do not know the exact answer to your suggestion but I know there is a problem right now that we need to think about.

CHILDRESS: Did you do any DOP testing on the ones that had the pleats blow out? The reason I ask is, we have done some of this and we find that even with a hole as large as a pencil they can still pass the ANSI N-510. I wonder if you did such tests on yours?

JOHNSON: Well, five of the six were not available for testing after the tornado test.

CHILDRESS: I mean after the pleat blow out?

JOHNSON: No, we did not look at that, but certainly I agree with you that there can be some pretty good sized holes and still have reasonable operation and pass the ANSI N-510 test.

MATHEWES: What about the sealing of HEPA filters after their lifetime of about three years? Was there any leakage caused by aging.

JOHNSON: If I understand your question, you want to know did the seals leak around the HEPA filters as the result of aging?

They would have passed. When they were pulled out of service they were all operational filters that were changed administratively, not because of damage or sealing problems.

MATHEWES: Is there any limit in time? Would you say the limit is five years, or 19 years, or what?

JOHNSON: I know what your saying, "What is the magic service life time that seems reasonable?" You have to realize that money certainly comes in to it because it is not an inexpensive decision. Do you change every five years, every eight years, every 12 years? It seems to me, in looking around, that there have been a number of standards, and they have been revised with no explanation. In ANSI N-510-1975 a replacement time of not more than five years was recommended. In the current ANSI N-510 there is no mention of replacement time schedules. I think ATI now recommends from five to eight years in one of their publications, for example. I am kind of undecided unless I know the chemical exposure conditions. The filters I used were not chemically abused filters. They just had good clean air going through them rather than anything that could have caused chemical deterioration. Therefore, the time is going to vary depending on the kind of air that goes through the filters. In the paper I wrote, there is a request that we start gathering data on performance of HEPA filters in various environments. I do not think we can say that five years or ten years is about right for every situation. We may find variable times depending on the chemical make-up of the exhaust air.

MATHEWES: Thank you, sir. I will take your words as a recommendation for our paper in Germany, and my recommendation, after what I have heard, will be five years as an appropriate time.

JOHNSON: I do not disagree with five years. That is a very conservative policy. There may be people who have the purse strings who will say we are all wet.

KUMAR: I just want to keep things in proper perspective. There are a number of filters which do not see any pressure pulses, hardly anything at all, and they do not get loaded either because they work hardly for 15 minutes a month, or something like that, and I think the age problem should be addressed properly. Since a number of ESF filter units in the field do not see any pressure transients or high relative humidity conditions, arbitrarily fixing the life of the HEPA filters is not a good idea (e.g., emergency ventilation systems in PWR plants).

JOHNSON: That is a statement rather than a question but I will make a comment. I assume what you are saying is that we need to look at extending ages for HEPA filters. I can parallel it by providing this analogy. If I were driving a race car and going to the Indianapolis 500, would I want ten year old tires on my car? Now, I see no difference in preparing for an accident scenario, especially now that the fate of a major nuclear industry, that is vital to all of us and that we here support, is in jeopardy. Are we going to say we are going to make a balance on dollars, alone? I think dollars are important, but I think we also need to say, "What is this system expected to do when it is called on?" And we must get good data to be

able to say we are making good decisions. You see, we have no data right now, other than what I have shown and referred to in my paper. I hope it gets us thinking about the matter.

ORNBERG: Just to pick up on what Kumar was saying, I think you are right, more research needs to be done in this area. I think, in applying the research in the regulatory area, you have to look at it from a systems response. One thing you did indicate is that you had 19 year old filters that had not seen a shock wave or tornado pressure. So, it is possible depending on the system, to make it that long. More research needs to be done to determine effects of aging and response to varying pressure. Regulations must look at this potential problem from a systems approach since system design may preclude exposure to tornado type pressures.

JOHNSON: The unfortunate thing in my case though, is that management expected the filter to perform correctly should the tornado have come by.

ORNBERG: Some systems may be designed to protect the filters from seeing the shock wave. So, I think you have got to look at it in a balanced way.

JOHNSON: I do not disagree.

RICKETTS: I would like to add a comment based on experience that we have had in testing new and aged filters under adverse conditions. Our results show that filters that do not come from the same production lot can show large variations in failure pressures. Anyone investigating this topic further should give serious consideration to obtaining filters from a single production lot.

JOHNSON: Certainly. The data we gather in the future needs to be well planned because it is going to be important and will allow us to make good decisions.

KRATZKE: How would one approach the characterization of the service life of a HEPA filter given the varied conditions and parameters associated with HEPA filter use?

JOHNSON: I think that is a good question, "How do we design the experiments?" We gave some thought to it and decided one of the key decisions is to break the HEPA filters down into the parts that you think would age. I think we will all agree that the media will change. There was a paper presented by K.S. Robinson from Harwell, UK. who described the effects of aging on media, primarily. We also need to deal with the adhesives that are used to hold the paper pack into the frame and look at their interaction and determine aging effect. We then need to come up with a series of tests that accelerate aging and compare the test results with what we know from similar tests on aged filters. The effect of chemical exposure of the filter must also be examined carefully. There are about three steps, as I see it, and I think they are achievable, I really do. The key issue, however, to accomplishing this project, is acceptance of it as a problem and obtaining adequate funding to carry out the needed research.

CLOSING COMMENTS OF SESSION CHAIRMAN HUFF

I think that the nuclear air cleaning community deserves a lot of credit for the role they play in accident mitigation. When it comes right down to it, and you look at the safety analyses (and I look at many of them), filters are very important. They play an extremely important role, and their integrity under a variety of conditions is of utmost concern to the nuclear community, to the reactor, and to the non-reactor community. I know that from personal experience.

One of the first topics that we covered here today includes decommissioning, a challenge that is going to continue as we dismantle some of the older facilities, particularly in the weapons complex. There are many challenges in the area of localizing contamination; i.e., not letting it get away from areas being decontaminated and not letting it clog up filters. Other than cost impacts, the fact that we can have significant quantities of radioactive dust released into the ducting as we are decommissioning a facility causes a further contamination problem that we must deal with because, eventually, we have to tear down these ducts. Hence, anything we can do to reduce the amount that goes to the filters and ducts is something we should continue to do. We had three papers on that subject and I think that they were all very good.

Reconcentration is another topic of interest in the public sector. The public gets concerned when contamination starts to reach a level they consider significant, and they consider significance a little bit differently than we do. I know that the NRC and the DOE have seen reconcentration problems in sewage treatment facilities. So, reconcentration is an issue not only in the area of nuclear air cleaning but also in waste treatment of other sorts.

I think we had a good discussion here today on the effects of temperature and structural stress. As a result of this discussion, we should conclude that we still have work to do in this area. Accidents involving fire seem to drive the safety analysis more today. As I look at safety analysis reports for non-reactor nuclear facilities, I find that accidents involving fires are a very important part : not just fires by themselves, but fires in conjunction with seismic events. You have to think about that eventually because if you have a seismic event that creates a fire in a facility, and you have aftershocks that can cause a loss of structural integrity of your filters, you might have problems that you had not anticipated. So, we have to look closely at the structural integrity of filters, not just from an aging standpoint but also from the standpoint of the effects of fire. We must look closely at the filter binders and find out what can be done to make them perform better under adverse conditions so that we can rely on the filters to be in place and effective if we have a seismic event, a fire, and aftershocks. We need to continue and expand our efforts in this area.

We know that there is considerable controversy in the world today concerning what we release from our nuclear plants. The public wants it to be zero. That is an excellent objective but we know that it can not be zero. But we can make such releases pretty small and we can certainly maintain credibility by making sure that our systems are reliable under the conditions that are postulated. Once again, I want to commend the nuclear air cleaning community for how far they have come. When you look back over the years, one can see that there has been significant positive progress in this area.