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Characteristics of Air Filter Media Used for Monitoring Airborne Radioactivity

L. B. LOCKHART, JR. AND R. L. PATTERSON, JR.

Physical Chemistry Branch
Chemistry Division

and

W. L. ANDERSON

Protective Chemistry Branch
Chemistry Division

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A comparison has been made of the more important characteristics of the available filter materials which are currently in use by various systems for monitoring airborne radioactivity throughout the world. Most of the materials described are commercially available; the information herein is presented with the hope that it will be of use to those whose programs involve the employment of air-filter media or who require such information for the design of air-filter systems.

The filter characteristics measured are such physical properties as tensile strength, thickness, density, ash content, retentivity toward 0.3μ dioctyl phthalate (DOP) aerosol particles as a function of air velocity, retentivity toward airborne fission products and natural radioactive aerosols (radon daughters) at several air velocities, flow rate as a function of pressure drop across the filter, and the relative rates of clogging by atmospheric dust.

The observation of a rapid change in flow with dust loading of some of the filter media suggests the systematic study of such changes as possibly a simple procedure for monitoring the dust content of the atmosphere.

INTRODUCTION

Air filtration is widely employed in studying the aerosol content of the atmosphere, since by this means it is possible to secure relatively large samples of airborne materials whose actual concentrations are generally extremely small. Such collections are followed by physical and chemical studies, often including weighing, to determine the concentration of contaminants in the air sample; in the case of airborne radioactivity, special techniques for evaluating the α, β, or γ activities of the collections are employed.

In the course of their independent development by various agencies and for varying purposes, a number of filtration systems and filtration media have been employed in monitoring the radioactivity of the atmosphere. For some purposes it has been sufficient to collect enough material to be able to detect a significant (order of magnitude) change in the concentration of airborne radioactive products; for others it has been necessary to collect, insofar as is possible, all radioactivity in a given quantity of air. The first case would thus have less stringent requirements on filter retentivity than the latter.

The filter retentivity, filter size, and the type and capacity of the blower are interrelated in that filters having the higher retentivities generally have greater resistance and hence require more powerful blowers to move a given volume of air in the same time interval; furthermore, the retentivity of most filter media for a given size particle increases as the linear velocity of the air through the filter increases. These factors, together with the different purposes for which air sampling systems have been devised, lead to a number of different possible combinations of filters and blowers.

Practical monitoring systems for determining radioactivity in the air vary widely, depending on the ultimate purpose for which the sample is being collected. For general monitoring, whose purpose is to serve as an alert or an alarm to initiate

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protective measures, a relatively inefficient filter can be tolerated so as to obtain the maximum collection of activity in a given time interval Small losses of activity through the filter or absolute calibrations of sampled volume are of secondary importance On the other hand, for the scientific study of airborne radioactivity, particularly when isotope ratios are of interest, it is essential to employ filters which retain essentially all of the particles containing radioactivity, the use of positive displacement or turbine-type blowers and of accurate means for determining airflow is also indicated

It should be noted, however, that systems can be overdesigned for a given task, utilizing costly, highly efficient filters and powerful blower systems when they are not necessarily required While the main purpose of this study has been to determine the effectiveness of various filter media under different operating conditions, this study also indicates areas where certain media may have an economic or operational advantage at no loss in effectiveness

Filter retentivity depends on a number of factors such as pore size, fiber size, mat thickness, filter compaction or density, development of an electrostatic charge, size and density of the entrained particle, and the velocity of air movement through the filter The most effective filters depend primarily on the retention of particles through the sieve action of small pores developed through compaction or other processes, or through the interception of the particles by a mat of fine fibers as the result of either a diffusion or impaction mechanism In most cases combinations of the above factors plus electrostatic effects are operating The physical parameters of the filter media determine the mechanism of collection and the adaptability of the filter to subsequent analytical schemes

The more common filters are of the fibrous type employing fibers of cellulose (cotton, esparto), synthetic organic materials (polystyrene, rayon), glass, asbestos, or combinations thereof, organic binders or gums are often added to increase strength (but with an increase in resistance) Membrane-type filters made of synthetic organic materials represent filters whose operation is largely sieve-like, though electrostatic and impaction processes impart a retentivity toward some airborne particles which are small enough dimensionally to pass through the pores in these filters The cellulose and synthetic organic filters afford an advantage in processing, since they are easily decomposed by burning and are essentially ashless, on the other hand, there is often an advantage associated with the presence of ash as obtained from glass or asbestos fibers, because a finite amount of material is available to observe and manipulate Suitable chemical processes are available to dissolve entirely the ash from either glass or asbestos filters or, indeed, to dissolve any of these filter media without ashing The latter is usually the preferred procedure, since there is less danger of loss of volatile elements

In addition to such fundamental factors as the retentivity and flow characteristics of the filters, the rate of change of flow with dust loading is of great importance, particularly when the collection period is measured in terms of hours or days rather than minutes The highly compacted filters, which are essentially surface collectors, are particularly susceptible to loss in flow through dust loading while the fibrous mats, with loose or less rigidly defined surfaces, show the least changes in resistance with time On the other hand, for some purposes, namely when the filters are to be used for subsequent α counting, only a front-surface collector can be used because of the importance of absorption of α energy by the filter medium for the more deeply penetrated surfaces

EXPERIMENTAL PROCEDURE AND RESULTS

An attempt has been made to secure for study as many as possible of the various filter media in use throughout the world for monitoring the atmosphere for radioactive particulate matter These media have been secured by the exchange of filter samples with agencies and institutions which employ filters not readily acquired by direct purchase in the United States As a result of the interest and cooperation of many individuals and groups, a wide spectrum of filter media has been accumulated and studied Unfortunately, however, the material from several major air sampling networks is not covered in this study, thus far, attempts to interest scientists in the USSR in an exchange of filter samples have been unsuccessful Information published in summary reports issued by the U S Atomic Energy Commission (1) and the European Nuclear Energy

Agency (2) has been useful in determining the extent to which the different filter media have been employed A summary of the air-filter media in use by the various organizations is given in Table 1

The study of the filter media has been carried out by two independent methods (a) the laboratory determination of such filter characteristics as thickness, density, tensile strength, ash content, pressure drop across the filter at various linear velocities, and retentivity toward 0 3μ dioctyl phthalate aerosol particles as a function of air velocity, and (b) a field or "practical" determination of filter retentivity toward radioactive aerosols existing in the atmosphere (both fission products and the smaller short-lived radon-daughter products) at several flow rates, of the effect of dust loading on airflow, and of the relative flow and pressure drop of the various filters in the same filter system

Laboratory Evaluation

To assess the performance of a filter, the filter should be evaluated against the type and size range of particles that will be encountered under working conditions and evaluated at the flow rate utilized by the sampler In general, it is impractical to subject filters to comprehensive tests of this nature, thus, it has been necessary to devise arbitrary methods, the results of which can be related to the actual performance of the filter While measurement of such an important factor as resistance to airflow can readily be made, other characteristics, such as rate of clogging and general serviceability, can be assessed only during actual exposure

A number of test methods have been developed, some of which are applicable to evaluation of the filters themselves while others pertain to evaluation of the materials from which the filters are derived At NRL a different and more exacting test was developed for use in the testing of military gas-mask filters, where the standards of protection are very much higher than those normally required for industrial filter materials This test is generally referred to as the dioctyl phthalate (DOP) test, it has been described in detail by Knudson and White (3) Instrumental parts of the DOP tester and theories of their operation have also been presented in the literature (4,5)

For our needs a very brief description will suffice A smoke generator is provided for producing a controlled, monodisperse liquid aerosol of DOP by condensation from the vapor state The droplets can be made extremely homogeneous at 0 3μ diameter with particle loadings of about 100 micrograms per liter of air Accurate measurements of smoke particle concentration are made in a light-scattering chamber provided with a sensitive photoelectric detector The penetrometer (detector) is calibrated against the full aerosol concentration (100 percent) and against absolutely clean air (0 percent) Penetration through a test specimen can then be read off directly in percent, with 0 001 percent being the ultimate sensitivity

Under the standardized condition of testing, DOP smoke penetration measurements are made at 28 linear feet per minute (85 liters of air per minute through 100 cm^2 of filter surface) To reach higher flow velocities the total flow is maintained while the filter area is reduced proportionately

Table 2 shows the resistance to airflow for all of the filter materials evaluated in terms of the pressure drop across the filter at various linear velocities through the filter In every instance the observed pressure drop is linear with flow rate, thus indicating streamline flow through the medium The actual resistance values given should be considered as representative of the specific filter evaluated, since considerable variations were observed among different sheets of the same material, this was especially true of the so-called "chemical" filter papers

Table 3 shows the variation in filtration efficiency toward 0 3μ DOP aerosol as a function of the air velocity The filtration performance of the various media seems to fall into one of three separate types The first type, illustrated by IPC 1478, shows a broad plateau of relatively constant penetration with increasing velocity This is characteristic of loosely woven, low-resistance materials These filters generally exhibit a high penetration for the 0 3μ test aerosol The second type, illustrated by Whatman #41 paper, shows a continuous decrease in penetration with increasing air velocity, which is indicative of the tightly packed (heavily calendered), high-resistance materials The penetration of this type is usually high at the low flow rates but is considerably lower at the higher air velocities

TABLE 1
Identification of Air Filter Media

Filter Type	Filter Designation	Manufacturer (or Distributor)	Organizations Employing the Filter for Air Monitoring Purposes*
Cellulose	Esparto	B O Morris, England	United Kingdom (Atomic Energy Research Establishment)*
	Gryksbo #8	Manufactured in Sweden	Denmark (Research Establishment Riso)*
	IPC 1478	Institute of Paper Chemistry, USA	United States (Defense Atomic Support Agency, High-Altitude Sampling Program)* United States (Atomic Energy Commission, "Ash Can" Balloon Sampling Program)
	MSA BM-2133	(Mine Safety Appliances Co , USA)	United States Public Health Service (Radiation Surveillance Network)*
	S and S 589/1	Schleicher and Schuell, Germany	Italy (Comitato Nazionale per L'Energia Nucleare)*
	S and S 589/2	Schleicher and Schuell, Germany	Italy (Comitato Nazionale per L'Energia Nucleare)*
	S and S 2430†	Schleicher and Schuell, Germany	Germany (Deutscher Wetterdienst)* Israel (Atomic Energy Commission)* Spain (Junta de Energia Nuclear)
	Struer	Manufactured in Denmark	Denmark (Research Establishment Riso)*
	TFA-41	(The Staplex Co , USA)	New Zealand (Dominion X-Ray and Radium Laboratory) Belgium (Royal Meteorological Institute)
	TFA-2133	(The Staplex Co , USA)	New Zealand (Dominion X-Ray and Radium Laboratory)
	Toyo 5A	Manufactured in Japan	Japan Meteorological Agency*
	Whatman #1	W and R Balston Ltd , England	Denmark (National Defence Research Establishment)
	Whatman #41	W and R Balston Ltd , England	Ireland (Meteorological Service) Netherlands (Royal Netherlands Meteorological Institute) Poland (Institute of Nuclear Research) Portugal (National Meteorological Service) Spain (Junta de Energia Nuclear)
	Whatman #541	W and R Balston Ltd , England	Belgium (Nuclear Energy Research Center) Luxemburg (Conseil National de l'Energie Nucleaire)
Cellulose-Asbestos	Draeger	Draegerwerk, Lubeck, Germany	Norwegian Defence Research Establishment*
	Draeger #6901	Draegerwerk, Lubeck, Germany	Germany (Heidelberg University)*
	HV-70	Hollingsworth and Vose, USA	India (Atomic Energy Establishment Trombay)
	S-P bleu (HYN 75%)	Etablissements Schneider-Poelman, France	France (Direction de la Météorologie Nationale)*
	S-P jaune (HYN 97%)	Etablissements Schneider-Poelman, France	France (Direction de la Meteorologie Nationale)*
	S-P rose (HYN 100%)	Etablissements Schneider-Poelman, France	France (Direction de la Meteorologie Nationale)*
	Toyo HE-10	Manufactured in Japan	Japan Meteorological Agency*
	Type 5	Hollingsworth and Vose, USA	U S Naval Research Laboratory*
	Type 6 (Navy N-15)	Hollingsworth and Vose, USA	U S Naval Research Laboratory* (NRL 80th Meridian Program 1957 1962)
Cellulose-Glass Fiber	Type 5G	Hollingsworth and Vose, USA	U S Naval Research Laboratory*
Glass Fiber	FOA-1-484	Gryksbo, Sweden	Sweden (Research Institute of National Defence)*
	Gelman Type A	(Gelman Instrument Co , USA)	—

Table Continues

*Samples supplied by indicated organizations, otherwise filters were obtained from commercial sources
†Available only as a narrow paper tape unsuited for this study, Carl Schleicher of Schleicher and Schuell (Keane, New Hampshire, USA) supplied sheets of S and S 2610 paper which was said to be the equivalent of S and S 2430

TABLE 1 (Continued)
Identification of Air Filter Media

Filter Type	Filter Designation	Manufacturer (or Distributor)	Organizations Employing the Filter for Air Monitoring Purposes*
Glass Fiber	Gelman Type E	(Gelman Instrument Co., USA)	—
	Hurlburt 934 AH	Hurlburt Paper Co., USA	Canada (Radiation Protection Division, Department of National Health and Welfare)*
	MSA 1106B	(Mine Safety Appliances Co USA)	U S Public Health Service (National Air Sampling Network)* Netherlands (Royal Netherlands Meteorological Institute)
	TFA-69 GF	(The Staplex Co., USA)	Mexico (Comision Nacional de Energia Nuclear)*
	Whatman GF/A	W and R Balston Ltd., England	United Kingdom (Atomic Energy Research Establishment)* Denmark (Research Establishment Riso) Ghana (University of Ghana)
Polystyrene	Microsorban	(Gelman Instrument Co., USA)	Canada (Radiation Protection Division, Department of National Health and Welfare)* U S. Atomic Energy Commission (HASL 80th Meridian Network) Austria (Bundesstaatlich Bakteriologisch-Serologische Untersuchungsanstalt)
	Delbag	Delbag Luftfilter, Germany	U S. Air Force (Cambridge Research Laboratories)* France (Direction de Metéorologie Nationale)*
Membrane	Millipore AA (0 8μ pore size)	Millipore Filter Corp., USA	Various organizations have been reported to use "Millipore" or "membrane" filters but the particular filters were not further identified
	Polypore AM-1 (5 0μ pore size)	(Gelman Instrument Co., USA)	Netherlands (Royal Netherlands Meteorological Institute) Czechoslovakia (Geophysical Institute) Belgium (Centre d'Etude de l'Energie Nucleaire)
	Polypore AM-3 (2 0μ pore size)	(Gelman Instrument Co., USA)	

*Samples supplied by indicated organizations, otherwise filters were obtained from commercial sources

The third type, illustrated by MSA 1106B, shows a changing penetration with flow. With an increase in velocity, the penetration increases to a maximum at about 30 cm per sec, but as the flow rate is further increased, penetration decreases progressively. This behavior has been studied by Ramskill and Anderson (6), who attribute the various shapes of the penetration-flow performances to the influence played by the various filtration mechanisms (diffusion, inertia, interception). In addition, these authors show how the character of the curves is controlled by aerosol particle size, particle density, diameter of the filter fiber, and interfiber spacing. It was determined that, in general, particles of higher density have less penetration through a given filter, especially at the higher velocities. It was also shown that, although particle shape was important, filtration performance could be predicted by using an average particle size for aggregates or irregularly shaped materials.

Field Evaluation of Filter Retentivity

The retentivity of the filters toward airborne radioactive materials was determined by means of a filter-pack technique wherein atmospheric air was drawn successively through the filter under study and then through a so-called ultimate filter (Type 6 cellulose-asbestos paper) clamped together in a suitable holder, after which the filters were separated and the radioactivity of comparable areas measured by standard β-counting techniques. Different flow rates were obtained by employing three different positive-displacement blowers driven by constant-speed electric motors: (a) a Leiman Model 29-6 blower driven by a 3-hp motor and having a capacity of about 20 cfm (cubic feet per minute) through a 2-1/2-in.-diameter Type 6 paper (the backup or final filter employed in these studies), (b) a Roots-Connersville Rotary-Positive blower (Type AF-24) driven by a 1-hp motor and having a capacity of about 19 cfm through a 4-in.-diameter Type 6 paper, and (c) a graphite vane vacuum pump (M-D

TABLE 2
Relationship of Pressure Drop to Flow Rate for Various Air Filter Media

Filter and Type	Pressure Drop (mm Hg) at Various Flow Rates						
	35 (cm/sec)	53 (cm/sec)	71 (cm/sec)	106 (cm/sec)	141 (cm/sec)	211 (cm/sec)	283 (cm/sec)
Cellulose							
Esparto	10	16	20	30	41	60	81
Gryksbo #8	25	38	51	77	100	155	202
IPC 1478	1	1.5	2	3	3.5	5.5	7.0
MSA BM-2133	6	8	11	17	22	33	44
S and S 589/1	18	27	37	56	74	112	149
S and S 589/2	29	48	67	106	134	213	270
S and S 2610	1	2	3	5	7	10	13
Struer	6	9	12	18	24	36	48
TFA-41	23	40	48	81	95	160	190
TFA-2133	5	8	12	16	25	33	51
Toyo 5A	15	23	30	45	61	92	123
Whatman #1	60	86	116	175	235	350	468
Whatman #41	24	36	48	72	95	146	194
Whatman #541	20	30	41	61	82	123	163
Cellulose-Asbestos							
Draeger	34	50	68	102	138	205	278
Draeger #6901	56	82	110	164	222	328	445
HV-70	44	64	87	127	172	254	343
S-P bleu	6	9	12	18	24	36	49
S-P jaune	15	21	29	44	57	86	114
S-P rose	38	57	75	112	148	225	290
Toyo HE-10	59	87	117	171	235	340	470
Type 5	3	5	7	10	14	20	27
Type 6 (Navy N-15)	22	32	43	67	86	130	192
Cellulose-Glass							
Type 5G	3	5	7	10	14	21	28
Glass Fiber							
FOA-1-484	18	30	37	61	80	126	168
Gelman Type A	23	33	43	65	85	129	170
Gelman Type E	19	28	38	57	76	114	150
Hurlburt 934AH	25	37	50	74	99	150	198
MSA 1106B	20	30	40	61	79	120	160
TFA-69GF	20	27	39	55	80	110	158
Whatman GF/A	20	29	40	60	78	118	157
Polystyrene							
Microsorban	14	21	29	43	57	85	112
Delbag	31	44	60	89	118	176	235
Membrane							
Millipore AA	98	142	195	285	388	570	–
Polypore AM-1	16	23	31	46	62	95	127
Polypore AM-3	56	84	117	190	237	380	470

Table 3
DOP Smoke Penetration of Various Filter Media as a Function of Air Velocity

Filter and Type	Penetration (%) of 0.3 μ DOP Particles at Various Flow Rates											
	7.2 (cm/sec)	10.7 (cm/sec)	14.2 (cm/sec)	17.6 (cm/sec)	26.7 (cm/sec)	35.3 (cm/sec)	53 (cm/sec)	71 (cm/sec)	106 (cm/sec)	141 (cm/sec)	211 (cm/sec)	283 (cm/sec)
Cellulose												
Esparto	40	42	45	46	45	44	42	40	32	22	14	8
Gryksbo #8	53	50	49	44	38	32	26	17	12	6	4	2
IPC 1478	74	78	80	88	90	90	90	90	90	90	85	80
MSA BM 2133	36	39	40	42	43	46	46	47	44	40	35	28
S and S 589/1	57	54	52	48	44	38	34	26	20	13	8	4
S and S 589/2	47	44	40	36	30	27	21	16	12	7	4	1
S and S 2610	68	70	72	75	78	80	80	80	78	72	62	55
Struer	33	30	26	24	16	12	8	5	3.5	1.5	0.8	0.4
TFA 41	40	38	35	34	26	22	14	10	2.0	1.0	0.5	0.03
TFA 2133	36	40	42	42	44	46	46	47	45	40	36	28
Toyo-5A	46	43	40	35	32	28	24	18	14	8	5	2
Whatman #1	31	21	14	12	7	4	0.95	0.30	0.061	0.015	0.001	0.000
Whatman #41	39	36	34	34	28	22	16	9	2	0.75	0.30	0.020
Whatman #541	73	70	66	64	56	50	40	31	22	14	9	4
Cellulose Asbestos												
Draeger	0.024	0.026	0.028	0.028	0.024	0.019	0.014	0.010	0.006	0.002	0.001	0.000
Draeger #6901	0.70	0.60	0.50	0.50	0.35	0.24	0.13	0.08	0.05	0.02	0.01	0.005
HV 70	4.0	3.4	2.9	2.5	1.8	1.2	0.8	0.36	0.20	0.08	0.05	0.02
S P bleu	52	53	54	56	56	56	54	52	45	40	28	18
S P jaune	14	15	15	16	15	14	12	10	7	5	3	1.5
S P rose	0.76	0.82	0.83	0.83	0.72	0.67	0.48	0.30	0.25	0.12	0.08	0.04
Toyo HE 10	0.22	0.18	0.12	0.12	0.070	0.041	0.014	0.006	0.004	0.002	0.000	0.000
Type 5	28	29	30	30	30	30	30	26	22	20	13	8
Type 6 (Navy N 15)	0.002	0.003	0.003	0.004	0.005	0.004	0.002	0.001	0.000	0.000	0.000	0.000
Cellulose Glass												
Type 5G	26	29	30	32	32	32	32	32	26	24	16	12
Glass Fiber												
FOA 1484	0.007	0.012	0.015	0.020	0.027	0.031	0.026	0.018	0.012	0.005	0.001	0.000
Gelman Type A	0.008	0.011	0.015	0.017	0.019	0.021	0.018	0.014	0.011	0.005	0.001	0.000
Gelman Type F	0.016	0.026	0.030	0.032	0.036	0.036	0.030	0.020	0.014	0.008	0.004	0.002
Hurlburt 934AH	0.006	0.008	0.009	0.010	0.010	0.008	0.006	0.004	0.003	0.002	0.001	0.000
MSA 1106B	0.020	0.032	0.042	0.055	0.068	0.065	0.048	0.038	0.022	0.010	0.005	0.001
TFA 69GF	0.025	0.037	0.050	0.052	0.058	0.065	0.052	0.040	0.024	0.010	0.006	0.001
Whatman GF/A	0.008	0.011	0.014	0.016	0.018	0.020	0.015	0.012	0.008	0.003	0.001	0.000
Polystyrene												
Microsorban	0.13	0.17	0.20	0.21	0.24	0.26	0.23	0.20	0.14	0.090	0.040	0.002
Delbag	0.16	0.23	0.30	0.40	0.45	0.48	0.40	0.30	0.20	0.10	0.050	0.005
Membrane												
Millipore AA	0.002	0.008	0.010	0.010	0.015	0.015	0.020	—	—	—	—	—
Polypore AM 1	10	12	12	12	12	10	8	7	5	3	2	1.5
Polypore AM 3	0.25	0.30	0.34	0.35	0.36	0.30	0.22	0.12	0.090	0.032	0.015	0.002

Blowers, Inc., Model 50-DA-3FS) driven by a 3/4-hp motor and having a capacity of about 8 cfm through a 4-in.-diameter Type 6 filter. Airflow as a function of the pressure drop across the filter was determined by calibration against the same flow meter; actual flow rates were monitored by observing the corresponding pressure changes with time.

Fission product radioactivity was collected by exposures of 8 to 72 hours depending on the work schedule, the quantity of radioactivity in the air, and the rate of dust loading of the filter. Dust loading of the hard-surfaced papers, particularly those with low initial flow rates, was often a limitation in securing a suitable sample; the resulting increased pressure drop across the filter caused the blower and motor to become overloaded and to overheat with the result that the collection was terminated. The flow rate was determined from the average of the initial and final flow rates. At the end of the collection period the filters were separated, placed in glassine envelopes, and stored for a minimum of 7 days to permit decay of the interfering natural radioactivity. The filters were counted for β activity in succession on the same counter using sufficiently long counting times (1 to 18 hours) to give reasonable statistical accuracy. Radioactive decay during this period was negligible and the relative counting rates did not need correction for decay or other variables (self-absorption of the β activity by the filter was neglected). A comparison of the activity of the initial filter with the total activity collected by the two filters was a measure of the retentivity of the initial filter.

Radon-daughter products (RaB+C) with their short effective half-lives were collected through a short sampling period (about 30 minutes) during which time about 50 percent of their equilibrium value was obtained. Dust clogging presented no problem in these short collections. Counting was started immediately after termination of the collection using either (a) the preferred procedure, which involved counting the filters simultaneously for 45 minutes on two identical β-counting units that had been intercalibrated, or (b) the original procedure, which consisted of counting the final filter for five successive 5-minute periods after which the initial (top) filter was counted for five or more 5-minute periods. The latter procedure was employed when there was only a limited number of counters available for use in this study. The results were plotted on semilog paper and the counting rates were extrapolated to a common time, for example, the midpoint of the counting period of the backup filter. The efficiency of retention was determined by a comparison of the activities on the two filters at that time. Often the RaB+C activity was so large that the longer-lived thoron-daughter products and fission products that were also collected could be ignored. When the natural activity was lower, a second count after 5 hours was made to determine the extent of correction required for these longer-lived isotopes. Since generally only a small fraction of the fission products penetrated to the second filter, the corrections were of minor importance. On many occasions during the period March through May (1963), natural activity levels were so low that no satisfactory collections could be made.

The statistical variation (standard deviation) of the counting rates was determined from the expression $\sigma = \sqrt{N}/N$, where N is the total number of counts. The degree of accuracy varied with the quantity of activity collected; σ was generally quite low for the fission product collections, except for some of the hard-surfaced papers which tended to become clogged before the desired size sample was obtained. With the natural radioactivity, sample size was determined both by the daily variations in the RaB+C content of the air and by the flow characteristic of the papers; these factors, combined with the short counting times, resulted in larger standard deviations in the measured retentivity for these determinations.

The measurements of the retentivity of natural activity (RaB+C) and of fission products by the various filters are summarized in Tables 4 and 5. In general, only the two series of measurements having the highest statistical significance have been included; those measurements which have been omitted were in essential agreement with those listed. Collections made during periods of rainfall have been omitted, because on several occasions activity was observed to have been transferred from the top to the bottom filter through the solvent action of the collected water droplets. The wide range of retentivity values that may be noted in several cases is due to either or both of two factors: (a) nonuniformity in the

TABLE 4
Measured Retentivity of Air Filters for Natural Radioactive Aerosols (RaB + C) in the Atmosphere

Filter Type	Filter	Date of Collection	Weather	Unit A Air Velocity (cm/sec)	Unit A Retention (%)	Unit B Air Velocity (cm/sec)	Unit B Retention (%)	Unit C Air Velocity (cm/sec)	Unit C Retention (%)
Cellulose	Esparto	11-8-62	Cloudy	60	59.5 ± 1.0	139	63.4 ± 0.5	314	88.3 ± 0.2
		2-6-63	Clear	60	50.1 ± 1.4	136	74.4 ± 0.5	326	87.9 ± 0.2
	Gryksbo #8	4-19-63	Cloudy	58	73.2 ± 1.1	118	84.1 ± 0.5	204	92.1 ± 0.2
	IPC 1478	10-22-62	Clear	62	8.8 ± 0.9	151	13.1 ± 0.6	338	21.9 ± 0.3
		3-1-63	Cloudy	61	6.7 ± 1.0	154	10.6 ± 0.5	373	24.1 ± 0.4
	MSA BM-2133	10-22-62	Clear	64	84.9 ± 1.7	139	87.9 ± 0.6	—	—
	(carbon side up)	10-24-62	—	—	—	141	78.1 ± 0.8	341	79.9 ± 0.5
		2-14-63	Clear	61	81.4 ± 1.2	146	84.4 ± 0.6	347	86.6 ± 0.3
	S and S 589/1	10-3-62	Cloudy	59	81.0 ± 0.8	127	92.1 ± 0.4	236	97.3 ± 0.1
		2-7-63	Hazy	58	84.4 ± 0.5	124	93.9 ± 0.2	235	97.2 ± 0.1
	S and S 589/2	10-3-62	Cloudy	56	88.1 ± 0.5	111	93.6 ± 0.3	174	99.1 ± 0.1
		2-27-63	Cloudy	58	74.7 ± 1.6	109	85.9 ± 0.9	197	95.5 ± 0.4
	S and S 2610	11-16-62	—	61	20.2 ± 0.8	—	—	347	60.7 ± 0.3
		11-16-62	—	—	—	146	32.9 ± 0.6	342	68.8 ± 0.3
	Struer	5-3-63	Clear	53	95.3 ± 0.6	88	99.0 ± 0.4	129	99.3 ± 0.2
	IFA-41	9-20-63	Clear	57	90.5 ± 0.3	128	95.8 ± 0.2	240	98.7 ± 0.1
		10-9-63	Clear	57	65.7 ± 0.9	129	78.8 ± 0.7	232	92.3 ± 0.3
		10-10-63	Hazy	58	81.5 ± 0.5	123	94.6 ± 0.2	211	99.2 ± 0.1
	IFA 2133	10-9-63	Clear	60	73.4 ± 0.7	145	72.2 ± 0.7	327	74.6 ± 0.3
	(carbon side up)	10-10-63	Hazy	59	75.4 ± 0.5	145	79.9 ± 0.4	322	89.8 ± 0.2
	Toyo 5A	11-9-62	Cloudy	59	81.1 ± 0.7	125	91.4 ± 0.4	239	97.5 ± 0.2
		4-23-63	Cloudy	60	77.8 ± 2.2	129	91.6 ± 0.8	259	96.8 ± 0.4
	Whatman #1	3-4-63	Clear	50	94.4 ± 1.2	81	96.5 ± 0.7	123	97.9 ± 0.4
		5-16-63	Cloudy	52	90.1 ± 0.7	82	96.9 ± 0.4	123	98.9 ± 0.2
	Whatman #41	10-11-62	Clear	57	82.2 ± 0.8	113	92.7 ± 0.5	196	98.3 ± 0.2
		2-27-63	Cloudy	59	69.0 ± 1.8	123	86.1 ± 0.7	227	93.7 ± 0.4
	Whatman #541	11-14-62	Clear	59	63.6 ± 1.4	122	82.4 ± 0.8	225	88.1 ± 0.3
		4-3-63	Clear	59	66.0 ± 1.1	126	78.8 ± 0.5	218	84.8 ± 0.3
Cellulose-Asbestos	Draeger	4-3-63	Clear	56	101.2 ± 0.6	106	99.9 ± 0.3	188	100.1 ± 0.2
		4-29-63	Clear	56	100.3 ± 1.4	108	100.5 ± 0.6	184	100.5 ± 0.3
	Draeger #6901	5-3-63	Clear	53	101.6 ± 1.9	112	100.9 ± 0.8	148	100.6 ± 0.3
		5-22-63	Clear	52	100.6 ± 0.6	85	100.5 ± 0.5	152	100.0 ± 0.2

(Table Continues)

TABLE 4 (Continued)
Measured Retentivity of Air Filters for Natural Radioactive Aerosols (RaB + C) in the Atmosphere

Filter Type	Filter	Date of Collection	Weather	Unit A Air Velocity (cm/sec)	Unit A Retention (%)	Unit B Air Velocity (cm/sec)	Unit B Retention (%)	Unit C Air Velocity (cm/sec)	Unit C Retention (%)
Cellulose Asbestos (Cont d)	HV-70	2-7-63	Hazy	55	98.7 ± 0.4	103	99.8 ± 0.2	191	99.8 ± 0.1
		5-16-63	Cloudy	55	98.4 ± 0.7	102	100.2 ± 0.3	183	99.5 ± 0.2
	S-P bleu	5-2-63	Clear	61	41.2 ± 4.6	139	51.0 ± 2.6	310	72.7 ± 1.0
		5-6-63	Cloudy	61	46.8 ± 1.8	141	58.9 ± 0.8	309	80.5 ± 0.4
	S-P jaune	5-10-63	Clear	60	82.7 ± 0.7	125	89.0 ± 0.3	259	95.6 ± 0.2
		5-17-63	Cloudy	59	78.9 ± 1.5	131	92.5 ± 0.6	270	97.5 ± 0.3
	S-P rose	4-17-63	Clear	56	99.9 ± 0.9	107	99.0 ± 0.5	197	99.8 ± 0.3
		5-3-63	Clear	57	98.4 ± 0.3	103	99.4 ± 0.2	191	100.0 ± 0.1
	Toyo HE-10	10-2-62	Clear	57	100.1 ± 0.4	88	99.8 ± 0.3	151	100.0 ± 0.2
		3-4-63	Clear	53	101.7 ± 1.1	74	99.3 ± 0.6	151	100.2 ± 0.3
	Type 5	10-12-62	Clear	—	—	148	73.8 ± 0.4	327	86.0 ± 0.2
		10-19-62	Clear	61	66.1 ± 0.7	149	73.1 ± 0.3	336	85.5 ± 0.2
	Type 6 (Navy N-15)	10-1-62	Hazy	58	100.1 ± 0.3	—	—	233	100.0 ± 0.1
		3-8-63	Clear	58	101.3 ± 1.4	120	99.9 ± 0.6	259	100.1 ± 0.3
		5-20-63	Cloudy	58	100.1 ± 0.5	119	99.4 ± 0.3	248	100.0 ± 0.1
Cellulose-Glass Fiber	Type 5G	2-20-63	Clear	61	59.6 ± 1.4	150	64.6 ± 0.6	342	74.0 ± 0.4
		3-1-63	Cloudy	61	63.6 ± 1.7	146	69.9 ± 0.8	344	81.1 ± 0.4
Glass Fiber	FOA-1-484	10-3-63	Clear	58	100.1 ± 0.4	131	100.1 ± 0.2	270	99.9 ± 0.1
	Gelman Type A	4-22-63	Cloudy	58	100.9 ± 2.3	123	100.0 ± 0.6	235	99.8 ± 0.3
	Gelman Type E	4-19-63	Clear	59	99.8 ± 0.5	123	99.5 ± 0.2	248	99.9 ± 0.1
	Hurlburt 934AH	10-2-62	Clear	57	100.7 ± 0.5	120	100.0 ± 0.2	209	100.0 ± 0.1
		3-7-63	Clear	58	100.6 ± 1.1	118	99.9 ± 0.7	237	100.1 ± 0.3
	MSA 1106B	9-28-62	Clear	58	99.8 ± 0.5	130	99.4 ± 0.3	250	99.7 ± 0.1
		5-20-63	Cloudy	59	100.1 ± 0.7	124	100.0 ± 0.3	261	99.9 ± 0.1
	TFA-69GF	9-20-63	Clear	57	99.7 ± 0.2	130	99.8 ± 0.1	258	99.9 ± 0.1
	Whatman GF/A	10-5-62	Cloudy	59	100.8 ± 1.0	126	99.3 ± 0.3	259	99.9 ± 0.1
		4-17-63	Cloudy	59	101.1 ± 0.9	125	99.4 ± 0.5	254	100.0 ± 0.3
Polystyrene	Microsorban	4-4-63	Clear	58	98.5 ± 0.9	123	98.1 ± 0.6	272	98.3 ± 0.3
		5-10-63	Clear	59	95.6 ± 0.7	136	94.8 ± 0.4	259	98.4 ± 0.1
	Delbag (France)	4-8-63	Clear	57	100.0 ± 3.2	123	95.4 ± 0.9	232	99.4 ± 0.4
		5-7-63	Clear	55	102.0 ± 2.8	119	97.6 ± 1.3	216	98.4 ± 0.6
Membrane	Millipore AA	2-6-63	Clear	45	100.1 ± 0.8	74	99.6 ± 0.4	117	99.7 ± 0.2
		4-26-63	Clear	47	98.5 ± 1.7	67	101.7 ± 1.0	91	100.2 ± 0.5
	Polypore AM-1	9-24-62	Clear	59	85.3 ± 0.6	132	91.7 ± 0.4	270	95.6 ± 0.2
		2-13-63	Clear	60	80.5 ± 2.2	130	91.8 ± 0.7	275	95.6 ± 0.3
	Polypore AM-3	9-24-62	Clear	56	99.3 ± 0.2	—	—	165	99.5 ± 0.2
		2-13-63	Clear	56	98.8 ± 2.2	113	99.4 ± 0.7	224	99.7 ± 0.3

TABLE 5
Measured Retentivity of Air Filters for Airborne Fission Products

Filter Type	Filter	Date of Collection	Weather	Unit A		Unit B		Unit C	
				Air Velocity (cm/sec)	Retention (%)	Air Velocity (cm/sec)	Retention (%)	Air Velocity (cm/sec)	Retention (%)
Cellulose	Esparto	11/6 8/62	Cloudy	60	93.8 ± 0.2	134	98.6 ± 0.1	217	99.7 ± 0.1
		1/22 23/63	Cloudy	60	88.8 ± 0.2	136	97.7 ± 0.1	310	98.1 ± 0.1
	Gryksbo #8	1/14-15/63	Clear	54	98.7 ± 0.4	91	99.6 ± 0.2	122	98.3 ± 0.2
	IPC 1478	8/31-9/4/62	Clear	46*	33.9 ± 0.3	153	56.1 ± 0.2	363	71.3 ± 0.2
		10/22-24/62	Clear	66	62.4 ± 0.2	148	68.2 ± 0.2	344	76.1 ± 0.1
	MSA BM-2133 (carbon side up)	9/25-26/62	Cloudy	60	93.3 ± 0.2	141	96.3 ± 0.1	295	98.8 ± 0.1
		12/7 10/62	Cloudy	60	98.0 ± 0.1	127	99.4 ± 0.1	259	99.8 ± 0.1
	MSA BM 2133 (carbon side down)	10/5-8/63	–	61	85.2 ± 0.2	141	88.9 ± 0.1	295	98.1 ± 0.1
	S and S 589/1	9/20-21/62	Clear	56	95.3 ± 0.2	103	98.7 ± 0.2	136	98.8 ± 0.2
		4/17-18/63	Clear	56	98.8 ± 0.2	113	99.7 ± 0.1	142	99.2 ± 0.1
	S and S 589/2	10/18-19/62	Clear	49	99.7 ± 0.6	92	99.6 ± 0.3	100	99.9 ± 0.3
		4/24-25/63	Clear	52	99.1 ± 0.3	96	99.6 ± 0.2	108	99.8 ± 0.1
	S and S 2610	11/14-16/62	Clear	61	77.2 ± 0.3	115	95.4 ± 0.1	223	98.1 ± 0.1
		12/12-13/62	Clear	61	70.2 ± 0.9	141	94.1 ± 0.3	334	91.9 ± 0.2
	Struer	1/16/63	Clear	48	101.9 ± 0.9	71	99.6 ± 0.7	86	100.0 ± 0.5
	TFA-41	10/29-30/63	Clear	54	100.4 ± 1.2	113	99.7 ± 0.8	186	99.1 ± 0.5
		10/30-31/63	Clear	–	–	111	100.8 ± 1.2	166	99.8 ± 0.7
	TFA-2133 (carbon side up)	10/11-14/63	Clear	59	92.3 ± 0.3	142	98.0 ± 0.1	259	99.7 ± 0.1
	Toyo 5A	9/11-12/62	Clear	37*	99.1 ± 0.2	124	98.5 ± 0.2	218	99.7 ± 0.1
		10/1-2/62	Clear	58	99.4 ± 0.3	118	97.2 ± 0.2	165	99.9 ± 0.1
	Whatman #1	10/11-12/62	–	48	100.3 ± 0.4	67	100.0 ± 0.5	78	99.8 ± 0.2
		1/31-2/1/63	Cloudy	44	99.9 ± 0.4	47	99.7 ± 0.4	57	99.3 ± 0.4
	Whatman #41	9/19-20/62	Clear	56	99.0 ± 0.2	97	99.7 ± 0.1	134	99.4 ± 0.1
		5/9-10/63	Clear	57	98.9 ± 0.2	102	99.3 ± 0.2	152	98.7 ± 0.1
	Whatman #541	10/17-18/62	Clear	50	98.4 ± 0.4	98	98.9 ± 0.3	126	97.3 ± 0.2
		4/4-5/63	Clear	56	93.0 ± 0.3	101	94.8 ± 0.2	166	96.0 ± 0.1
Cellulose-Asbestos	Draeger	11/27-28/62	Cloudy	55	101.1 ± 0.2	100	100.1 ± 0.1	151	100.0 ± 0.1
		1/10-14/63	Clear	55	99.9 ± 0.4	101	100.2 ± 0.2	181	100.2 ± 0.2
	Draeger #6901	11/26-27/62	Cloudy	51	101.7 ± 0.5	79	100.0 ± 0.2	118	100.1 ± 0.2
		5/22-23/63	Clear	52	99.9 ± 0.2	93	100.1 ± 0.2	124	99.9 ± 0.1

Table continues

*A different filter unit was employed for the low velocity collections prior to Sept 19 1962

TABLE 5 (Continued)
Measured Retentivity of Air Filters for Airborne Fission Products

Filter Type	Filter	Date of Collection	Weather	Unit A		Unit B		Unit C	
				Air Velocity (cm/sec)	Retention (%)	Air Velocity (cm/sec)	Retention (%)	Air Velocity (cm/sec)	Retention (%)
Cellulose-Asbestos (Cont d)	HV 70	10/10-11/62	Clear	55	99.3 ± 0.3	101	99.8 ± 0.2	137	100.0 ± 0.1
		12/19-20/62	Cloudy	53	100.9 ± 0.6	85	100.3 ± 0.4	96	100.1 ± 0.4
	S P bleu	3/27 29/63	Clear	60	91.5 ± 0.1	126	98.3 ± 0.1	211	99.4 ± 0.1
		4/23-24/63	Cloudy	61	83.8 ± 0.2	136	98.2 ± 0.1	282	99.6 ± 0.1
	S-P jaune	3/21-22/63	Cloudy	59	100.1 ± 0.4	125	100.0 ± 0.2	216	100.1 ± 0.1
		5/7 8/63	Cloudy	59	98.4 ± 0.1	129	100.0 ± 0.1	229	99.9 ± 0.1
	S P rose	3/20-21/63	Clear	55	100.3 ± 0.2	103	100.0 ± 0.1	178	100.1 ± 0.1
		4/16-17/63	Clear	55	99.8 ± 0.1	101	99.9 ± 0.1	144	99.9 ± 0.1
	Toyo HE-10	10/2-3/62	Cloudy	54	100.5 ± 0.8	81	100.0 ± 0.6	99	99.9 ± 0.4
		1/24 25/63	Clear	52	100.4 ± 0.4	85	100.1 ± 0.2	116	100.2 ± 0.2
	Type 5	12/14 17/62	Clear	61	95.1 ± 0.2	130	99.3 ± 0.1	215	99.5 ± 0.1
		1/4 7/63	Cloudy	61	95.6 ± 0.2	127	99.3 ± 0.1	184	99.8 ± 0.[illegible]
	Type 6 (Navy N 15)	6/27 29/62	Clear	44*	100.2 ± 0.4	121	100.1 ± 0.1	284	99.6 ± 0.1
		10/12-15/62	Cloudy	57	99.9 ± 0.1	116	100.0 ± 0.1	203	100.0 ± 0.1
		10/31 11/2/62	–	58	100.1 ± 0.3	127	100.1 ± 0.1	304	100.0 ± 0.1
Cellulose Glass Fiber	Type 5G	6/29 7/2/62	Cloudy	46*	74.8 ± 0.4	145	88.9 ± 0.2	340	98.5 ± 0.1
		9/24-25/62	Cloudy	61	90.8 ± 0.3	143	96.2 ± 0.1	321	99.2 ± 0.1
		10/26-30/62	–	60	90.7 ± 0.1	143	97.3 ± 0.1	307	99.0 ± 0.1
Glass Fiber	FOA 1 484	10/4 7/63	Clear	57	100.2 ± 0.2	125	99.9 ± 0.1	149	99.9 ± 0.1
	Gelman Type A	12/13-14/62	Clear	58	99.6 ± 0.3	120	100.1 ± 0.2	235	100.1 ± 0.1
	Gelman Type E	10/8-10/62	Cloudy	58	100.2 ± 0.3	122	100.0 ± 0.2	145	99.7 ± 0.1
	Hurlburt 934AH	10/15-17/62	–	57	99.8 ± 0.1	115	99.9 ± 0.1	167	100.0 ± 0.1
		12/27-28/62	Clear	57	99.9 ± 0.2	101	99.9 ± 0.2	121	100.1 ± 0.1
	MSA 1106B	10/24-26/62	Cloudy	58	99.8 ± 0.2	109	100.0 ± 0.2	173	100.1 ± 0.1
		12/26-27/62	Clear	58	99.9 ± 0.2	122	100.0 ± 0.1	177	100.0 ± 0.1
	IFA-69GF	10/14-15/63	Clear	56	101.2 ± 1.3	113	99.9 ± 0.4	143	100.1 ± 0.3
	Whatman GF/A	11/13-14/62	Cloudy	58	99.9 ± 0.2	123	100.0 ± 0.1	246	100.0 ± 0.1
		1/2 3/63	Cloudy	58	99.8 ± 0.3	121	99.6 ± 0.2	184	100.0 ± 0.1
Polystyrene	Microsorban	9/28-10/1/62	–	59	100.0 ± 0.2	130	100.0 ± 0.1	201	100.0 ± 0.1
		11/16-19/62	Cloudy	57	100.0 ± 0.1	97	99.8 ± 0.1	177	99.9 ± 0.1
	Delbag (USAF)	6/22 25/62	Cloudy	44*	99.8 ± 0.4	128	99.5 ± 0.1	279	99.7 ± 0.1
	(France)	3/22-25/63	–	57	100.0 ± 0.1	108	100.0 ± 0.1	197	100.0 ± 0.1
	(France)	5/16-17/63	Clear	57	99.8 ± 0.3	115	100.0 ± 0.2	241	99.9 ± 0.1
Membrane	Millipore AA**	–	–	–	–	–	–	–	–
	Polypore AM 1	8/23-24/62	Clear	–	–	131	99.8 ± 0.2	236	99.6 ± 0.1
		1/17/63	Clear	59	100.3 ± 0.6	123	100.0 ± 0.4	177	100.2 ± 0.3
	Polypore AM-3**	–	–	–	–	–	–	–	–

*A different filter unit was employed for the low velocity collections prior to Sept 19 1962

**Flow resistance too high for long collections to be made retentivity for fission products inferred from RaBC measurements to be essentially 100%

filter media and (b) significant day-to-day differences in the size distribution of particles with which the airborne radioactivity was associated. The latter led to the undertaking of another study involving the use of packs of three or more filters as a means of determining the particle size distribution of airborne radioactivity (7). The effective size of fission-product particulate matter decreased steadily from January through May (1963), after which time the size appeared to remain fairly constant.

Field Evaluation of Other Filter Characteristics

Filters of each type were selected at random from the available supply and used for the determination of some of the physical characteristics of the filter material. While the number available was not sufficient to categorize the filter rigorously, it was sufficient to indicate the general behavior of filters from this source. This information is presented in Table 6.

The filters were weighed on an analytical balance and an average weight (mg/cm^2) was calculated for each material. Measurements of filter thickness (caliper) were made by standard procedures used in the paper industry. The ash contents were determined by igniting one or more of the weighed samples of each material at 750°C in a muffle furnace for an hour and then weighing the residue. In order to obtain a quantitative estimate of the ruggedness of the various filters, the average tensile strength was determined by measurement of several 1-inch-wide strips of each material by use of an Instron Tensile Testing Machine; the rate of extension was 0.5 in. per minute, in accord with accepted practice.

The airflow and associated pressure drop across a 4-in.-diameter filter (effective area 60.0 cm^2) were determined for three of the filters of each type (including the heaviest and lightest of those weighed) with a Roots-Connersville blower unit (Type AF-24) operated at 1250 rpm. The flow was determined by a Fischer and Porter flowmeter (range 0 to 55 cfm) and the pressure was determined by a bellows-type pressure gage (range 0 to 30 cm Hg). The relationship between airflow and pressure drop (vacuum) across the filter, which is characteristic of the blower used, is shown in Fig. 1. The relative positions which the various filters would assume along this curve are indicated by the average values obtained for each filter medium. For a given filter material no direct relationship between filter weight and flow characteristics was apparent.

The effect of dust loading on the flow rate through the filter was determined by exposing filters in groups of three to five in separate positive-displacement blower units while measuring the pressure across the filter (convertible to flow rate) as a function of time. Since the atmospheric dust loading varies widely both daily and seasonally, one filter of each group was used as a standard to normalize the varying dust loadings to an "average" day; Gelman Type A glass fiber paper was selected as the reference on the basis of availability and because it generally underwent a readily measurable change in flow during an 8-hour period. For long collection periods, Type 5G cellulose-glass fiber paper was employed as a standard because of its slower rate of clogging; Whatman #1 paper was used as a secondary standard when faster clogging filters were being evaluated.

The percent change in flow of each filter was compared with the volume of air filtered (in m^3/cm^2) which had been corrected by a factor related to the dust loading of the air during the period of measurement. The correction factor derived for each set of collections was the ratio of the volume of "standard" air required to cause a 10 percent decrease in flow of the reference paper relative to the volume required to cause a similar decrease in the reference filter. It was, in effect, the relative dust loading in the atmosphere during the collection as compared to an "average" summer day. Average dust loadings, over a 24-hour period, were quite variable, as evidenced by an approximately five to one range in values obtained for the reference filter during 20 collections. Even greater short-term variations were observed. In this comparison it has been necessary to assume a uniform dust concentration in the air during the period of simultaneous exposure of the filters and also a linear change in filter performance with dust loading, at least during the initial phase (10 to 20 percent reduction in flow). The relative volumes of air (in cubic meters filtered per square centimeter of filter surface) required to produce a 10 percent decrease in the initial flow rate in comparable positive-displacement blower systems is presented in Table 6. The rate of change of

TABLE 6
Summary of Physical Characteristics of Filter Media

Filter and Type	Thickness (mm)	Tensile Strength (Kg/cm)	Weight (mg/cm²)	Ash Content		Performance in Standard System		Effect of Dust Loading	
				(%)	(mg/cm²)	Flow (m³/hr)	Pressure (cm Hg)	Volume Filtered at 10% Reduction in Flow (m³/cm²)	Decrease in Flow (% per m³/cm²)
Cellulose									
Esparto	1 37	1 62†	24 9	0 25	0 061	42 0	5 5	35 7±6 6 (4)*	0 28
Gryksbo #8	0 18	1 74	8 2	0 16	0 014	33 8	10 9	1 95±0 6 (2)	5 1
IPC 1478	0 56	0 18†	14 8	0 12	0 019	51 0	< 1 0	>>150 (3)	<< 0 1
MSA BM-2133	1 83	0 58	32 7	0 12	0 038	45 5	3 3	>>100 (4)	< 0 1
S and S 589/1	0 18	0 96	8 2	< 0 10	< 0 010	36 5	9 0	1 97±0 56 (3)	5 1
S and S 589/2	0 17	1 49	8 0	< 0 10	< 0 010	30 6	13 5	1 25±0 35 (3)	8 0
S and S 2610	0 56	0 51	12 1	< 0 10	0 011	49 6	< 1 0	87 (1)	0 11
Struer	0 18	1 52	7 6	0 20	0 015	24 6	19 1	1 38±0 34 (2)	7 2
TFA-41	0 25	1 17	9 0	< 0 10	< 0 010	35 2	10 1	2 50±0 03 (2)	4 0
TFA-2133	1 85	1 02	32 2	< 0 10	0 025	45 5	3 3	>100 (3)	< 0 1
Toyo 5A	0 23	1 09	9 1	< 0 10	< 0 010	38 4	7 7	2 66±0 52 (4)	3 8
Whatman #1	0 15	1 67	8 4	0 13	0 011	22 9	21 1	0 56±0 05 (15)	17 9
Whatman #41	0 25	1 41	8 9	< 0 10	< 0 010	33 8	10 8	2 00±0 28 (5)	5 0
Whatman #541	0 15	2 24	8 0	< 0 10	< 0 010	35 7	9 6	0 96±0 25 (4)	10 4
Cellulose-Asbestos									
Draeger	0 94	0 15	22 3	9 37	2 09	30 8	13 6	8 3±1 8 (6)	1 2
Draeger #6901	0 56	0 67	18 8	5 22	0 97	25 5	18 4	5 4±0 7 (3)	1 9
HV-70	0 23	0 78	8 2	20 97	1 71	28 2	15 9	6 0±0 4 (3)	1 7
S-P bleu	0 28	1 83	9 1	1 95	0 178	44 7	3 6	12 8±2 7 (4)	0 78
S-P jaune	0 33	1 88	12 4	7 07	0 873	38 6	7 3	15 3±1 6 (2)	0 76
S-P rose	0 46	2 05	16 8	16 16	2 72	29 7	14 4	13 2 (1)	0 75
Toyo HE-10	0 66	0 75	20 9	9 10	1 91	24 8	19 0	8 1±2 0 (4)	1 2
Type 5	0 74	1 59†	12 3	1 93	0 233	48 8	1 2	31 0±6 9 (3)	0 32
Type 6(Navy N-15)	1 22	0 19	28 1	9 97	2 79	35 2	10 0	39 4±10 6 (6)	0 25
Cellulose-Glass									
Type 5G	0 76	1 31†	14 9	8 08	1 20	48 6	1 4	49 4±7 9 (6)	0 20
Glass Fiber									
FOA-1-484	0 33	0 15	6 3	99 3	6 26	36 4	9 1	35 7±7 3 (4)	0 28
Gelman Type A	0 46	0 38	9 4	99 4	9 36	35 4	9 9	20 0 (20)	0 50
Gelman Type E	0 46	0 86	9 0	98 1	8 95	36 4	9 1	18 8±1 2 (2)	0 53
Hurlburt 934AH	0 30	0 10	6 8	99 5	6 75	33 8	11 1	21 3±4 2 (6)	0 47
MSA 1106B	0 28	0 12	6 0	99 6	5 96	35 9	9 4	23 3±2 6 (3)	0 43
TFA-69GF	0 23	0 41	5 3	99 2	5 22	35 4	9 9	13 9±1 7 (2)	0 72
Whatman GF/A	0 25	0 11	5 5	99 0	5 49	36 0	9 3	27 0±1 4 (5)	0 37
Polystyrene									
Microsorban	1 55	0 15	21 7	< 0 10	0 016	39 1	7 3	47 6±13 3 (6)	0 21
Delbag	1 52	0 15	24 9	< 0 10	0 016	31 9	12 5	34 7±5 4 (3)	0 29
Membrane									
Millipore AA	0 15	0 29	4 8	< 0 10	< 0 010	19 2	24 4	6 3±0 3 (4)	1 6
Polypore AM-1	0 15	0 41	5 2	< 0 10	< 0 010	39 6	6 9	4 1±0 8 (6)	2 4
Polypore AM-3	0 15	0 72	6 6	< 0 10	< 0 010	30 2	14 1	3 2±0 5 (3)	3 1

*Number of observations indicated in ( )
†Filters have a scrim backing for added strength

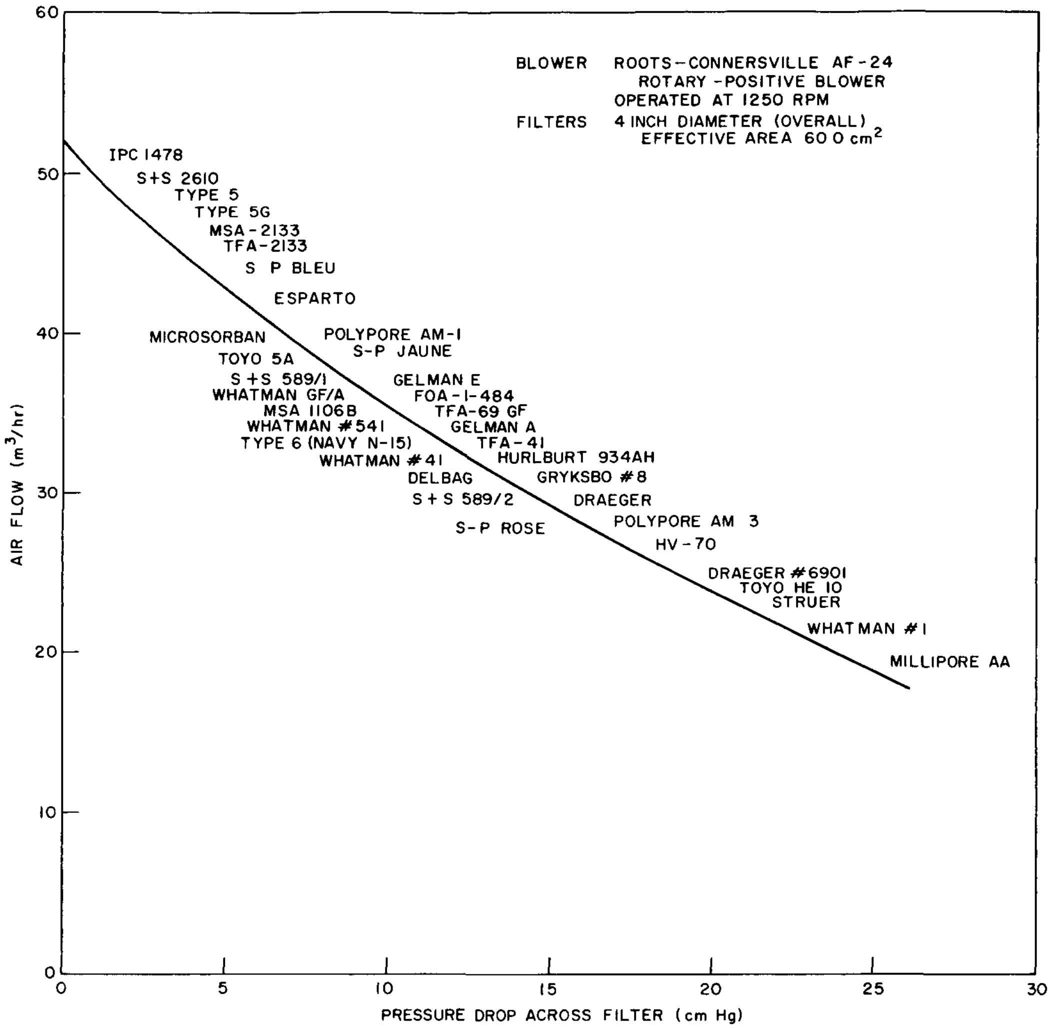

Fig 1 — Pressure flow characteristics of filter materials in a positive displacement blower system

flow with volume filtered would be greater in centrifugal or turbine-type blower systems since these generally exhibit a nonlinear flow-pressure relationship A sketch of the relative clogging rates of the various classes of air-filter materials is shown in Fig 2

Finally, an attempt was made to evaluate the effect of the filter media themselves as absorbers for the fission product β activity collected during normal operations The method involved counting the front of an exposed filter, counting the back side of the filter, and then the front again with a similar clean filter interposed as an absorber between the radioactive filter and the counter A rough determination of the apparent depth of penetration was made by comparing these results with an aluminum absorption curve of a fission product collection of similar age The absorption of the bulk filter materials for fission product β activity was dependent on the mass of the filter (mg/cm^2) rather than its composition and was similar to that of an equivalent thickness (mg/cm^2) of aluminum However, due to nonuniformity of the filters and variations in the dust loading of the various filters, it was not possible to determine the effective depth of penetration of the radioactive particles The insensitive counter employed in this study (effective air path and window thickness equivalent to nearly 10 mg/cm^2 of aluminum) discriminated against the low-energy β's, consequently, self-absorption corrections of only a few percent were indicated

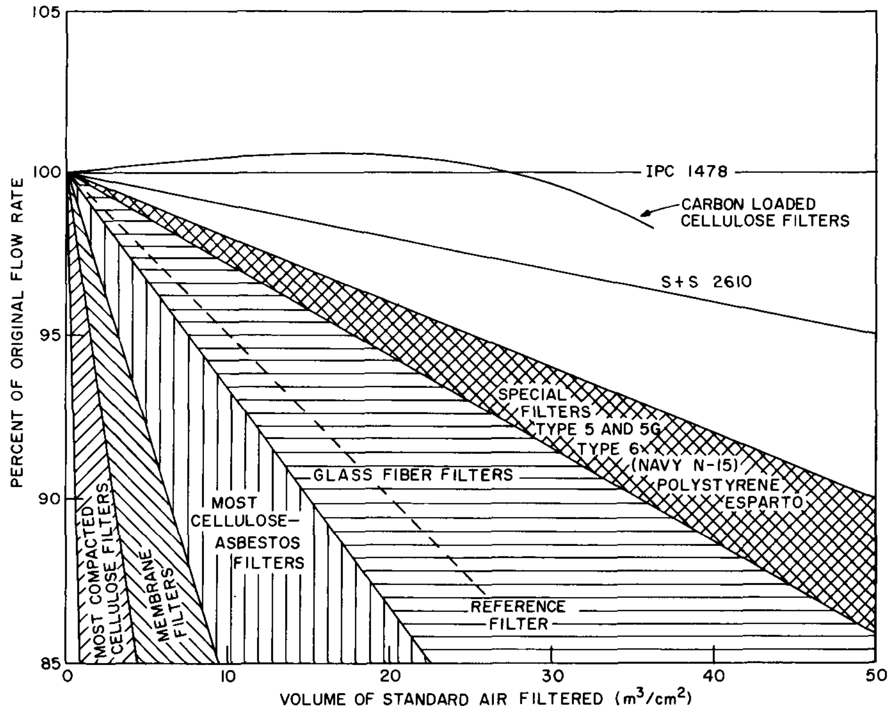

Fig. 2 – Relative clogging rates of various classes of air-filter materials

for most materials (most compacted or high-density filters) though for a few of the thicker cellulose filters a correction near 10 percent was indicated. These corrections would be significantly greater on systems employing counters having thin windows since fission product mixtures are heavily weighted with low-energy β emitters.

CONCLUSIONS

Since the effectiveness of any filtration method, either for the collection of aerosols or their removal from the air, depends to an important degree on the filter material that is used, the properties of the filter should be carefully considered in the design of any air-monitoring or air-purification system. In this study a number of the more important characteristics of a series of air-filter materials have been evaluated and compared so as to make possible a more scientific choice of a filter material for any particular use; no attempt is made to indicate which material should be used in any given situation.

The reported measurements indicate that the available filters cover a wide range of values in each of the physical or performance characteristics, permitting a balance to be reached in the filter selected for a given system or for one or more particular features to be optimized, generally at the expense of the others. The information reported covers such physical properties of the filters as the tensile strength, thickness, density, and ash content, the pressure-flow characteristics of clean filters, the effect of dust loading on filter performance, and the retentivity of the filters for various aerosols (*i.e.*, DOP, fission products, radon daughters attached to atmospheric aerosols) as a function of air velocity through the filter.

The study of the effect of dust loading on filter performance was complicated by the day-to-day variation in the dust content of the atmosphere. It may be possible to take advantage of this observation to devise a system for monitoring the dust content of the atmosphere which depends on the measurement of the change in flow of a "standard" filter with exposure time. Such a procedure should be inherently simpler than the present practice of determining the dust content from the weight gain of an exposed filter or from densitometer readings of the blackness of the filter.

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U S Naval Research Report 6054
CHARACTERISTICS OF AIR FILTER MEDIA USED FOR MONITORING AIRBORNE RADIOACTIVITY, by L B Lockhart, Jr , R L Patterson, Jr , and W L Anderson 17 pp and figs March 20, 1964

A comparison has been made of the more important characteristics of the available filter materials which are currently in use by various systems for monitoring airborne radioactivity throughout the world Most of the materials described are commercially available, the information herein is presented with the hope that it will be of use to those whose programs involve the employment of air-filter media or who require such information for the design of air-filter systems

The filter characteristics measured are such physical properties as tensile strength, thickness, density, ash content, retentivity toward 0 3μ dioctyl phthalate (DOP) aerosol particles as a function

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1 Particulate filters – Materials

2 Radioactive airborne particles – Removal

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