COMPARISON OF PERFORMANCE CHARACTERISTICS OF SOME FILTERS USING THORON DAUGHTERS AS RADIOACTIVE AEROSOL

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Abstract—The important characteristics of air sampling filters are collection efficiency, flow resistance and surface collection efficiency. A comparison was made for these performance characteristics between the filters used at present in JAERI for air sampling (mostly imported) and those (made in trial) by a Japanese manufacturer. Collection efficiency, and surface collection efficiency and also alpha energy resolution were tested using the Millipore AA filter as a reference filter and thoron decay daughters as a test aerosol; the significant particles were less than 0.1 micron in diameter.

In the cellulose filters tested, Toyo No. 5A and Toyo No. 1 showed nearly the same performance characteristics as Whatman 41, and the collection efficiencies of these three types of filters were over 90% at face velocities larger than 64 meters per minute.

In the cellulose asbestos filters tested, for alpha air sampling Toyo HE-40 proved superior to HV-70. This filter has a collection efficiency greater than 99.5%, and about the same surface collection efficiency as the glass fiber filter Gelman E, generally used for alpha air sampling. On the basis of these tests, it was decided to use the cellulose asbestos filter Toyo HE-40 for alpha air sampling in JAERI.

1. INTRODUCTION

The important characteristics of air sampling filters are collection efficiency, air flow resistance and surface collection efficiency. The last one is more important for alpha air sampling, because direct alpha counting is only effective for particles collected on or near the filter surface. A comparison was made for these performance characteristics between the filters used at present in JAERI for air sampling (mostly imported) and those proposed for use (mostly made in trial by a Japanese manufacturer).

Collection efficiency, surface collection efficiency, and also alpha energy resolution were tested using the Millipore AA filter as a reference filter and thoron decay daughters as a test aerosol; the significant particles were less than 0.1 micron in diameter.

It is recognized that Millipore AA does not collect all particles in the size range of natural activity,[1] whereas it is reported that Millipore AA has an efficiency over 99.9% for D.O.P. particles 0.3 micron in diameter,[2, 3] and for uranine particles both 0.27 micron and 0.025 micron in diameter.[4]

The present report describes the testing procedure and the results obtained. The data obtained were compared on relative, rather than absolute, values.

2. FILTERS TESTED AND RADIOACTIVE AEROSOL USED

The characteristics of filters used at present and proposed for use in air sampling in JAERI are shown in Table 1. The pore sizes tabulated for the filters, except Millipore AA, were

Table 1. *Filter Tested*

Filter and type	Thickness mm	Weight mg/cm²	Tensile strength kg/cm	Pore size μ	Fiber diameter μ
Cellulose					
Whatman 41	0.22	12.1	1.40	38	25
Toyo No. 1	0.21	11.6	2.60	25	25
Toyo No. 5A	0.23	12.1	1.13	30	25
Cellulose asbestos					
HV-70 9 mil	0.39	16.6	2.66	30	25
Toyo HE-10	1.11	41.5	1.13	36	25
Toyo HE-13	0.97	36.2	1.40	44	25
Toyo HE-40	0.42	13.5	3.07	32	25
Glass Fiber					
Gelman E	0.29	9.7	0.55	8.9	0.4
Toyo GA-100	0.30	10.0	0.08	12	0.6
Toyo GA-200	0.75	31.0	0.16	12	0.6
Toyo GB-100	0.41	14.8	0.08	8	0.3
Toyo GH-100	0.36	17.2	0.33	12	0.6
Membrane					
Millipore AA	0.17	4.2	0.33	0.80	—

obtained using the so-called bubble test* based on capillarity, which measures the maximum value. Millipore AA was found to have a pore size of 2.5 microns when measured by this method.

Thoron decay daughters were used as the test aerosol; the decay series is shown in Fig. 1. The size distribution for the series of particles

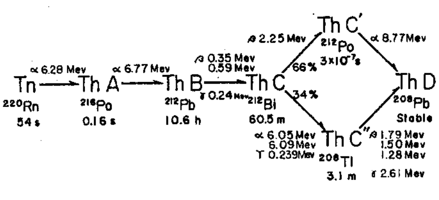

FIG. 1. Thoron decay series.

* The data were presented by the research group of Toyo Roshi Co., Ltd.

was measured using an electron microscope, after collecting the particles on a collodion film. This method was used because measurements made first by the cascade impactor method indicated most of the particles to be smaller than 0.3 micron in diameter. The results of electron microscope measurements showed that most of the particles were smaller than 0.1 micron in size. Consequently, the size distribution for the test aerosol was considered as approximately the same as, or a little larger than, the size range of the natural radioactive aerosol in the atmosphere—0.015–0.5 micron in size range.[5]

3. TEST PROCEDURE AND RESULTS

3.1. *Collection Efficiency*

The experimental apparatus used is shown in Fig. 2. Two air samplers, with a Millipore AA filter as the reference collector, were used

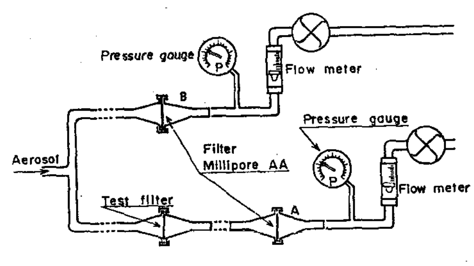

FIG. 2. Experimental apparatus.

simultaneously at the same flow rate. The reference filter (A) collected the aerosol penetrating the test filter, and the other, (B), collected the aerosol directly.

The collection efficiency ϵ was determined from the following equation;

$$\epsilon = (1 - \eta) \times 100\ (\%), \qquad \eta = n_A/n_B,$$

where n_A = gross alpha count rate for the particles collected on the reference filter (A),

n_B = gross alpha count rate for the particles collected on the reference filter (B).

The sampling periods varied from about 10 to 30 min, depending on the concentration of airborne activity, which was of the order of 10^{-8} μCi/cc during the test. As a rule, the sampling time was determined by the times required for the counting rate of the reference filter (B) to be more than 2000 cpm. The effective diameters of the filters were 40 mm, and the face velocities tested were 32, 48 and 64 m/min. Gelman E was selected as the reference filter at the face velocities of 48 and 64 m/min. This was because Millipore AA could not be used at higher velocities due to a shortage of the pumping power. The collection efficiency of Gelman E was considered to be over 99%, compared with Millipore AA, from the results obtained in the measurements described below and by others.[2, 3]

The results, obtained for the cellulose filters, are shown in Fig. 3, in which it is seen that the collection efficiency will increase with the face velocity, as described in other reports.[2-4] The average values of collection efficiencies for the filters tested are summarized in Table 2, together with other performance data. From the collection efficiency data in Table 2, it is seen that Toyo HE-10 and HE-40 are not inferior to HV-70 of the cellulose asbestos filters.

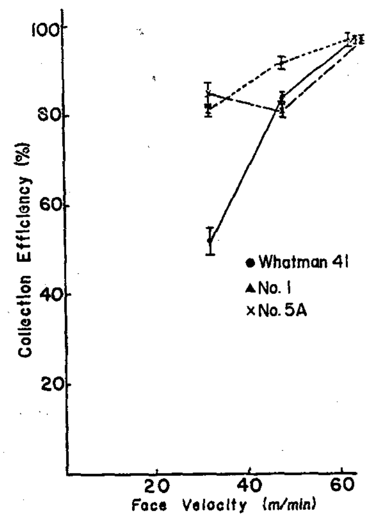

FIG. 3. Collection efficiency of cellulose filters.

3.2. *Surface Collection Efficiency*

In order to compare surface collection, two different techniques are usually used: one[6] is to measure the counting loss due to the burial of radioactive particles in the filter material, and the other[7] is to measure the alpha energy resolution of particles collected on the filter material. In the present experiment, both techniques were used for comparing surface collection efficiency for the thoron decay daughters. For the Millipore AA filter used as a reference filter, the alpha counting loss due to burial can be neglected because of the filter thickness (4 mg/cm^2 in weight) and the superiority in surface collection efficiency; that is, the surface collection efficiency is considered to be approximately one.

(a) *Comparison of counting loss due to burial.* In order to compare the surface collection efficiency of test filters with that of Millipore AA, the ratios were determined by the following equation:

$$F_i^x = \frac{N_i^x/N_\gamma^x}{N_i^{AA}/N_\gamma^{AA}},$$

where F_i^x $(i = \alpha, \beta)$ = relative surface collection efficiency for alpha or beta activity, respectively,

N_i^x $(i = \alpha, \beta)$ = counting rate of the alpha or beta emitters, respectively, collected on the filters denoted by x,

N_γ^x = net count rate of the 0.239-MeV ThC gamma, which is that within the channel width of a half maximum in the gamma pulse height spectrum.

Filters were counted using the following detectors: a ZnS(Ag) scintillation counter for alphas, a G.M. counter for betas, and a NaI scintillation counter with pulse height analyzer for gammas. The measurements were made at the face velocities of 32 and 64 m/min, but no significant difference was observed in the ratios at the two velocities. The average values for the face velocity of 32 m/min are shown in Table 2.

(b) *Alpha energy resolution.* Measurements were made of the thoron daughters collected on the filters at both a face velocity of 32 m/min, and at the maximum face velocity available by the 2 h.p. vacuum pump, which is used for air sampling in JAERI. The energy resolution (%) for 8.77 MeV ThC′ alphas was determined, using a solid-state (silicon p-n junction) detector and multichannel PHA, at room temperature (20°C) and without a collimator. Under these conditions the energy resolution was 6.0% for a ^{239}Pu (E_α = 5.15 MeV) source, thinly deposited on a metal disk.

The alpha spectra for HE-40 are shown in Fig. 4. The energy resolution data obtained are shown in the right columns of Table 2, in which it can be seen that the energy resolution improves with increase of the face velocity. These results agree with theory because the contribution of impaction to the collection is larger at higher velocities.

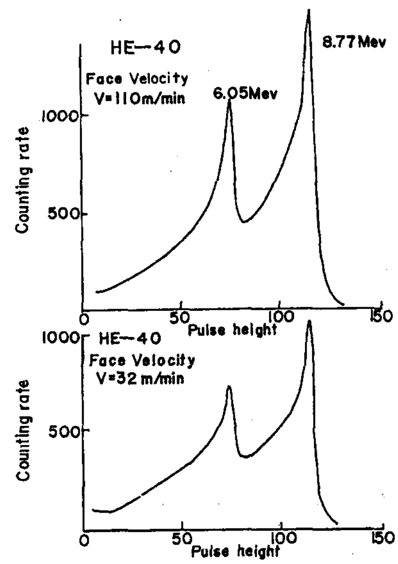

FIG. 4. Alpha spectra of Tn daughters collected on HE-40 filter.

From the data on surface collection efficiency and alpha energy resolution in Table 2, it can be seen that the glass fiber filters Gelman E and GB-100, and the cellulose asbestos filter HE-40 are superior in surface collection efficiency to the others, excepting Millipore AA.

3.3. *Air Flow Resistance*

The relationship between the air flow rate and pressure drop was measured on the test filters for an effective filter diameter of 50 mm. The results obtained for the celullose filters are shown in Fig. 5. The glass fiber filters GB-100 and GH-100 were mechanically so weak that they broke at higher velocities. The face velocities for the test filters at the pressure drops 200 and 300 mm Hg are shown in Table 2.

Table 2. Summary of Characteristics of the Filter Tested

Filter and Type		Face velocity (m/min)		Collection efficiency (%)			Surface collection efficiency		Alpha energy resolution at 8.77 MeV	
		Pressure drop		Face velocity			α	β		
		mm/Hg 200	mm/Hg 300	m/min 32	m/min 48	m/min 64	m/min 32	m/min 32	m/min 32	max face velocity
Cellulose	Whatman 41	Δ 92 × 120	Δ 120 × 180	52	84	97	0.67	0.73	37	(%) 28 (95 m/min)
	Toyo No. 1	80	100	81	92	97	0.36	0.49	45	26 (80 m/min)
	Toyo No. 5A	100	140	85	81	97	0.63	0.81	38	26 (87 m/min)
Cellulose asbestos	HV-70	100	150	99	98	98	0.61	0.76	28	18 (130 m/min)
	Toyo HE-10	100	140	99.7	99.7	99.7	0.55	0.74	46	24 (100 m/min)
	Toyo HE-13	200	—	79	92	89	0.12	0.36	30	31 (160 m/min)
	Toyo HE-40	100	140	99.7	99.9	99.6	0.81	0.86	16	13 (110 m/min)
Glass fiber	Gelman E	130	180	99.7	(99.9)	—	0.91	0.89	19	13 (96 m/min)
	Toyo GA-200	150	190	98	97	99	0.53	0.86	32	24 (96 m/min)
	Toyo GB-100	160	—	99	(99.9)	99.95	0.95	0.69	20	13 (80 m/min)
	Toyo GH-100	200	—	79	85	93	0.55	0.86	28	18 (80 m/min)
Membrane	Millipore AA	—	—	99.95	—	—	1.0	1.0	8.4	8.4 (34 m/min)

Δ and × show that the weight of the filter paper is 19 and 17 mg/cm^2, respectively.

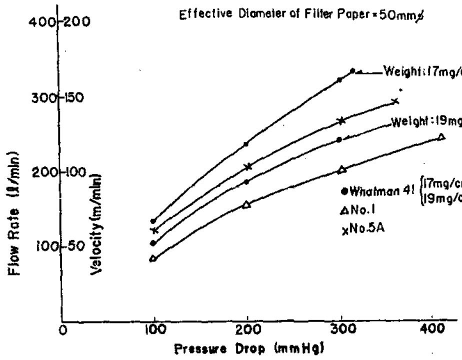

FIG. 5. Pressure drop vs. flow rate of cellulose filters.

4. DISCUSSION

4.1. *Comparison of the Results With Those by Others*

The collection efficiency of filters depends a great deal on the characteristics and size distribution of the particles. In Table 3, the data obtained by other workers[3, 4, 6] are compared with the data obtained by the authors. It appears that no significant difference can be observed among the given data.

The surface collection efficiencies measured by others[6, 8] are compared with the authors' data in Table 4, where the values by C. L. Lindeken[6] were measured relative to Millipore AA. In Table 4, it can be seen that the data agree on a relative basis with respect to filter material.

Table 3. Collection Efficiency of Filter for Various Aerosols

Filter	Particle		Collection efficiency			Reference
	Material	Diameter μ	m/min 15 %	m/min 30 %	m/min 60 %	
Whatman 41	D.O.P.	0.3	72	84	98	3
	Uranine	0.025	82.0	75.0	82.0	4
	Uranine	0.27	87.2	91.0	94.5	4
	Natural activity	—	52	68	78	6
	Natural activity	—	—	69.0	86.1	3
	Tn daughters	<0.1	—	52	97	
Toyo No. 5A	D.O.P.	0.3	68	76	86	3
	Natural activity	—	—	—	—	6
	Natural activity	—	—	77.8	91.6	3
	Tn daughters	<0.1	—	85	97	
HV-70	D.O.P.	0.3	98.2	99.2	99.8	3
	Uranine	0.025	95.2	97.6	98.9	4
	Uranine	0.27	98.2	97.2	96.5	4
	Natural activity	—	—	—	98	6
	Natural activity	—	—	98.4	99.8	3
	Tn daughters	<0.1	—	99	98	
Toyo HE-40	D.O.P.	0.3	99.93	99.98	99.996	3
	Natural activity	—	—	—	—	6
	Natural activity	—	—	100.1	99.3	3
	Tn daughters	<0.1	—	99.7	99.7	
Gelman E	D.O.P.	0.3	99.964	99.970	99.986	3
	Natural activity	—	—	—	98	6
	Natural activity	—	—	99.8	99.5	3
	Tn daughters	<0.1	—	99.7	—	

Table 4. Comparison of Surface Collection Efficiency of Filters

Filter	Surface collection efficiency		
	Uranium compound[8]	Natural activity[6]	Tn daughters
Whatman 41	~70	38	67
HV-70		80	61
Gelman E		89	91

4.2. *Reliability of the Data*

The data obtained for the collection efficiency and the surface collection efficiency, relative to Millipore AA, were not very accurate. However, from the comparisons given above and because of the rather good performance of Millipore AA as a reference filter, the data obtained could furnish information of considerable value.

5. SUMMARY

The important performance characteristics of filters were measured, mainly relative to Millipore AA. The results obtained are summarized in Table 2, in which it is seen that the data obtained agree well with those by others.

Of the cellulose filters tested, Toyo No. 5A and No. 1 showed similar performances to Whatman 41, and the collection efficiencies of these three filters were over 90% for thoron daughters at face velocities larger than 64m/min. However, these filters are not suitable for alpha air sampling because of poor surface collection efficiency.

The collection efficiencies of the cellulose asbestos filters, excepting Toyo HE-13, were over 98% at the face velocities tested. Toyo HE-40 proved to be superior to HV-70 in alpha air sampling because this filter has a large collection efficiency and about the same surface collection efficiency as the glass fiber filter, Gelman E.

Of the glass fiber filters, Toyo GB-100 showed a similar performance to Gelman E which is usually used for alpha air sampling due to its good performance. This filter, made in trial, cannot be used for routine air sampling because of mechanical weakness.

Finally, it may be considered that for air sampling, the cellulose filter Toyo No. 5A and No. 1 can be used instead of Whatman 41, and the cellulose asbestos filter Toyo HE-40 can be used instead of HV-70 and Gelman E. That is, Toyo HE-40 is found to be sufficiently usable for alpha air sampling.

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