

**Determination of Radon Concentration
in the Air Through
Measurement of Its Solid Decay Products**

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

*Physical Chemistry Branch
Chemistry Division*

and

C. R. HOSLER

*Air Resources Laboratory
U S Weather Bureau*

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**U.S. NAVAL RESEARCH LABORATORY
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ABSTRACT

An analytical method has been devised for the determination of the radon concentration in the air by measurement of the radioactive decay of the solid radon daughters collected on air filters during a fixed sampling period. The ratio of the radioactivity present at two periods, determined by an initial count immediately after termination of sampling and a second count an hour later, is used to estimate the extent of radioactive equilibrium established between radon and its daughters and to obtain a correction factor for relating radon daughter activity to radon activity.

The disintegration rates of the various decay products of radon as a function of the age of the radon conglomerate have been calculated during the growth and collection periods and for successive 5-minute decay periods extending through the first 71 minutes following termination of filtration. A procedure for the calibration of β counters for the evaluation of RaB and RaC activities was established. Use was made of this analytical method to determine radon concentrations in the air near ground level.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

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DETERMINATION OF RADON CONCENTRATION IN THE AIR THROUGH MEASUREMENT OF ITS SOLID DECAY PRODUCTS

INTRODUCTION

A relationship between the natural radioactivity of the air and meteorological factors has been recognized for many years, and some of the variables have been studied (1-10). The measurement of natural radioactivity in the air was included in the International Geophysical Year Program on Atmospheric Nuclear Radiation; however, the potential of radioactivity as a meteorological tracer has not yet been fully realized. During recent years the emphasis has been on the exploitation of man-made radioactive tracers inserted into the atmosphere at various altitudes by nuclear detonations. With the slow disappearance of this material, tracer studies, of necessity, must be carried out with the variety of natural isotopes normally present in the atmosphere, unless a decision is reached to introduce new radioactive sources into the environment.

The natural radioactive products of interest in this study arise from decay of radioactive materials in the ground which releases the rare gases radon and thoron to the atmosphere. These gases undergo radioactive decay primarily within the lowest part of the atmosphere, with the formation of various radioactive descendants which are electrically charged, chemically reactive, and have atomic dimensions. These particles immediately become attached to the extremely small, highly mobile ions or particles in the air (11). Because of their short lifetimes, the radioactivity is essentially removed by decay before appreciable growth in particle size or deposition can occur. The long-lived Pb^{210} , a descendant of radon, has been observed to be associated with larger particles (12), as predicted by Junge (10). Such isotopes as Be^7 , P^{32} , P^{33} , S^{35} , etc., produced in the upper atmosphere by the action of cosmic rays would be expected to behave similarly to Pb^{210} .

A significant difference should exist between the radioactive isotopes having different half-lives: fission debris or long-lived natural airborne radioactivities should be attached to dust particles which might be expected to be about average in size and to have a normal charge distribution, while the shorter lived natural radioactive products should be attached to smaller, more highly charged particles than the average. These observations have been confirmed by the filter collection of fission products with a higher retention efficiency than for the natural radioisotopes RaB+C and ThB+C and by the more efficient collection of these latter products by charged wires.

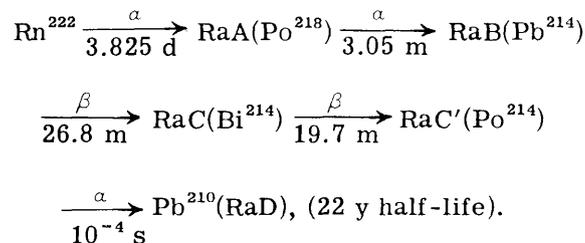
Radon and its daughter products, RaA , RaB , and RaC (or RaC'), and decay products of thoron are suitable for study; however, techniques for collection and evaluation of the gaseous radon are more cumbersome than for its solid decay products or for those of thoron. At the present time, measurement of the longer lived thoron daughters (ThB , 10.6-hr half-life; ThC , 60.5-min half-life) is complicated by the presence of a considerable background of fission products in the atmosphere which limits the speed and accuracy with which the ThB measurements can be made. This report is concerned with the development of procedures for the evaluation of the radon in the atmosphere through radioactivity measurement of the filterable decay products of radon.

THEORETICAL CONSIDERATIONS

Any analytical method for determination of radon through measurement of its decay products must take into account the extent of equilibrium established between radon and

its short-lived descendants in the air and the extent to which this radioactivity distribution is modified by the filtration procedure and radioactive decay processes. A simple measurement of either α or β activity cannot be directly related to the radon concentration; the problem is to find a supplementary measurement or series of measurements which will adequately define the extent of secular equilibrium existing during the sampling period.

The portion of the uranium decay series of concern in this study is as follows:



Radon gas diffuses from the earth's surface essentially free of any daughter activity and within a matter of hours comes into secular equilibrium with its shorter lived descendants. For the purpose at hand the radioactive series can be considered to end at the long-lived Pb^{210} , since previous studies have shown the concentration of Pb^{210} and its descendants in the air to be negligible (13).

Growth of Radon Descendants

Details of the calculations of the growth of radon daughters with time after diffusion of radon from the soil are shown in Appendix A. The relationship between the age τ of the radon conglomerate and the atom ratio of RaC to RaB, defined as ρ , is shown in Fig. 1, together with the relationship between the time τ and the radon/RaB activity ratio. The large correction factor required to relate RaB to radon for recent additions of radon to the atmosphere is apparent.

Filter Collections of Radon Decay Products

The calculation of the rate of accretion of radioactivity from a fixed concentration of radon by a filter of 100% efficiency sampling at a uniform flow rate is described in Appendix B for radon conglomerates of several ages: 5 min ($\rho = 0.048$), 20 min ($\rho = 0.190$), 45 min ($\rho = 0.390$), 80 min ($\rho = 0.564$), and at secular equilibrium ($\rho = 0.735$). Corrections for the decay and growth of the various products during the collection period have been applied. The radioactivities of RaA, RaB, and RaC (or RaC') on the filter as a function of ρ for collections of 5 and 20 min duration are plotted in Fig. 2. It is again apparent that, for a given sampling rate and a given concentration of radon in the air, both the extent of radioactive equilibrium, as exemplified by the ρ value, and the length of the sampling period influence the quantity of radioactivity collected, particularly for those daughters most removed in time from the radon parent. For all practical purposes (i.e., $\tau > 20$ min), RaA can be considered to be in secular equilibrium with radon in the air; also, for filter collections of 20 min or longer, equilibrium between RaA or radon in the air and RaA on the filter may be considered to have been established.

Rate of Decay of Collected Radioactivity

The calculated values of the radioactive decay rates for RaA, RaB, and RaC (or RaC') collected during 5- and 20-min collection periods from a known concentration of radon in various degrees of equilibrium with its decay products are given in Appendix C. This

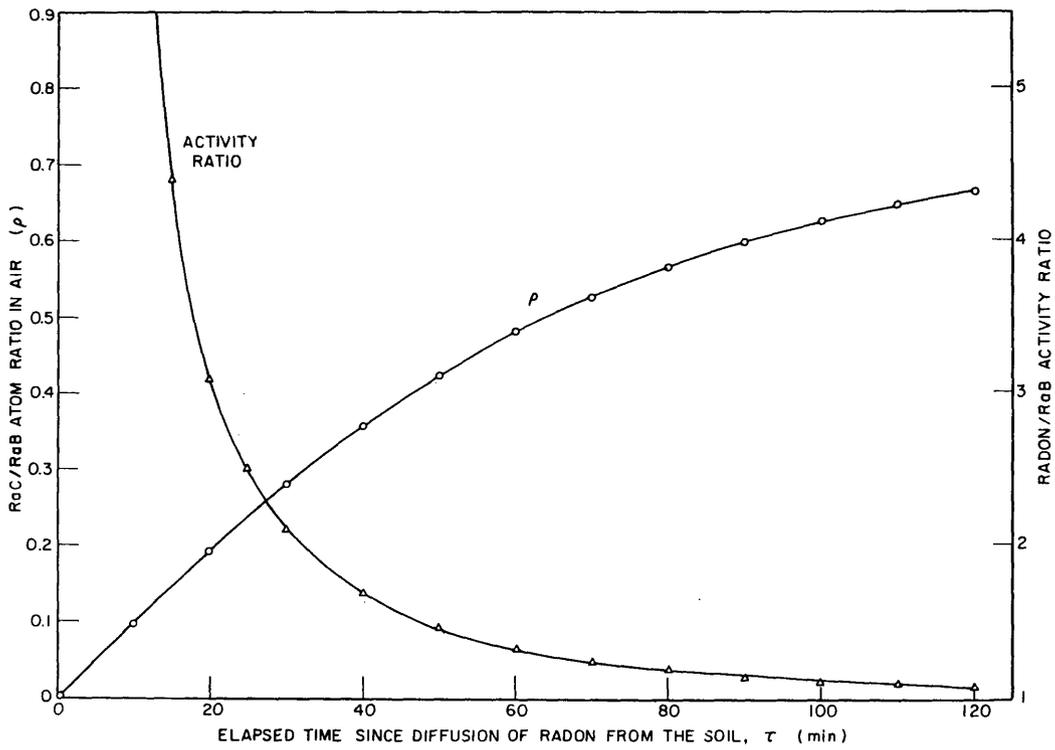


Fig. 1 - Relationship between RaC/RaB atom ratios (ρ), radon/ RaB activity ratio and the time (τ) since diffusion of radon from the soil

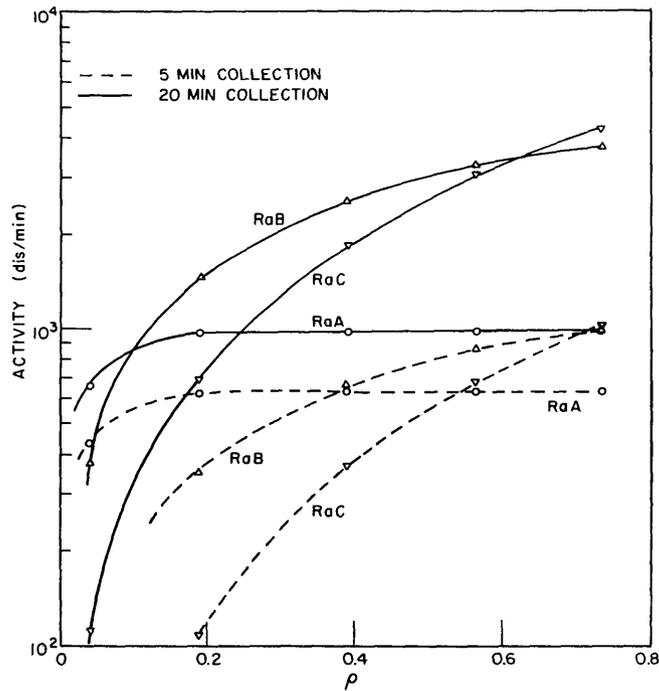


Fig. 2 - Relationships between ρ and radon daughter activities on a filter at the termination of 5- and 20-min collection periods

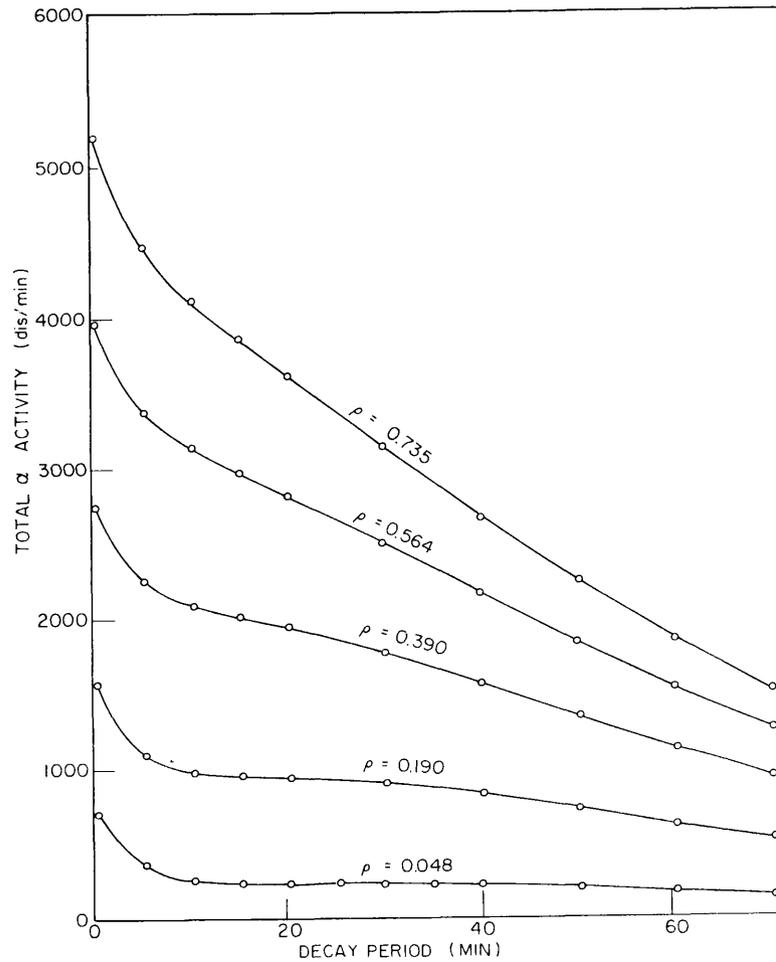


Fig. 3 - Gross α disintegration rates of decay products from 100 picocuries of radon per unit volume of air following a 20-min filtration period

information can be employed to find the most effective means for determining ρ , τ , or other parameters needed to obtain a suitable correction factor for relating either α or β count rates on the filter to radon concentrations in the air.

Calculated gross α and β counting rates as a function of time following termination of the sampling period for various values of ρ are shown in Figs. 3 and 4 for 20-min collections. The gross β counting rates for 5-min collections are shown in Fig. 5. The total β activity of RaB plus RaC is considered as a unit because there is no simple way of distinguishing between the two; the use of an absorber sufficient to prevent counting of RaB would also reduce RaC count rates to an unacceptable level. Similarly, the α emitters RaA and RaC' (the count rate of RaC' is identical to that of RaC) must be considered together. This is unfortunate in both cases, since, as shown in Fig. 6, the change in the disintegration rate of RaC (or RaC') with time would afford the most sensitive means of determining ρ . Instrumentation is available which is capable of determining RaC or RaC' in the presence of the other components, but it is too complicated and costly for the contemplated application.

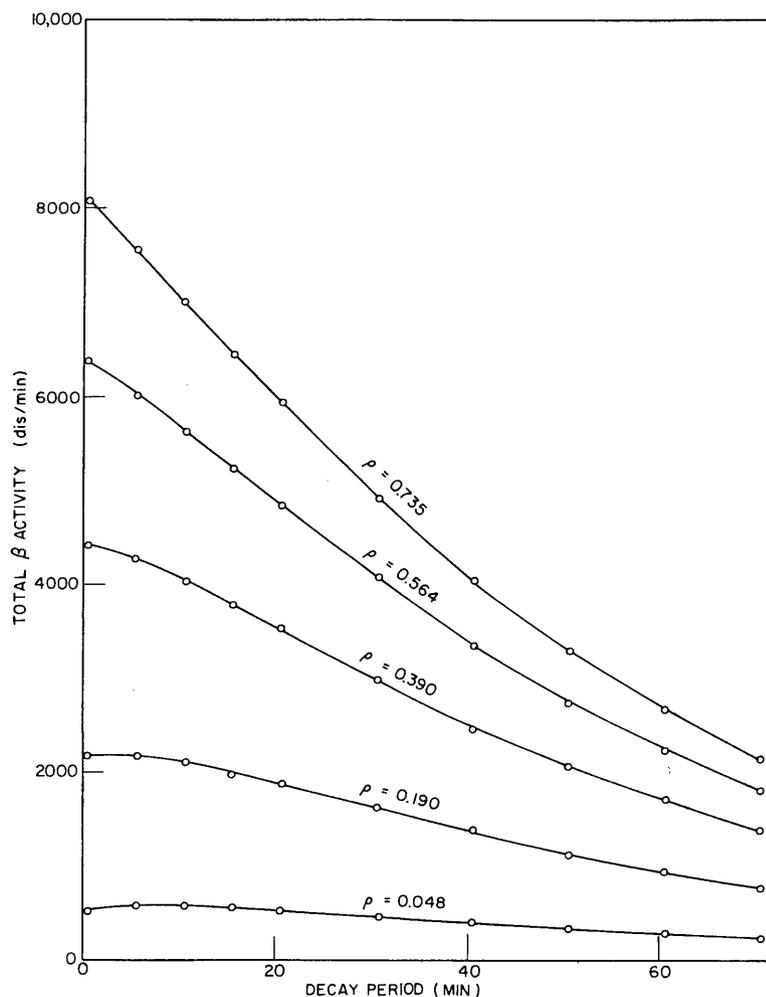


Fig. 4 - Gross β disintegration rates of decay products from 100 picocuries of radon per unit volume of air following a 20-min filtration period

It is apparent that an evaluation of ρ can be made by comparing either the gross α or β disintegration rates during two widely separated periods of time, and from this a determination of the "average" radon concentration can be obtained from the disintegration rate during any time interval. Theoretically, more information can be obtained from the gross α decay curve by comparing three different counting periods; e.g., ρ could be evaluated from the ratio of the disintegrations occurring during the 15 through 30 min and 45 through 60 min periods, which would define the shape of the RaC' decay curve for the initial period and enable a separate determination of RaA to be made. An excess of RaA over that indicated in Fig. 3 (or the appropriate table) would be an indication of the influx into the sampled volume of radon depleted in solid decay products. The problems of the quantitative evaluation of α disintegration rates may prevent successful exploitation of this series of measurements, however.

EXPERIMENTAL PROCEDURE

An absolute determination of the radon concentration in an air sample can be made if the sample can be assumed to have resulted entirely from a single instantaneous emission

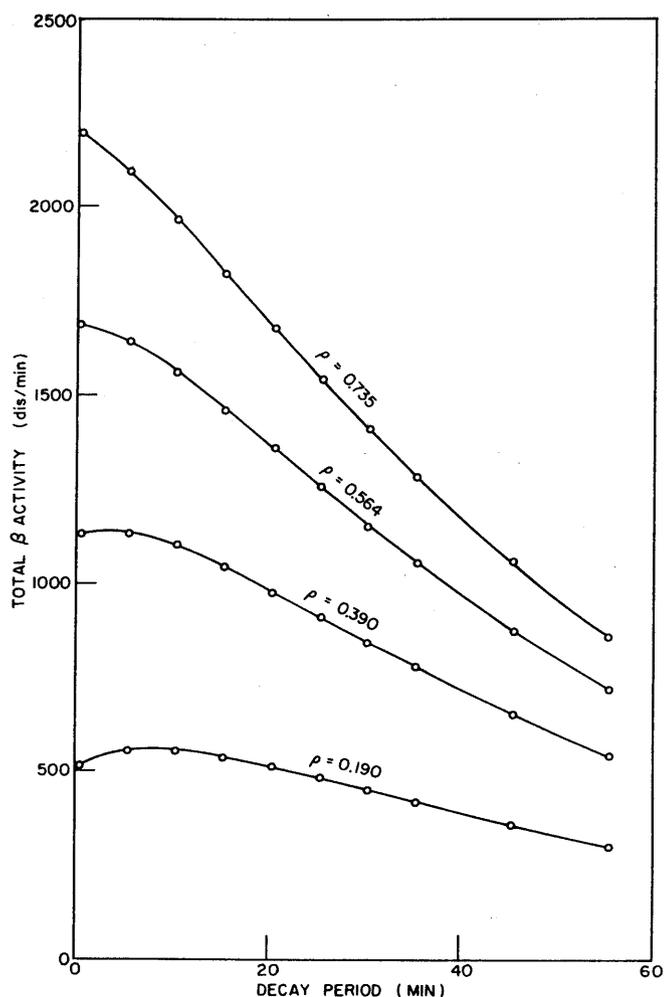


Fig. 5 - Gross β disintegration rates of decay products from 100 picocuries of radon per unit volume of air following a 5-min collection period

of radon from the soil or if the radon conglomerate can be assumed to maintain a constant age during the collection. The calculations presented in the previous sections are based on the latter premise, since atmospheric processes involve dynamic equilibria which often change relatively slowly with time. In any case the age determined can be considered an "effective" age which discriminates rather strongly against freshly emitted radon. The possibility of evaluating the atmospheric radon on the basis of two or more components of different age has been considered briefly, but the cumulative errors inherent in the required series of measurements of collected activity suggest that the results would be no more meaningful than those obtained in the simpler procedure.

Calibration of Counting Procedures

Another critical factor in the radon determination is the required calibration of the counter equipment toward the different energy particles. Since the calibration of filter collections is simpler for β than for α activities, due to the greater range of β particles, the use of β measurements is preferred. The procedure employed is outlined in Appendix D.

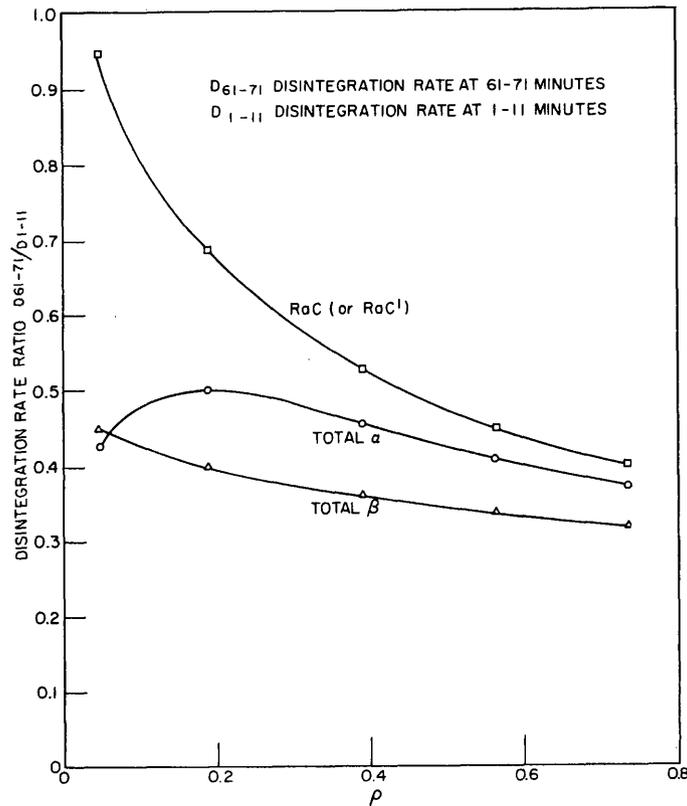


Fig. 6 - Relationships between ρ and the relative disintegration rates of RaC (or RaC'), total α , and total β at two time intervals following the end of collection

The counting of β activity collected from the atmosphere has generally been accomplished through use of 2-in.-diameter, mica-window (5.6 mg/cm^2), halogen-filled Geiger-Muller tubes (Amperex 120N) and conventional scaling equipment. Automatic and repetitive count recording on a preset time schedule has been done with Ametron count recorders (Streeter-Amet). Counting intervals have been of 5 or 10 min duration to amass sufficient counts to give reasonable statistical accuracy to the results.

The characteristics of the β emissions of RaB and RaC and the estimated counting efficiencies of these emissions on a typical counting unit are outlined in Appendix D. The β spectra are further complicated by the emission of conversion electrons which will be counted as β particles. According to Rutherford, Chadwick, and Ellis (14), the rate of emission of conversion electrons by RaB amounts to about 25% of the β emissions from RaB, while conversion electrons contribute about 5% to the count rate of RaC; it is assumed that they are counted with the same effectiveness as the β particles.

Determination of Air Flow Rate and Filter Efficiency

In this program positive displacement blowers, either Roots-Connersville Type AF-315 and AF-24 or Leiman Model 29-6 blowers driven by 1 to 3 hp electric motors, have been employed to draw air through 2-1/2-inch filters (effective area 25.7 cm^2) at the

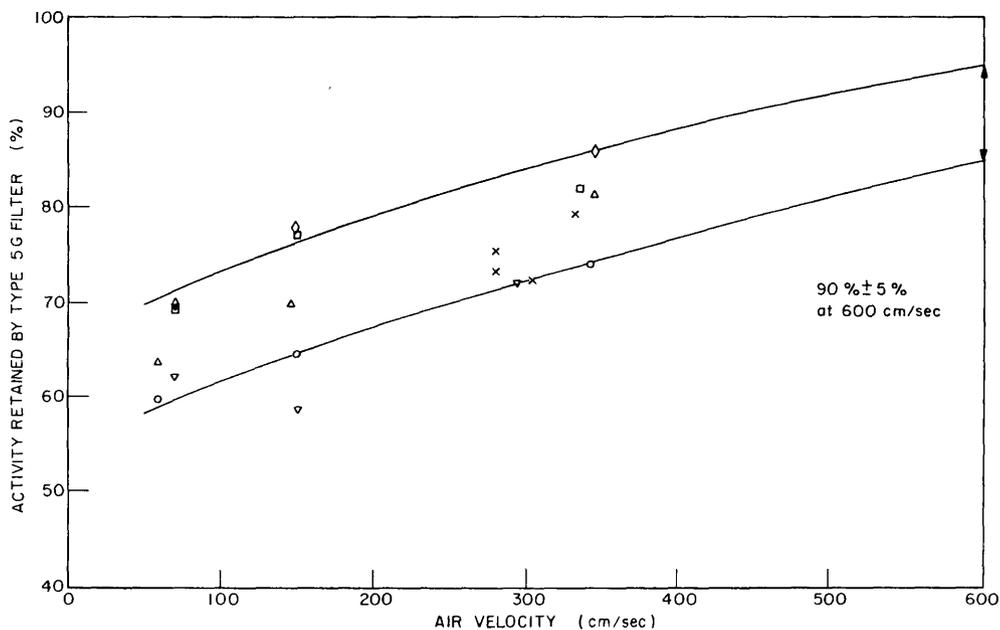


Fig. 7 - Retention of RaB+C activity by Type 5G filters as a function of air velocity through the filter

rate of 14 to 33 ft³/min (0.40-0.95 m³/min). For some collections a Type 5G cellulose-glass-fiber filter was used because it combined low resistance to flow with a relatively high filter efficiency for aerosols containing attached natural radioactivity; the use of the glass-fiber filters in other collections removed the necessity for applying a correction for filter efficiency.

The blower capacity with filters of different resistance was determined by use of a large-diameter rotameter-type flow meter (Fischer and Porter Flowrater, 55 ft³/min capacity); simultaneous measurements of the pressure drop (vacuum) in the blower inlet were also made. Subsequent readings of pressure could thus be related to air flow. Normally, no measurable change in flow occurs during collections of 20 min or less.

Since the type 5G filter does not have 100% retentivity for the natural radioactive aerosols, it was necessary to determine its retention efficiency through use of a filter pack technique (15). The RaB+C radioactivity retained on the Type 5G filter was compared with that which penetrated the filter but was retained by an "absolute" filter (Type 6). Unfortunately, the use of a high-resistance backup filter decreased the flow rate during the test to values lower than those encountered during normal filtration; hence an extrapolation was required to estimate the filter efficiency at the higher flow rate. The effect of flow rate on filter retentivity is shown in Fig. 7, with an extrapolation to the higher flow encountered in actual practice with a single filter. An efficiency of 90% ± 5% is reasonable for the Type 5G filter at a linear velocity near 1200 ft/min (610 cm/sec). Day-to-day variations do occur, however, which are a function of the size distribution of the normal atmospheric aerosols to which the radon daughter products become attached (16). To avoid the uncertainty in retentivity of the filter engendered by these variations, the use of a more efficient filter is warranted, in spite of the lower flow and higher power requirements. Most of the glass-fiber papers should be entirely satisfactory for this purpose; some experimental runs with Gelman Type A filters are described in a later section.

Evaluation of Gross β Activity, ρ , and Radon Concentration

From the information presented in Appendix C on the β activity of radon daughter products as a function of time, it is possible to incorporate a factor for the counting efficiency of the various activities so as to provide information on the counting rate versus time for various radon compositions in the air. These correction factors can be derived as in Appendix D; an incorporation of a correction for the effect of conversion electrons would also be required.

The gross β (or α) counting rate for each time interval can be obtained by summing the count rates of the individual isotopes obtained from the tables in Appendix C by applying the appropriate counter efficiency factor. The gross β counts of radon daughter products to be expected from the filtration for 20- and 5-min periods at the rate of 1 m³/min of air containing 100 picocuries (pCi) of radon per m³ are given in Tables 1 and 2 for a typical counting unit. The age of the mixture is characterized by the ratio of the total counts during the 61 through 71 min decay period to the total counts during the 1 through 11 min decay period. This ratio may be used, as shown in Fig. 8, to determine the gross β count to be expected during the initial 10-min decay period from 100 pCi/m³ radon in the air filtered at the rate of 1 m³/min for 20 min. The measured initial count, after multiplication by a filter efficiency correction and a flow correction, can be divided by the calculated gross β count to give the number of multiples of 100 pCi/m³ radon in the air mass sampled. A similar plot of the activity ratio at these two periods can be used to estimate ρ , the RaC/RaB atom ratio in the air sampled, as shown in Fig. 9.

RESULTS AND DISCUSSION

Detailed calculations of some radon determinations involving 20-min collections of radon daughter activity on 2-1/2-in.-diameter Type 5G cellulose-glass-fiber filters (Hollingsworth and Vose) and on Type A glass-fiber filters (Gelman) are presented in Table 3 to demonstrate the method. Corrections have been made, as shown, for the air flow rate, filter efficiency, and counter background. Corrections have been applied also for the relatively small contribution of thoron daughter products (ThB+C) and of fission products to the total β count. This information was obtained by recounting the filters some 5 to 7 hr following collection, after all short-lived radon decay products had disappeared, and again some 10 or more hours later, after decay had removed a substantial portion of the ThB+C complex (10.6 hr half-life). The indicated uncertainties shown are the standard deviations based on counting statistics alone and give an indication of the precision of the determinations. The decrease in activity concentration as the morning progressed is to be expected as the result of the breakup of the nighttime inversion condition by the increased atmospheric mixing caused by solar heating.

Several series of measurements made during other time periods when the activity concentrations of the radon daughter products were considerably higher are reported in Table 4. The higher activity results in a smaller error (standard deviation) in the total counts during the two time periods and hence greater accuracy in the determination of the radon concentration and in ρ . The low value obtained in the 1530-1550 collection of October 8 is typical of the concentrations found during the late afternoon (17,18).

A number of other determinations have been made on various collecting and counting installations but are not reported here. Some of the results pertaining to the extent of secular equilibrium between radon and its daughters as indicated by the ratio of counts during the final and initial periods will be summarized, however. Sixteen collections made at 15 m height during September and October 1964 gave an average counting ratio (61 through 71 min period to 1 through 11 min period) of 0.334 ± 0.003 (standard deviation) corresponding to a ρ value of 0.63 ± 0.021 ; the extreme range of values was 0.307 to 0.349 for the counting ratio and 0.84 to 0.51 for ρ . Another set of 16 collections made during

Table 1
 Calculated β Activity from 100 pCi of Radon per m^3 of Air Sampled at the Rate of $1 m^3/min$ for 20 min

Radon Equilibrium Condition	Initial Activity (t_{-1})		Final Activity (t_{61-71})		Activity Ratio		
	Disintegrations	Counts*	Disintegrations	Counts*	Disintegrations	Final/Initial	
		Type 5G		Glass		Type 5G	Glass
Age (τ): 5 min $\rho = 0.048$	RaB	3798	506	522	864	115	119
	RaC	1687	253	257	1594	239	243
	Total	5485	759	779	2458	354	362
Age (τ): 20 min $\rho = 0.190$	RaB	13170	1753	1811	2879	383	396
	RaC	8233	1232	1255	5640	860	844
	Total	21403	2985	3066	8519	1227	1256
Age (τ): 45 min $\rho = 0.390$	RaB	22700	3021	3121	4903	653	674
	RaC	19562	2928	2981	10279	1567	1567
	Total	42262	5949	6102	15182	2192	2241
Age (τ): 80 min $\rho = 0.564$	RaB	28946	3853	3980	6227	829	856
	RaC	30758	4604	4688	13775	2062	2099
	Total	59704	8457	8668	20002	2891	2955
Age (τ): ∞ $\rho = 0.735$	RaB	33221	4422	4568	7136	950	981
	RaC	41689	6241	6353	16562	2479	2524
	Total	74910	10663	10921	23698	3429	3505

*For collections made on Type 5G and Gelman Type A glass-fiber filters, respectively.

Table 2
 Calculated β Activity from 100 pCi of Radon per m^3 of Air Sampled at the Rate of $1 m^3/min$ for 5 min

Radon Equilibrium Condition	Initial Activity (t_{-1})		Final Activity (t_{61-71})		Activity Ratio		
	Decays	Counts*	Decays	Counts*	Decays	Final/Initial	
		Type 5G		Glass		Type 5G	Glass
Age (τ): 20 min $\rho = 0.190$	RaB	3803	506	523	865	115	119
	RaC	1687	253	257	1594	239	243
	Total	5490	759	780	2459	354	362
Age (τ): 45 min $\rho = 0.390$	RaB	6665	887	916	1472	196	202
	RaC	4626	693	705	2932	439	447
	Total	11291	1580	1621	4404	635	649
Age (τ): 80 min $\rho = 0.564$	RaB	8541	1137	1174	1871	249	257
	RaC	7751	1160	1181	3953	552	602
	Total	16292	2297	2355	5824	841	859
Age (τ): ∞ $\rho = 0.735$	RaB	9823	1307	1351	2142	285	295
	RaC	10950	1639	1669	4771	714	727
	Total	20773	2946	3020	6913	999	1022

*For collections made on Type 5G and Gelman Type A glass-fiber filters, respectively.

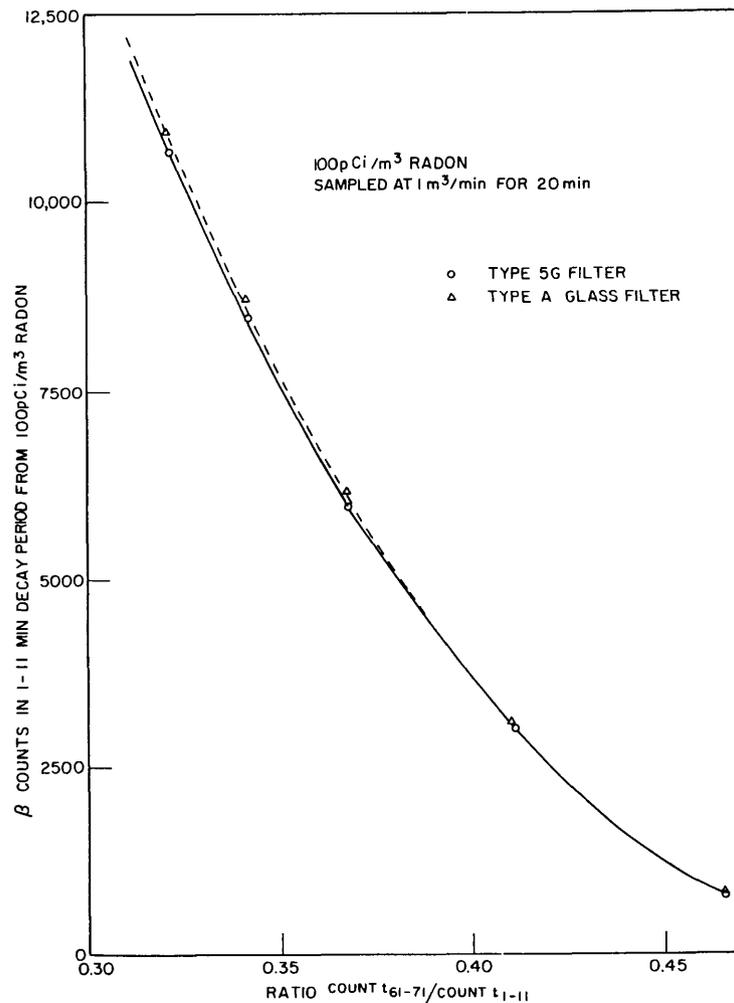


Fig. 8 - Relationship between the total β count during the initial period and the ratio of counts during the final (t_{61-71}) to initial (t_{1-11}) decay periods

this period on another unit at 7 m height (but counted on the same calibrated counter) gave an average counting ratio of 0.335 ± 0.002 (range 0.316 to 0.345) and a corresponding ρ of 0.62 ± 0.016 . The correction associated with this departure from secular equilibrium (10%), as given in Fig. 1, is of the same magnitude as the uncertainty in the determination of the activity concentration which results from the statistical variation in counting. For conditions when low radon concentrations are encountered in the atmosphere, use of an average correction factor for equilibrium departure is warranted.

The average ρ of 0.62 would be expected for a radon source whose residence time in the free air was about 100 min, as shown in Fig. 1. Interpretation of this average ρ in terms of a two-component mixture of fresh radon (age τ of 20 min) and an old component ($\tau = \infty$) indicates a mixture consisting of about 45% of the younger component. It is thus evident that evaluation of the radon concentration is seriously dependent on the determination and interpretation of the ρ values. Under the sampling conditions employed in this study (a height of 20 to 45 ft above ground in an area of atmospheric turbulence), excessive amounts of fresh radon deficient in its decay products should not accumulate; and

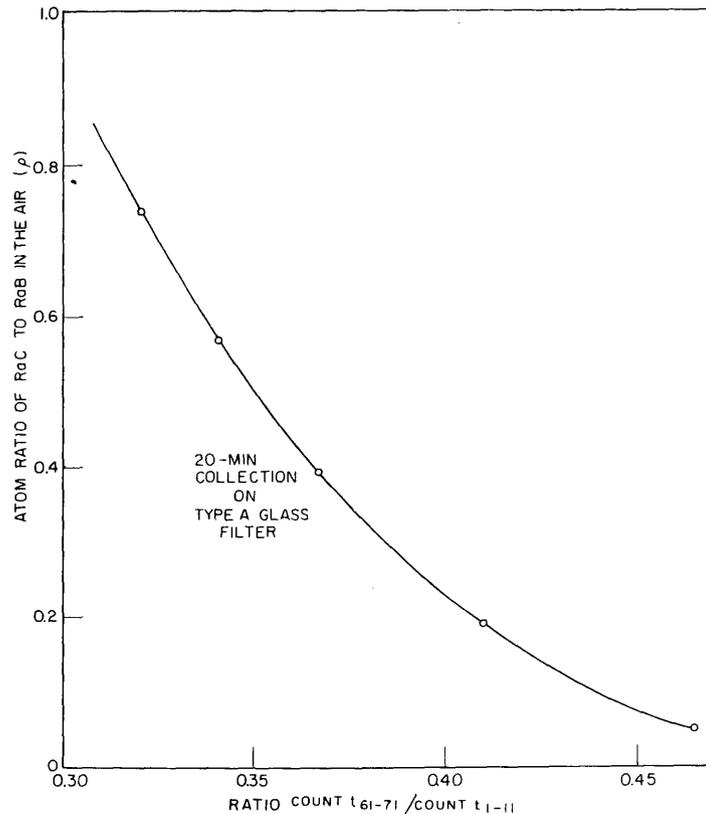


Fig. 9 - Relationship between the atom ratio of RaC to RaB in the air and the ratio of counts during the final to initial decay periods

the resulting conglomerate can perhaps be realistically considered to have a unique age. Closer to the earth's surface and, particularly, during the initial stages of the buildup of a strong inversion condition, however, ρ would certainly be better interpreted in terms of two (or more) radon sources of different age.

The several duplicate runs that have been made to compare the ρ values determined from gross β decay and from RaC decay (gross β penetrating a 200 mg/cm² Al absorber) show equivalent results within the rather large statistical uncertainty in the counting. The low count rate in the RaC determination, however, is partly compensated for by the increased sensitivity of ρ to the ratio of counts at the two different counting periods, as indicated by Fig. 6.

The concepts developed here will be of use in more accurately defining the radon concentration of the air under those conditions which result in high ambient radon concentrations, namely, in poorly ventilated spaces such as exist in mines or caves, or under strong atmospheric inversion conditions. In the case of mines, for example, activity may be so high that use may be made of a 5-min sampling schedule. The shorter sampling period is not justified for normal atmospheric sampling unless some arbitrary value of ρ can be assigned. Some situations may exist, however, where it would be desirable to make a series of closely spaced measurements, even of a relatively low order of accuracy, to obtain information on large-scale, rapid changes in radon concentrations (as in the breakup of a strong inversion condition in the atmosphere).

Table 3
 Determination of Atmospheric Radon Concentrations and the RaC/RaB Atom Ratio (ρ) From
 Experimental Data (Collections Made Sept. 22, 1964; Weather: Cloudy, No Precipitation)

Time (EDT)	Collection Data		Sampling Height (m)	Item	Counting Data			Ratio of Count at $t_{6.1-7.1}$ to Count at $t_{1-1.1}$	Corrections		Corrected Counts	Theoretical Counts/10 min From 100 pCi/m ³ Radon	Radon Conc. (pCi/m ³)	RaC/RaB Atom Ratio (ρ)
	Flow (m ³ /min)	Filter			Counts	Flow			Filter Efficiency					
						$t_{1-1.1}$	$t_{6.1-7.1}$							
0730-0750	0.940	Type 5G	15	Gross	12080	4400	0.331 ± 0.007	1.06	1.11	13470	9640 ± 780	140 ± 11	0.65 ± 0.06	
				Back-ground	-290	-290								
				ThB+C	-312	-292								
				Fission Products	-36	-36								
				RaB+C	11442 ± 110	3782 ± 67								
0900-0920	0.603	Gelman A	15	Gross	10320	3910	0.340 ± 0.008	1.66	1.00	16080	8790 ± 860	183 ± 18	0.58 ± 0.06	
				Back-ground	-290	-290								
				ThB+C	-344	-322								
				Fission Products	-0	-0								
				RaB+C	9686 ± 102	3298 ± 58								
1030-1050	0.600	Gelman A	15	Gross	6890	2600	0.329 ± 0.010	1.67	1.00	10630	10030 ± 1150	106 ± 11	0.66 ± 0.08	
				Back-ground	-290	-290								
				ThB+C	-232	-217								
				Fission Products	-0	-0								
				RaB+C	6368 ± 83	2093 ± 51								
1200-1220	0.940	Type 5G	15	Gross	7420	2770	0.328 ± 0.009	1.06	1.11	8130	9970 ± 1050	82 ± 9	0.67 ± 0.07	
				Back-ground	-290	-290								
				ThB+C	-181	-170								
				Fission Products	-44	-44								
				RaB+C	6905 ± 86	2266 ± 53								

Table 4
Results of Some Typical Measurements of Radon Concentrations and ρ Values

Time	Collection Data			Intake Ht. (m)	RaB+C Activity (corr.)		Ratio of Final to Initial Count	Corrections		Corrected Counts	Theoretical Counts for 100 pCi/m ³ Radon	Radon Conc. pCi/m ³ *	RaC/RaB Atom Ratio ρ *
	Flow	Filter	Unit		Initial t ₁₋₁₁	Final t ₆₁₋₇₁		Flow	Filter Efficiency				
September 15, 1964													
0715-0735	0.918	Type 5G	L 29-6	15	39403	13166	0.334	1.09	1.11	47680	9300	513 ± 23	0.62 ± 0.03
0846-0906	0.918	Type 5G	L 29-6	15	27549	9184	0.333	1.09	1.11	33330	9400	355 ± 17	0.63 ± 0.04
0926-0946	0.918	Type 5G	L 29-6	15	29743	9781	0.329	1.09	1.11	35990	9840	366 ± 17	0.66 ± 0.04
October 8, 1964													
0818-0838	0.453	Gelman A	RC-315	7	22384	7610	0.340	2.21	1.00	49470	8760	563 ± 35	0.58 ± 0.04
0948-1008	0.453	Gelman A	RC-315	7	16484	5426	0.329	2.21	1.00	36430	10030	363 ± 25	0.66 ± 0.05
1530-1550	0.402	Gelman A	RC-315	7	3399	1163	0.342	2.49	1.00	8460	8550	99 ± 18	0.56 ± 0.10
October 13, 1964													
0720-0740	0.464	Gelman A	RC-315	7	21701	7265	0.335	2.16	1.00	46870	9300	504 ± 30	0.61 ± 0.04
0850-0910	0.456	Gelman A	RC-315	7	19113	6501	0.340	2.19	1.00	41860	8760	477 ± 31	0.58 ± 0.04
1040-1100	0.453	Gelman A	RC-315	7	15627	5204	0.333	2.21	1.00	34540	9550	362 ± 25	0.63 ± 0.05

*Uncertainty is the standard deviation (σ) based on counting statistics.

SUMMARY AND CONCLUSIONS

Procedures have been devised whereby the collection and measurement on a rigid time schedule of the filterable radon decay products can be interpreted in terms of "effective" radon concentrations existing in the air during the collection period. It is recognized, however, that radon recently exhaled from the ground and highly deficient in its β -emitting daughter products will be greatly underestimated by this technique. Further study is required to determine the best experimental means for obtaining data which can be interpreted in terms of mixtures of radon conglomerates of different age.

Accuracy in the determination of the ratio of RaB+C activity during the different counting periods is severely limited by the rather low counting rates obtained from the atmospheric radon concentrations normally encountered. The inherent uncertainty in many cases results in calculated radon concentrations having a built-in error equivalent to that which the method is designed to eliminate. Another limitation, currently being evaluated, is the uncertainty introduced by treating the conversion electrons as being equivalent in counting efficiency to the β particles emitted by RaB and RaC.

The tabular data presented, however, will be useful in interpreting experimental results obtained from other studies of radon decay products, namely, of the α -emitting RaA and RaC' and the higher energy β -emitter, RaC. In their present state the concepts described should be useful in evaluating radon concentrations under conditions of high ambient radon concentration. Further study of the relationship of ρ to various meteorological conditions is warranted, since it may serve as a useful index to atmospheric stability.

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APPENDIX A

GROWTH OF RADON DESCENDANTS FROM A RADON SOURCE

A minute-by-minute calculation for a period of 120 min has been made of the growth of the radon decay products RaA, RaB, and RaC (or its equivalent, RaC') from a source of 100 picocuries (1.766×10^6 atoms) of radon. Negligible decay of the parent radon would have occurred during this 2-hr period. The decay factors employed were: for RaA, 0.203 min^{-1} ; for RaB, 0.0255 min^{-1} ; and for RaC, 0.0346 min^{-1} . The accumulation and decay of each descendant in turn was calculated; corrections were also applied for the decay of each daughter by assuming a linear formation rate during the 1-min accumulation periods. The pertinent atom concentrations, activity concentrations and various ratios of interest are presented in Table A1 for 5-min intervals.

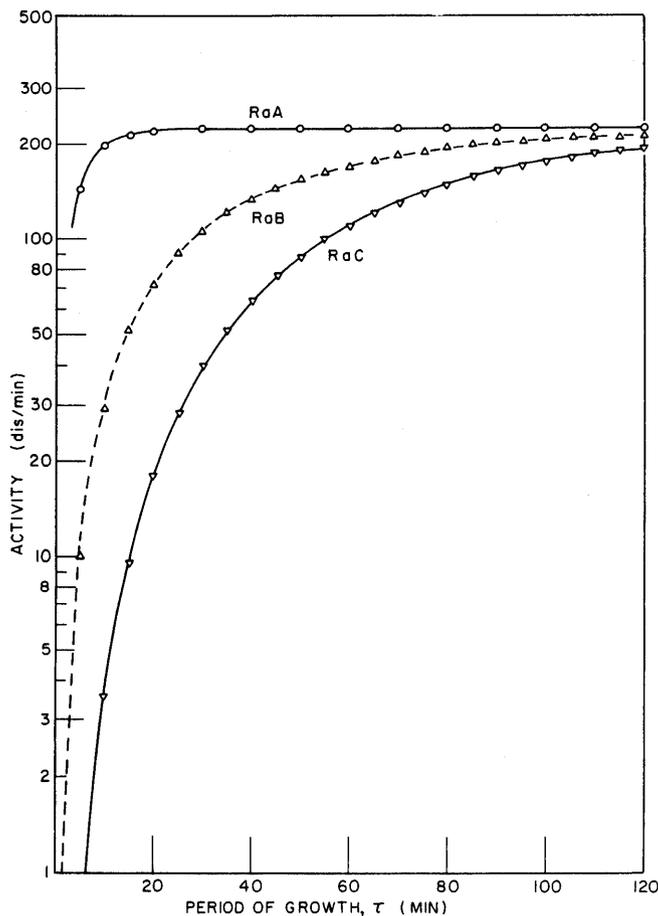


Fig. A1 - Growth of radioactivity of radon decay products from a 100-pCi source of radon

The growth of the radioactivity of the various products is shown in Fig. A1. The results are in agreement with those developed in more conventional manner from the solution of the appropriate differential equations. The direct approach was taken here since it was desired to have numerical values for employment in subsequent calculations.

Other relationships involving the atom ratio RaC/RaB (ρ), the elapsed time τ since diffusion of radon from the soil, and the radon/RaB activity ratio are shown in Fig. 1 in the body of the report.

Table A1
Growth of Radon Descendants From a Constant 100-pCi Source of Radon

Elapsed Time (min)	Atoms			Atom Ratio ρ^*	Radioactivity (dis/min)			Activity Ratios			
	RaA	RaB	RaC		Time Interval (min)	RaA	RaB	RaC	$\frac{\text{RaC}}{\text{RaA}}$	$\frac{\text{RaC}}{\text{RaB}}$	$\frac{\text{Radon}}{\text{RaB}}$
0	0	0	0	-	-	0	0	0	-	-	-
5	666	424	21	0.048	4-5	142	10	0.6	0.004	0.060	22.2
10	881	1216	113	0.093	9-10	196	29	3.5	0.018	0.120	7.7
15	951	2044	291	0.142	14-15	213	51	9.5	0.044	0.187	4.4
20	972	2817	535	0.190	19-20	219	71	17.9	0.082	0.251	3.1
25	978	3511	825	0.235	24-25	222	89	28.1	0.126	0.315	2.5
30	978	4126	1147	0.278	29-30	222	106	39.2	0.177	0.371	2.09
35	978	4667	1485	0.318	34-35	222	119	51.1	0.230	0.428	1.87
40	978	5142	1828	0.355	39-40	222	132	63.1	0.284	0.478	1.68
45	978	5560	2168	0.390	44-45	222	143	75.1	0.338	0.526	1.55
50	978	5927	2501	0.422	49-50	222	153	86.8	0.391	0.569	1.45
55	978	6249	2820	0.451	54-55	222	160	98.1	0.442	0.612	1.39
60	978	6533	3123	0.478	59-60	222	168	108.9	0.491	0.648	1.32
65	978	6782	3408	0.503	64-65	222	175	119.0	0.536	0.680	1.27
70	978	7002	3674	0.525	69-70	222	180	128.5	0.579	0.714	1.23
75	978	7193	3925	0.546	74-75	222	186	137.3	0.619	0.739	1.19
80	978	7363	4154	0.564	79-80	222	190	145.5	0.656	0.767	1.17
85	978	7512	4365	0.581	84-85	222	194	153.0	0.689	0.790	1.14
90	978	7642	4558	0.597	89-90	222	198	159.9	0.720	0.809	1.12
95	978	7757	4736	0.611	94-95	222	200	166.1	0.748	0.828	1.11
100	978	7858	4897	0.623	99-100	222	202	171.8	0.774	0.849	1.10
105	978	7947	5043	0.635	104-105	222	205	177.0	0.797	0.862	1.08
110	978	8025	5175	0.645	109-110	222	207	181.8	0.819	0.877	1.07
115	978	8094	5295	0.654	114-115	222	209	186.0	0.838	0.889	1.06
120	978	8155	5402	0.662	119-120	222	210	189.8	0.855	0.903	1.06
∞	978	8597	6318	0.735	-	222	222	222.0	1.000	1.000	1.00

* ρ = atom ratio of RaC/RaB.

APPENDIX B

FILTER COLLECTION OF RADON DECAY PRODUCTS

An evaluation of the rate of accumulation of radon daughter products in different stages of equilibrium with the parent radon has been made at 1-min intervals over a collection period of 20 min. It has been assumed that the radon conglomerate maintains a constant age during the collection; in other words, the rates of diffusion, mixing, and radioactive decay within the air mass are considered to be in such a state of dynamic equilibrium that an "effective" age, equivalent to τ , can be assumed. The calculation is based on an unlimited source of radon having a concentration of 100 picocuries of radon per unit volume, where the unit volume is defined as the volume of air passing through the filter per minute; moreover, 100% retention of radon daughters but zero retention of radon itself is assumed. Corrections for less than 100% filter retention can readily be applied later; experimental evidence indicates no measurable amount of radon is retained by the filter.

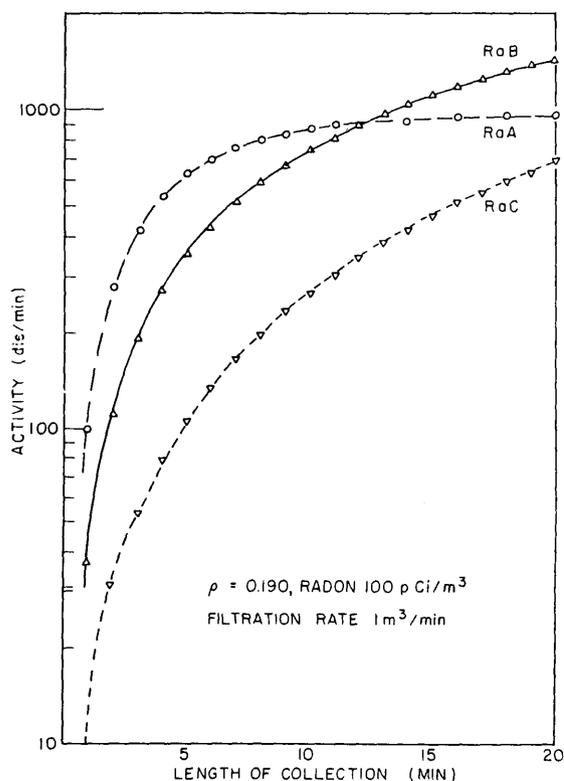


Fig. B1 - Growth of a radon daughter activity on a filter from filtration of a radon source in non-equilibrium with its descendants

Each daughter product, RaA, RaB, and RaC, has been considered separately with accretion of atoms of the isotope both from the atmospheric source and from its predecessor in the radioactive series being taken into account. In the data presented in Table B1, five different radon mixtures are considered: (a) age $\tau = 5 \text{ min}$ ($\rho = 0.048$); (b) $\tau = 20 \text{ min}$ ($\rho = 0.190$); (c) $\tau = 45 \text{ min}$ ($\rho = 0.390$); (d) $\tau = 80 \text{ min}$ ($\rho = 0.564$); and finally (e) $\tau = \infty$ ($\rho = 0.735$), indicating radon in secular equilibrium with its short-lived descendants.

The rates of growth of each of the daughter activities as a function of time during the 20-min collection period for the conditions where $\rho = 0.190$ and $\rho = 0.735$ are shown in Figs. B1 and B2. The relationships between ρ and each of the individual radioisotopes following collections periods of 5 and 20 min are shown in Fig. 2 in the body of the report.

Details of the calculation of the accumulation of RaA, RaB, and RaC from an equilibrium mixture of radon and its daughter products during a 5-min filtration period are shown in Table B2 to demonstrate the method employed. A similar procedure was used to obtain the data presented in Appendixes A and C, also.

Table B1
Collection of Radon Decay Products on a Filter From a Radon Source of 100 pCi per Unit Volume*

Elapsed Time (min)	Atoms			Activity (dis/min)†		
	RaA	RaB	RaC	RaA	RaB	RaC
$\rho = 0.048$						
1	599	485	27	67	7	0.5
2	1076	1078	66	189	21	1.7
3	1456	1751	120	286	37	3.3
4	1759	2482	190	363	56	5.5
5	2001	3256	278	424	75	8.2
6	2194	4059	381	473	95	11.6
7	2347	4879	502	512	116	15.6
8	2469	5711	639	544	137	20.1
9	2566	6546	793	569	158	25.2
10	2644	7378	963	589	181	30.9
11	2705	8205	1147	604	201	37.3
12	2755	9023	1347	616	223	43.9
13	2794	9831	1559	627	244	51.1
14	2825	10626	1785	635	264	59.0
15	2851	11406	2022	641	285	67.0
16	2870	12173	2271	646	304	75.6
17	2886	12924	2531	650	324	84.6
18	2899	13659	2800	653	343	93.9
19	2909	14377	3080	656	363	103.6
20	2916	15043	3368	658	381	113.5
$\rho = 0.190$						
1	874	2877	562	98	37	10
2	1572	5855	1180	275	113	31
3	2127	8898	1853	417	191	53
4	2569	11975	2580	530	270	78
5	2922	15060	3360	619	349	105
6	3203	18140	4191	691	429	133
7	3427	21195	5072	748	509	163
8	3606	24220	5999	793	587	195
9	3749	27200	6970	829	664	228
10	3862	30135	7983	859	740	263
11	3952	33020	9034	882	816	300
12	4024	35845	10120	900	890	337
13	4082	38615	11245	914	962	376
14	4128	41325	12395	926	1032	416
15	4164	43975	13575	936	1101	457
16	4194	46565	14780	943	1170	499
17	4217	49095	16010	949	1235	542
18	4236	51565	17260	954	1300	586
19	4250	53975	18525	957	1363	630
20	4262	56330	19810	960	1424	675
$\rho = 0.390$						
1	879	5587	2201	99	71	38
2	1580	11205	4469	277	217	117
3	2139	16825	6801	420	361	198
4	2584	22410	9194	533	507	282
5	2939	27945	11645	623	649	366
6	3222	33410	14155	695	792	454
7	3446	38790	16710	753	932	543
8	3626	44080	19315	798	1069	634
9	3769	49270	21960	835	1205	726
10	3884	54355	24645	864	1338	821
11	3975	59335	27365	887	1468	915
12	4047	64205	30120	906	1595	1011
13	4105	68965	32900	920	1719	1109
14	4151	73615	35700	932	1841	1208
15	4188	78160	38520	942	1959	1307
16	4216	82590	41355	949	2075	1406
17	4240	86920	44205	955	2188	1506
18	4258	91140	47065	959	2298	1607
19	4273	95255	49935	963	2407	1708
20	4285	99270	52805	966	2512	1808

Elapsed Time (min)	Atoms			Activity (dis/min)†		
	RaA	RaB	RaC	RaA	RaB	RaC
$\rho = 0.564$						
1	879	7367	4175	99	95	73
2	1580	14720	8393	277	286	221
3	2139	22030	12650	420	474	370
4	2584	29265	16945	533	662	521
5	2939	36405	21275	623	848	673
6	3222	43430	25635	695	1031	825
7	3446	50335	30020	753	1211	979
8	3626	57110	34425	798	1387	1134
9	3769	63750	38850	835	1561	1290
10	3884	70245	43285	864	1730	1445
11	3975	76600	47735	887	1897	1602
12	4047	82810	52190	906	2059	1758
13	4105	88875	56645	920	2217	1915
14	4151	94800	61100	932	2372	2072
15	4188	100580	65545	942	2523	2230
16	4216	106220	69985	949	2671	2385
17	4240	111730	74410	955	2815	2542
18	4258	117090	78820	959	2955	2697
19	4273	122330	83215	963	3092	2853
20	4285	127430	87590	966	3226	3006
$\rho = 0.735$						
1	879	8585	6317	99	111	111
2	1580	17125	12635	277	333	333
3	2139	25590	18945	420	552	556
4	2584	33950	25255	533	769	778
5	2939	42190	31555	623	983	1000
6	3222	50285	37845	695	1194	1222
7	3446	58235	44120	753	1401	1444
8	3626	66025	50380	798	1604	1664
9	3769	73650	56620	835	1803	1884
10	3884	81115	62830	864	1998	2103
11	3975	88410	69015	887	2190	2322
12	4047	95535	75170	906	2376	2539
13	4105	102490	81295	920	2557	2754
14	4151	109290	87375	932	2734	2969
15	4188	115650	93245	942	2909	3182
16	4216	122390	99250	949	3077	3389
17	4240	128700	105210	955	3242	3599
18	4258	134850	111120	959	3403	3808
19	4273	140850	116990	963	3561	4016
20	4285	146700	122800	966	3713	4222

*Unit volume is defined as volume passing through the filter per minute at a constant rate.
†Disintegrations during preceding minute.

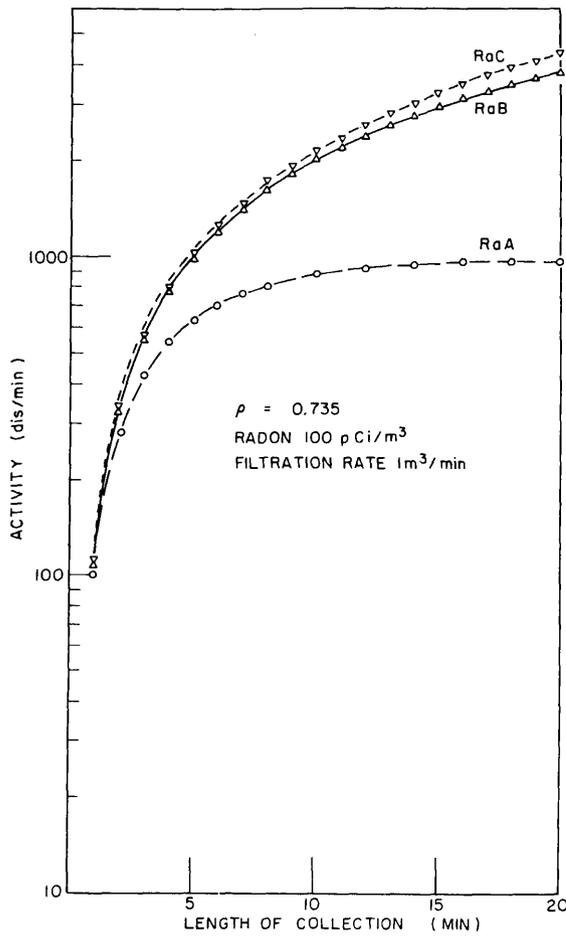


Fig. B2 - Growth of radon activities on a filter from filtration of a radon source in secular equilibrium with its descendants

Table B2
Accumulation of RaA, RaB, and RaC Through Filtration of Air Containing 100 pCi of Radon in Secular Equilibrium with Its Daughters ($\lambda = 0.735$)

Time Interval (min)	From Filtration		From Predecessor		From Previous Minute		Totals	
	Collection (atoms)	Decay (atoms)	Growth (atoms)	Decay (atoms)	Carryover (atoms)	Decay (atoms)	(atoms)	(Decays)
RaA								
0-1	978	- 99	+ 0	- 0	+ 0	- 0	= 879	99
1-2	978	- 99	+ 0	- 0	+ 879	- 178	= 1580	277
2-3	978	- 99	+ 0	- 0	+ 1580	- 321	= 2138	420
3-4	978	- 99	+ 0	- 0	+ 2138	- 434	= 2583	533
4-5	978	- 99	+ 0	- 0	+ 2583	- 524	= 2938	623
RaB								
0-1	8597	- 109	+ 99	- 1	+ 0	- 0	= 8586	110
1-2	8597	- 109	+ 277	- 4	+ 8586	- 219	= 17128	332
2-3	8597	- 109	+ 420	- 5	+ 17128	- 437	= 25594	551
3-4	8597	- 109	+ 533	- 7	+ 25594	- 653	= 33955	769
4-5	8597	- 109	+ 623	- 8	+ 33955	- 866	= 42192	983
RaC								
0-1	6318	- 109	+ 110	- 2	+ 0	- 0	= 6317	111
1-2	6318	- 109	+ 332	- 6	+ 6317	- 219	= 12633	334
2-3	6318	- 109	+ 551	- 10	+ 12633	- 437	= 18946	556
3-4	6318	- 109	+ 769	- 13	+ 18946	- 656	= 25255	778
4-5	6318	- 109	+ 983	- 17	+ 25255	- 874	= 31556	1000

APPENDIX C
RADIOACTIVE DECAY OF FILTER COLLECTIONS OF
RADON DAUGHTER PRODUCTS

Summations of the radioactive disintegrations taking place during 5-min intervals following 20-min and 5-min collection periods and a 1-min period for sample manipulation are shown in Tables C1 and C2, respectively. As in the previous calculations, these results are based on a minute-by-minute accounting of the changes occurring in each of the radioisotopes in the decay chain. The 5-min counting periods can be regrouped into multiples of 5 min, as desired, for comparison with experimental data counted over a longer period to improve its statistical accuracy.

The basic data contained in this table can be modified by inclusion of filter efficiency and counter correction factors for the various radioisotopes so that calculated counting rates can be compared directly with experimental data.

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Table C1
Radioactive Decay of Radon Descendants Following a 20-min Collection
on a Filter of 100% Retentivity for Radioactive Aerosols*

Total Radioactive Decays During Time Interval											
Time Interval (min)	RaA	RaB	RaC	Total α	Total β	Time Elapsed (min)	RaA	RaB	RaC	Total α	Total β
$\rho = 0.048$						$\rho = 0.564$					
0-20	Air filtered under conditions of constant flow					0-20	Air filtered under conditions of constant flow				
20-21	Sample removed from blower and placed in counter					20-21	Sample removed from blower and placed in counter				
21-26	1578	1961	750	2328	2711	21-26	2317	15318	15461	17778	30779
26-31	508	1837	937	1445	2774	26-31	745	13628	15297	16042	28925
31-36	162	1651	1067	1229	2718	31-36	240	12030	14894	15134	26924
36-41	52	1462	1146	1198	2608	36-41	77	10590	14308	14385	24898
41-46	17	1288	1182	1199	2470	41-46	25	9313	13602	13627	22915
46-51	6	1134	1186	1192	2320	46-51	7	8187	12813	12820	21000
51-56	3	999	1166	1169	2165	51-56	4	7194	11982	11986	19176
56-61	0	877	1129	1129	2006	56-61	0	6323	11136	11136	17459
61-66	0	771	1079	1079	1850	61-66	0	5559	10294	10294	15853
66-71	0	677	1022	1022	1699	66-71	0	4884	9472	9472	14356
71-76	0	595	959	959	1554	71-76	0	4292	8682	8682	12974
76-81	0	523	894	894	1417	76-81	0	3772	7930	7930	11702
81-86	0	460	829	829	1289	81-86	0	3314	7219	7219	10533
86-91	0	404	765	765	1169	86-91	0	2913	6556	6556	9469
$\rho = 0.190$						$\rho = 0.735$					
0-20	Air filtered under conditions of constant flow					0-20	Air filtered under conditions of constant flow				
20-21	Sample removed from blower and placed in counter					20-21	Sample removed from blower and placed in counter				
21-26	2304	6923	3900	6204	10823	21-26	2317	17594	21219	23536	38813
26-31	741	6247	4333	5074	10580	26-31	745	15627	20470	21215	36097
31-36	238	5545	4585	4823	10130	31-36	240	13788	19533	19773	33321
36-41	77	4889	4683	4760	9572	36-41	77	12134	18467	18544	30601
41-46	25	4302	4667	4692	8969	41-46	25	10670	17320	17345	27990
46-51	7	3781	4564	4571	8345	46-51	7	9379	16136	16143	25515
51-56	4	3327	4399	4403	7726	51-56	4	8245	14950	14954	23195
56-61	0	2922	4192	4192	7114	56-61	0	7245	13782	13782	21027
61-66	0	2570	3958	3958	6528	61-66	0	6367	12654	12654	19021
66-71	0	2257	3707	3707	5964	66-71	0	5594	11572	11572	17166
71-76	0	1984	3449	3449	5433	71-76	0	4916	10551	10551	15467
76-81	0	1743	3191	3191	4934	76-81	0	4321	9589	9589	13910
81-86	0	1532	2941	2941	4473	81-86	0	3798	8696	8696	12494
86-91	0	1347	2699	2699	4046	86-91	0	3338	7866	7866	11204
$\rho = 0.390$						*Based on sampling of 100 pCi of radon per unit volume in various stages of equilibrium with its descendants.					
0-21	Air filtered under conditions of constant flow										
20-21	Sample removed from blower and placed in counter										
21-26	2317	11994	9644	11961	21638						
26-31	745	10706	9918	10663	20624						
31-36	240	9463	9941	10181	19404						
36-41	77	8333	9767	9844	18100						
41-46	25	7330	9452	9477	16782						
46-51	7	6443	9034	9041	15477						
51-56	4	5664	8551	8555	14215						
56-61	0	4977	8025	8025	13002						
61-66	0	4374	7484	7484	11858						
66-71	0	3845	6937	6937	10782						
71-76	0	3379	6396	6396	9775						
76-81	0	2969	5875	5875	8844						
81-86	0	2609	5376	5376	7985						
86-91	0	2294	4903	4903	7197						

Table C2
 Radioactive Decay of Radon Descendants Following a 5-min Collection
 on a Filter of 100% Retentivity for Radioactive Aerosols*

Total Radioactive Decays During Time Interval											
Time Interval (min)	RaA	RaB	RaC	Total α	Total β	Time Interval (min)	RaA	RaB	RaC	Total α	Total β
$\rho = 0.190$						$\rho = 0.564$					
0-5	Air filtered under conditions of constant flow					0-5	Air filtered under conditions of constant flow				
5-6	Sample removed from blower and placed in counter					5-6	Sample removed from blower and placed in counter				
6-11	1579	1963	750	2329	2713	6-11	1589	4484	3841	5430	8325
11-16	509	1840	937	1446	2777	11-16	511	4057	3910	4421	7967
16-21	163	1654	1068	1231	2722	16-21	164	3601	3895	4059	7496
21-26	52	1464	1145	1197	2609	21-26	53	3177	3813	3866	6990
26-31	17	1292	1183	1200	2475	26-31	17	2795	3678	3695	6473
31-36	6	1134	1187	1193	2321	31-36	6	2458	3507	3513	5965
36-41	3	999	1167	1170	2166	36-41	3	2162	3312	3315	5474
41-46	0	877	1129	1129	2006	41-46	0	1899	3105	3105	5004
46-51	0	773	1081	1081	1854	46-51	0	1669	2891	2891	4560
51-56	0	679	1021	1021	1700	51-56	0	1468	2675	2675	4143
56-61	0	597	959	959	1556	56-61	0	1290	2467	2467	3757
61-66	0	524	896	896	1420	61-66	0	1134	2264	2264	3398
66-71	0	460	829	829	1289	66-71	0	996	2068	2068	3064
71-76	0	405	765	765	1170	71-76	0	875	1885	1885	2760
$\rho = 0.390$						$\rho = 0.735$					
0-5	Air filtered under conditions of constant flow					0-5	Air filtered under conditions of constant flow				
5-6	Sample removed from blower and placed in counter					5-6	Sample removed from blower and placed in counter				
6-11	1589	3486	2223	3812	5709	6-11	1589	5167	5526	7115	10693
11-16	511	3179	2403	2914	5582	11-16	511	4656	5424	5935	10080
16-21	164	2828	2498	2662	5326	16-21	164	4129	5254	5418	9383
21-26	53	2499	2523	2576	5022	21-26	53	3640	5032	5085	8672
26-31	17	2200	2495	2512	4695	26-31	17	3204	4770	4787	7974
31-36	6	1934	2424	2430	4358	31-36	6	2816	4484	4490	7300
36-41	3	1702	2326	2329	4028	36-41	3	2475	4186	4189	6661
41-46	0	1494	2206	2206	3700	41-46	0	2175	3874	3874	6049
46-51	0	1313	2077	2077	3390	46-51	0	1912	3579	3579	5491
51-56	0	1154	1940	1940	3094	51-56	0	1680	3289	3289	4969
56-61	0	1014	1801	1801	2815	56-61	0	1478	3013	3013	4491
61-66	0	892	1664	1664	2556	61-66	0	1297	2748	2748	4045
66-71	0	783	1532	1532	2315	66-71	0	1139	2501	2501	3640
71-76	0	689	1400	1400	2089	71-76	0	1003	2270	2270	3273

*Based on sampling of 100 pCi of radon per unit volume in various stages of equilibrium with its descendants.

APPENDIX D

CALIBRATION OF β COUNTING PROCEDURES

The β counting equipment was calibrated by counting β standards of various β_{\max} energies arranged as nearly as possible in the identical conditions under which the exposed filters were evaluated. The β standards employed were Cs^{137} (0.52 MeV (92%), 1.19 MeV(87%)), Pb^{210} (Bi^{210} , 1.17 MeV) and U_3O_8 (UX_2 , 2.32 MeV).

In the preparation of the standards, a known quantity of a standardized radioisotope solution was equilibrated with the carrier isotope in an acid solution and then the tagged carrier precipitated quantitatively by addition of an appropriate reagent. The precipitated material was filtered and dried. Weighed 50.0-mg mounts were made on 2-in.-diameter plastic planchets and their radioactivity checked on previously standardized equipment.

Other 50.0-mg quantities of tagged material were evenly spread over a 25.7-cm² circular area of aluminum foil (equivalent to the exposed area of the filter), lightly cemented in place with a dilute solution of polystyrene in xylene or of shellac in alcohol, and covered with a 0.00025-in. thickness of Mylar polyester film for protection. Before inserting under the counter window, these standards were placed in a filter holder over a piece of the same type filter paper used in the collection of airborne radioactivity; back-scattering should thus have been equivalent in the two cases. All of the standards were made in triplicate, and the range of variation from the highest to the lowest in any series did not exceed 2%.

The UX_2 and Bi^{210} (RaE) standards were counted with the aluminum foil side (0.005 and 0.001 in. thick, respectively) between the radioactivity and the counter window to minimize the counting of other radioactive components, namely, the 24.1-day Th^{234} (UX_1 , 0.20-MeV β), the 25-hr Th^{231} (UY, 0.30-MeV β), and various α particles in the U_3O_8 , and α particles from Po^{210} in the Bi^{210} standard. The Cs^{137} standard was counted through the thin plastic cover. In each case, β absorption curves were made and corrections applied to the gross disintegration rates to give the true number of particles penetrating the absorber.

A calibration curve of the response of a typical counting unit used in this study to β particles of different energies is shown in Fig. D1. The calculated β counting efficiencies for RaB (0.65 MeV) and RaC (3.17 MeV (23%) and 1.65 MeV (77%)) deposited on Gelman Type A glass-fiber filters are 10.7% and 14.0%, respectively, in this equipment. The overall factors for converting disintegrations to counts, including the incorporation of corrections for the 25% and 5% contributions of conversion electrons in the two cases, are 0.134 and 0.147, respectively.

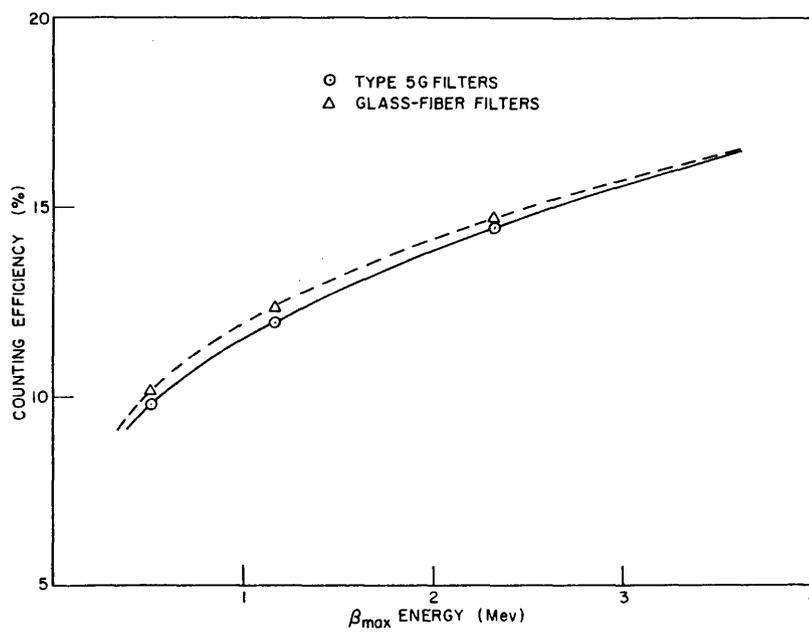


Fig. D1 - Counter response as a function of β_{max} energy

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<p>An analytical method has been devised for the determination of the radon concentration in the air by measurement of the radioactive decay of the solid radon daughters collected on air filters during a fixed sampling period. The ratio of the radioactivity present at two periods, determined by an initial count immediately after termination of sampling and a second count an hour later, is used to estimate the extent of radioactive equilibrium established between radon and its daughters and to obtain a correction factor for relating radon daughter activity to radon activity.</p> <p>The disintegration rates of the various decay products of radon as a function of the age of the radon conglomerate have been calculated during the growth and collection periods and for successive 5-minute decay periods extending through the first 71 minutes following termination of filtration. A procedure for the calibration of β counters for the evaluation of RaB and RaC activities was established. Use was made of this analytical method to determine radon concentrations in the air near ground level.</p>		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Atmospheric radioactivity measurement Radon Secular equilibrium RaA RaB RaC RaC' Radon decay products Filter collection of radioactive matter						

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