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The Measurement of Low Concentrations of Radon-222 Daughters in Air, with Emphasis on RaA Assessment

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ABSTRACT. A number of methods exist for the measurement of the activity concentrations of radon-222 daughters in air but in most cases interest is centred on determining the Working Levels. In those instances where individual daughter activity concentrations are assessed the precision of the assessment of RaA (^{218}Po) is poor unless spectrometry is used. In environmental monitoring the measurement of RaA activity concentrations is a reliable indicator of radon activity concentrations. Following a brief review of established methods of radon daughter activity concentration measurement, a method is given which enables activity concentrations as low as 0·05 pCi l^{-1} (50 pCi m^{-3}) of RaA to be measured with simple readily transportable equipment. The method presented here also measures RaB (^{214}Pb) and RaC (^{214}Bi) activity concentrations and Working Levels with improved precision compared with established methods.

1. Introduction

Inhalation of radon (^{222}Rn) and its daughters at high activity concentrations is associated with increased respiratory cancer mortality among uranium and other underground miners (Archer, Wagoner and Lundin 1973). The short-lived daughters of radon are ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po, known historically as RaA, RaB, RaC and RaC′. RaA and RaC′ are alpha-emitting nuclides but RaC′ has a short half-life of 160 μs and for practical purposes can be considered to be always in equilibrium with RaC. Thus the α-emission from RaC′ may be regarded as a prompt α-emission from RaC. The hazard from inhalation of radon laden air is generally accepted to be due predominantly to the short lived daughter products and the widely used unit of exposure to these daughters is the Working Level (WL). One Working Level is defined as 'any combination of the short lived decay products of ^{222}Rn; RaA, RaB, RaC and RaC′ in one litre of air which will result in the ultimate release of $1{\cdot}3 \times 10^5$ MeV of alpha energy in decaying to RaD (^{210}Pb)'. Although this definition is satisfied by an activity concentration of 100 pCi l^{-1} each of RaA, RaB, RaC and RaC′ the definition is independent of any particular state of daughter equilibrium.

Most rocks and soils contain uranium as a minor contaminant in concentrations of typically 1–4 parts per million (Evans 1969) and consequently some uranium is found in materials used for the construction of buildings. Radon, being the gaseous element in the uranium decay series, diffuses out of soils and building materials and the entire population is exposed to low activity concentrations of this radioisotope and its daughters. Quite apart from the industrial hazards of exposure to radon laden air in the mining industry it is important

to know the levels of exposure of the population now. In this way a sound basis will exist for assessing the radiological implications of future changes in building practice such as the use of by-product gypsum and other waste materials which have higher uranium concentrations than traditional materials. To this end the National Radiological Protection Board instituted a project to estimate the exposure of the general public to the short-lived daughters of ^{222}Rn in domestic dwellings.

The activity concentration of ^{222}Rn anticipated in dwellings was about 0·3 pCi l^{-1}. Equipment for the direct measurement of radon gas at this concentration is bulky and necessitates counting periods of many hours for each sample. It was considered more convenient to measure the daughter activity concentrations and in particular that of RaA, but established methods of assessing radon daughter concentrations at low levels required equipment that was unsuitable for a survey of domestic dwellings or had poor precision for RaA assessment. The method detailed here was devised with the desirable properties of employing easily transportable equipment and permitting the measurement of RaA activity concentrations at an order of magnitude lower than is possible with the previously established methods.

2. Methods of measuring radon daughter concentrations

Table 1 lists the physical properties of the short-lived daughters of ^{222}Rn and from table 1 it follows that if the activity concentrations in air of RaA,

Table 1. Properties of the short-lived daughter products of ^{222}Rn

Nuclide	Half-life	Radiation emitted	α-energy (MeV)	No. of atoms per 100 pCi	Fractional contribution to WL under conditions df equilibrium
RaA (^{218}Po)	3·05 min	α	6·00	977	0·105
RaB (^{214}Pb)	26·8 min	β, γ	—	8585	0·516
RaC (^{214}Bi)	19·7 min	β, γ	—	6311	0·379
RaC′ (^{214}Po)	160 μs	α	7·68	8×10^{-4}	0·000

RaB and RaC in pCi l^{-1} are Q_1, Q_2 and Q_3 respectively the Working Level is given by

$$\text{WL} = 10^{-3}(1{\cdot}05Q_1 + 5{\cdot}16Q_2 + 3{\cdot}79Q_3) \qquad (1)$$

Eqn (1) indicates that at conditions not too far removed from equilibrium ($Q_1 = Q_2 = Q_3$) the major contributor to Working Levels is the RaB concentration Q_2. Assessing the hazard from radon daughters is of prime importance in uranium mines and to a lesser extent in other mining industries, since in many mines radon daughter levels may reach several Working Levels unless preventive measures are taken. One method of assessing the exposure in Working Levels is that due to Kusnetz (1956). In this method air is sampled through a filter paper for a short time (commonly five or ten minutes) and the

total volume sampled is recorded. At least 40 min is allowed to elapse after sampling is completed before the count rate from the deposited alpha-activity on the filter paper is measured. A factor, dependent upon the time elapsed between sampling and counting, can be found relating the count rate at the time of measurement to the Working Levels existing at the time of sampling. This method only provides an estimate of Working Levels and gives no information on the individual daughter concentrations. The activity concentration of RaA (with a half-life of 3·05 min) follows quite closely that of radon and an assessment of the RaA activity concentration can be useful in locating the source of the radon in a particular environment. A procedure for measuring the individual daughter concentrations was devised by Tsivoglou, Ayer and Holaday (1953) and modified by Thomas (1972) and is referred to as the Thomas–Tsivoglou method. This method involves sampling the atmosphere of interest through a filter paper at a constant flow rate (V l min^{-1}) for 5 min. The filter paper is then placed in an alpha counting equipment (of efficiency E cpm/dpm) and the gross alpha counts from the nuclides deposited on the filter paper measured over three time intervals; from 2 to 5, 6 to 20 and 21 to 30 min from the end of the sampling period. From the three counts so obtained equations can be solved to determine the activity concentrations of each of the nuclides RaA, RaB and RaC and also the Working Levels. However, in this method, of the total RaA deposited on the filter paper 40% will have decayed by the end of the sampling period and 62% by the start of the first count period. As a result the assessment of RaA by this method is much less precise than that of RaB and RaC. At the concentrations of RaA encountered in mines the precision of this method is quite adequate, a coefficient of variation of 11·7% being obtained with a flow rate of 10 l min^{-1} and detection efficiency of 0·20 cpm/dpm when the activity concentrations of RaA, RaB and RaC are 100 pCi l^{-1} each, but unless a very high flow rate is used (requiring a pump which is not easily carried by one person) the errors in RaA assessment are such that the method did not lend itself to the envisaged survey of dwellings.

A more precise method of measuring RaA concentrations is the use of alpha spectrometry (e.g. Jonassen and Hayes 1974) but the equipment is bulky, expensive and inconvenient for use in domestic premises. Duggan and Howell (1969), also using α-spectrometry, reduced the errors in RaA measurement by the expedient of counting while sampling was in progress. James and Strong (1973) adopted the same procedure and devised a method and an instrument, The Radon Daughter Monitor, which provides a rapid assessment of the RaA concentration and Working Levels. In this instrument the filter paper in the sampling head is viewed by a silicon surface barrier detector in such a way that it is possible to sample the air and record the alpha decay of deposited nuclides while sampling is in progress. In the James–Strong method the air sample is taken from 0 to T minutes and a gross alpha count C_1 recorded during this period. The sampling is stopped at time T and a second gross alpha count, C_2, taken from $T+1$ minutes to $2T+1$ minutes; this will be referred to as the static count. The ratio C_2/C_1 of the two gross alpha counts is calculated and from prepared tables factors can be found relating C_1 to the RaA activity

concentration in pCi l^{-1} and the static count C_2 to the Working Levels. James and Strong prepared tables for values of T of 2, 5 and 10 min. As only two counts are used in this case for a situation involving three nuclides, a model of the atmosphere has to be used to determine the relationship between the nuclide ratios Q_2/Q_1 and Q_3/Q_1. Two models were used and tables prepared for each model. One model was based on the growth of daughters from an isolated radon source and the other on a 'mine tunnel' model in which radon is emanating from the walls of a mine tunnel through which air is passing. Using the $T = 5$ min regime the coefficient of variation for RaA activity concentration assessment is 6% with a flow rate of 10 l min^{-1} and detector efficiency 0·20 when the activity concentrations of RaA, RaB and RaC are 100 pCi l^{-1} each. This assumes that the atmosphere of interest behaves according to one of the assumed models. To remove the necessity for assuming a model for the atmosphere whilst retaining the improved precision of the RaA concentration assessment, it was decided to use the Radon Daughter Monitor designed by James and Strong but to use a method amalgamating theirs and that of Thomas–Tsivoglou.

3. The present method

3.1. *Development of the method*

The method of measurement decided upon was to take a gross alpha count from the filter paper as sampling took place from 0 to T_1 minutes. At time T_1 both the sampling and this first gross alpha count C_1 would be terminated and C_1 recorded. After resetting the counting equipment a static gross alpha count C_2 would be taken from T_1+1 to T_2 minutes. The counting equipment would again be reset and a second static gross alpha count taken from T_2+1 to T_3 minutes to yield count C_3. This regime was denoted by the general time set $I\,(T_1, T_2, T_3)$. Equations could be derived to enable the activity concentrations Q_1, Q_2 and Q_3 pCi l^{-1} of RaA, RaB and RaC respectively to be calculated from the values of C_1, C_2 and C_3.

The Radon Daughter Monitor has a background counting rate of 0·3 cpm typically and Thomas (1972) demonstrated that low background counting rates do not significantly affect the results of the measurements. In what follows the background counting rate is assumed to be zero but sufficient information is provided to permit the reader to incorporate the effects of background counting rate if that is necessary (see Thomas 1972 for details).

The equations for the nuclide activity concentrations are of the general form:

$$\left.\begin{aligned} Q_1 &= \frac{1}{VE}(K_{11}C_1 + K_{12}C_2 + K_{13}C_3)\ \text{pCi}\,l^{-1} \\ Q_2 &= \frac{1}{VE}(K_{21}C_1 + K_{22}C_2 + K_{23}C_3)\ \text{pCi}\,l^{-1} \\ Q_3 &= \frac{1}{VE}(K_{31}C_1 + K_{32}C_2 + K_{33}C_3)\ \text{pCi}\,l^{-1} \end{aligned}\right\} \qquad (2)$$

where V is the flow rate in $1\,m^{-1}$ and E is the detector efficiency in cpm/dpm. The coefficients K_{ij} depend on the values of the times T_1, T_2 and T_3.

By combining eqn (2) with eqn (1') an equation can be formed to give the Working Level, WL, in terms of the independently measured quantities C_1, C_2 and C_3

$$\text{WL} = \frac{10^{-3}}{VE}(MC_1+NC_2+PC_3) \tag{3}$$

where M, N and P are found from

$$\begin{bmatrix} M \\ N \\ P \end{bmatrix} = \begin{bmatrix} K_{11}K_{21}K_{31} \\ K_{12}K_{22}K_{32} \\ K_{13}K_{23}K_{33} \end{bmatrix} \begin{bmatrix} 1{\cdot}05 \\ 5{\cdot}16 \\ 3{\cdot}79 \end{bmatrix}. \tag{4}$$

The object was to find values of T_1, T_2 and T_3 resulting in acceptable coefficients of variation for the Q values. As a first approximation to the standard deviation due to counting statistics the method adopted by Thomas may be used. This regards C_1, C_2 and C_3 as independent Poisson variates and the standard deviation S_i on Q_i is given by

$$S_i = \frac{1}{VE}\left(\sum_{j=i}^{3} K_{ij}^2 C_j\right)^{\frac{1}{2}}. \tag{5}$$

It was obviously necessary to restrict the number of time values investigated in some way. Sampling and counting times of less than five minutes were thought unlikely to produce adequate counts for statistical purposes and a total measurement time much in excess of one hour was regarded as impracticable for a large survey. In addition sampling and counting times were restricted to integral numbers of minutes. A one minute time interval was allowed to elapse between the end of one count period and the start of the next to allow the results to be recorded and the equipment reset. Time sets were investigated covering all values of T_1 from 5 to 20 min, T_2 from T_1+6 to T_1+21 min and T_3 from T_2+6 to T_2+21 min. A computer program was written which tabulated the coefficients K_{ij} of eqns (2) for each of the above time sets and also listed the standard deviation S_i due to counting statistics for each time set and for each nuclide for the conditions $Q_1 = Q_2 = Q_3 = 1$ pCi l^{-1} at a flow rate $V = 1\,l\,min^{-1}$ and detector efficiency $E = 1$ cpm/dpm.

In general the uncertainties in the assessment of the daughter activity concentrations decrease as the lengths of the two static counting times increase. The uncertainties in the measurement of RaB and RaC also decrease with increasing sampling time but the uncertainty in the estimation of RaA activity concentration passes through a minimum at a sampling time of 15 min. Fig. 1 illustrates the variation in relative standard deviation of RaA, RaB and RaC as a function of sampling time T_1 for $T_2 = (T_1+21)$ min, $T_3 = (T_1+42)$ min under equilibrium conditions. Of the time sets investigated, that promising the smallest uncertainty in RaA concentration assessment was I (15, 36, 57), which

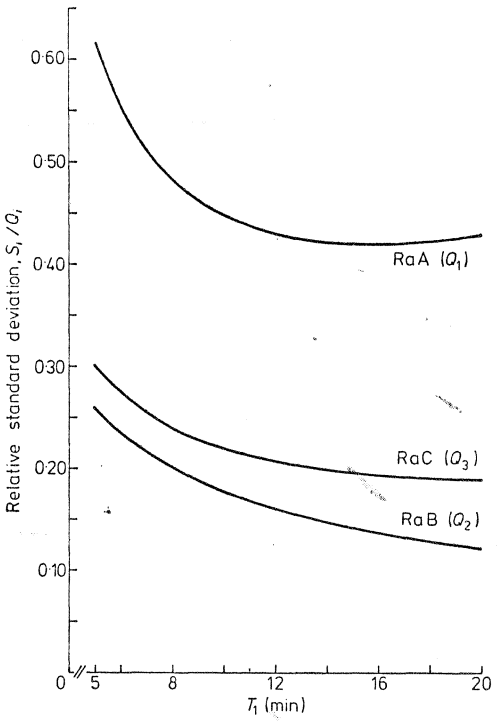

Fig. 1. Relative standard deviation for the time set $I\,(T_1, T_1+21, T_1+42)$ for $Q_1 = Q_2 = Q_3 = 1$ pCi l^{-1}. Flow rate $V = 1$ l min^{-1}, counting efficiency $E = 1$ cpm/dpm.

means count whilst sampling from 0 to 15 min, count without sampling 16–36 min, count without sampling 37–57 min. However, in cases where the daughter activity concentrations were high, adequate precision would be achieved with shorter measurement times. Table 2 lists the coefficients K_{ij} for a selection of time sets. The set $I\,(5, 25, 35)$ is given as it enabled a comparison of results obtained by the Thomas–Tsivoglou method and the present method to be carried out on the same sample within the same total measurement time (see below).

Fig. 2 compares the relative standard deviation of different time sets for the measurement of low concentrations of RaA under conditions of daughter

Table 2. Coefficients K_{ij} for

$I\,(T_1, T_2, T_3)$	K_{11}	K_{12}	K_{13}	K_{21}
$I\,(5, 25, 35)$	0·07836	−0·02391	0·03206	0·00900
$I\,(5, 21, 37)$	0·08232	−0·02798	0·01608	0·01237
$I\,(10, 21, 32)$	0·03144	−0·03295	0·01841	0·00703
$I\,(10, 26, 42)$	0·02610	−0·01875	0·01137	0·00176
$I\,(15, 31, 47)$	0·01434	−0.01628	0·01032	0·000305
$I\,(15, 36, 57)$	0·01305	−0·01152	0·008043	−0·000456

equilibrium. This represents the worst case for errors in RaA assessment. The curve for the Thomas–Tsivoglou method is also given in fig. 2 for comparison and the improvement in RaA activity concentration measurements is apparent.

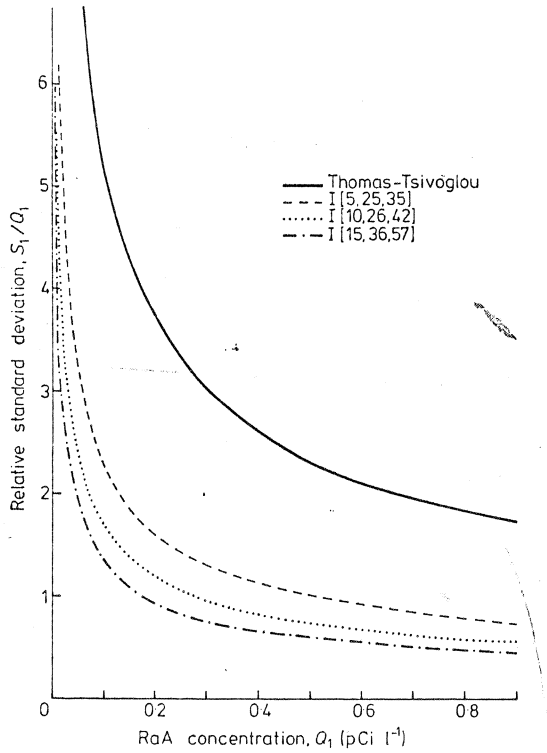

Fig. 2. Comparison of the relative standard deviation of RaA assessment for low concentrations, $Q_1 = Q_2 = Q_3$, $V = 1$ l min^{-1}, $E = 1$ cpm/dpm.

These curves are plotted for a flow rate $V = 1$ l min^{-1} and detector efficiency $E = 1$ cpm/dpm. The counts recorded during any interval for a given activity concentration of daughter products is proportional to the product of flow rate and efficiency and it follows from eqn (5) that the relative standard deviation for any practical values of the flow rate V and efficiency E can be found by dividing the values given in fig. 2 by $(VE)^{\frac{1}{2}}$. The relative standard deviation on

selected time sets I (T_1, T_2, T_3)

K_{22}	K_{23}	K_{31}	K_{32}	K_{33}
−0·01378	0·04373	−0·02128	0·01877	−0·02663
−0·01726	0·02534	−0·02445	0·02204	−0·01355
−0·02198	0·02562	−0·00963	0·02232	−0·01398
−0·00821	0·01297	−0·00582	0·01222	−0·008309
−0·005271	0·008867	−0·002585	0·009129	−0·006709
−0·002514	0·005825	−0·001800	0·006257	−0·005047

measurements of RaB and RaC activity concentrations are also reduced by the present method. In all cases smaller uncertainties result from the present method for the same sampling time (5 min) and overall measurement period (35 min) as the Thomas–Tsivoglou method; the uncertainties being further reduced if the sampling and total measurement time are increased.

Thomas takes as a useful criterion of the sensitivity of the measurement system for a particular daughter product that value of the daughter activity concentration at which the relative standard deviation is 0·50. To enable this to be calculated it is necessary to calculate the number of counts in each period arising from given activity concentrations of daughter products. The counts obtained from the present method are given by

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = VE \begin{bmatrix} L_{11} & L_{12} & L_{13} \\ L_{21} & L_{22} & L_{23} \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix}. \qquad (6)$$

Table 3 presents values of the coefficients L_{ij} for the selected time sets used in table 2. The sensitivities of these time sets and the Thomas–Tsivoglou

Table 3. Coefficient L_{ij} for selected time sets $I\ (T_1, T_2, T_3)$

$I\ (T_1, T_2, T_3)$	L_{11}	L_{12}	L_{13}	L_{21}	L_{22}	L_{23}	L_{31}	L_{32}	L_{33}
I (5, 25, 35)	19·70	1·511	26·20	29·97	60·97	136·19	5·386	41·77	37·51
I (5, 21, 37)	19·70	1·511	26·20	27·43	43·87	114·55	9·068	68·61	65·24
I (10, 21, 32)	59·64	11·21	99·07	33·45	59·08	152·34	12·31	86·62	103·45
I (10, 26, 42)	59.64	11·21	99·07	40·20	99·72	210·62	17·36	138·75	119·95
I (15, 31, 47)	107·01	35·15	211·09	49·00	163·30	291·20	25·44	208·65	165·84
I (15, 36, 57)	107·01	35·15	211·09	57·58	231·34	358·77	33·23	274·26	171·37

method are compared in table 4 for different conditions of equilibrium. The results are again normalised for a flow rate efficiency product VE of 1·00 so that the sensitivities at any existing value of this product are given by dividing the results in table 4 by the actual product value. Table 4 illustrates the dramatic improvement in the sensitivity of the RaA activity concentration assessment achieved by counting while sampling.

3.2. *Operational experience with the present method*

In a survey of radon daughter concentrations in domestic dwellings (to be published in 1978) the measurements were carried out mainly using the regimes I (15, 36, 57) and I (10, 26, 42) but occasional measurements were made using the regime I (5, 25, 35). This last regime allowed the radon daughter activity concentration to be evaluated by the Thomas–Tsivoglou method and the present method using the same sample and the same instrument (the Radon Daughter Monitor). In this way uncertainties in flow rate and counting efficiency are common to both measurement techniques and do not affect the

Table 4. Comparison of the sensitivities of various methods of radon daughter concentration assessments for different nuclide ratios
(Sensitivity is taken as the concentration of that daughter product at which the relative standard deviation of the measurement is 0·5)

Method	Nuclide ratio $Q_1 : Q_2 : Q_3$	Sensitivity pCi l^{-1} (VE = 1·00) RaA	RaB	RaC
Thomas–Tsivoglou	1 : 1 : 1	11·0	1·07	1·24
	1 : 0·6 : 0·4	5·91	0·94	1·63
	1 : 0·3 : 0·1	3·07	0·88	3·07
	1 : 0·1 : 0·02	1·94	1·25	7·94
	1 : 0 : 0	1·51	—	—
Present method				
I (5, 25, 35)	1 : 1 : 1	2·00	0·84	0·64
	1 : 0·6 : 0·4	1·23	0·75	0·89
	1 : 0·3 : 0·1	0·79	0·73	1·90
	1 : 0·1 : 0·02	0·63	1·15	6·04
	1 : 0 : 0	0·57	—	—
I (5, 21, 37)	1 : 1 : 1	2·01	0·62	0·58
	1 : 0·6 : 0·4	1·23	0·56	0·81
	1 : 0·3 : 0·1	0·82	0·56	1·82
	1 : 0·1 : 0·02	0·68	0·97	6·38
	1 : 0 : 0	0·63	—	—
I (10, 21, 32)	1 : 1 : 1	2·01	1·04	0·71
	1 : 0·6 : 0·4	1·12	0·92	0·95
	1 : 0·3 : 0·1	0·64	0·90	1·97
	1 : 0·1 : 0·02	0·46	1·55	6·29
	1 : 0 : 0	0·40	—	—
I (10, 26, 42)	1 : 1 : 1	1·10	0·28	0·31
	1 : 0·6 : 0·4	0·62	0·25	0·41
	1 : 0·3 : 0·1	0·36	0·24	0·84
	1 : 0·1 : 0·02	0·26	0·38	2·51
	1 : 0 : 0	0·23	—	—
I (15, 31, 47)	1 : 1 : 1	0·99	0·18	0·25
	1 : 0·6 : 0·4	0·55	0·16	0·33
	1 : 0·3 : 0·1	0·29	0·16	0·65
	1 : 0·1 : 0·02	0·19	0·24	1·79
	1 : 0 : 0	0·15	—	—
I (15, 36, 57)	1 : 1 : 1	0·71	0·08	0·15
	1 : 0·6 : 0·4	0·39	0·07	0·21
	1 : 0·3 : 0·1	0·21	0·07	0·41
	1 : 0·1 : 0·02	0·14	0·11	0·10
	1 : 0 : 0	0·11	—	—

validity of the intercomparison. Fig. 3 shows the results of the RaA intercomparison. The uncertainties shown in this figure are one standard deviation due to counting statistics calculated according to eqn (5). The detector efficiency of the Radon Daughter Monitor was 0·2 and the flow rates used were in the region of 55 l min^{-1}.

For measurements of radon daughter activity concentrations in the open air the regime I (15, 36, 57) produced useful assessments of RaA activity concentrations down to 0·05 pCi l^{-1} (with a flow rate efficiency product of 10). In the present method, as with the Thomas–Tsivoglou method, the precision of Working Level assessment is higher than that for any of the daughter

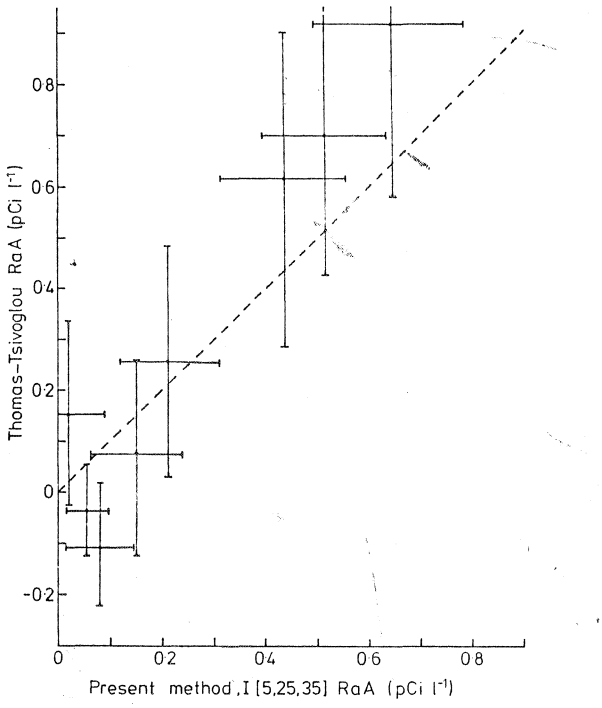

Fig. 3. Measurement of RaA concentrations in dwellings using Thomas–Tsivoglou and I (5, 25, 35) on the same sample.

concentrations. Using the I (15, 36, 57) regime with a system having a flow rate efficiency product of 10 a coefficient of variation of 14% at 10^{-4} WL under conditions of daughter equilibrium is obtained.

4. Conclusion

The method outlined in this paper for the measurement of radon daughter activity concentrations offers the possibility of using simple portable equipment to assess RaA activity concentrations at levels as low as 0·05 pCi l^{-1} (approximately 0·5 atoms per litre). With a total measurement time of 35 min the sensitivity of the present method for RaA assessment shows an improvement by a factor of five over that of Thomas–Tsivoglou which also requires 35 min for a measurement. By extending the overall measurement time to 57 min the limit of detection is an order of magnitude lower than that for the Thomas–Tsivoglou method.

Résumé

Les mesures de faibles concentrations d'éléments enfantés de radon-222 dans l'air, avec accent sur l'estimation du RaA

Un certain nombre de méthodes existent pour mesurer la concentration d'activité d'éléments enfantés de radon 222 dans l'air mais dans la plupart des cas, l'intérêt est centré sur la détermination des niveaux de fonctionnement. Dans les cas particuliers où les concentrations d'activité des éléments enfantés individuels sont évalués, la précision de l'évaluation du RaA (^{218}Po) est médiocre, sauf si la spectrométrie est utilisée. Pour contrôler l'environnement, les mesures des concentrations d'activité du RaA fournissent une indication faible des concentrations d'activité du radon. Après avoir brièvement passé en revue les méthodes reconnues de mesures des concentrations d'activité des éléments enfantés de radon, l'auteur expose une méthode permettant de mesurer des concentrations d'activité aussi faibles que 0,05 pCi l^{-1} (50 pCi m^{-3}) du RaA au moyen d'un matériel transportable simple. La méthode décrite mesure aussi les concentrations d'activité du RaA (^{214}Pb) et du RaC (^{214}Bi) et les niveaux de fonctionnement avec une précision améliorée en comparaison avec les méthodes établies.

Zusammenfassung

Die Messung niedriger Konzentrationen von Radon-222 Töchtern in Luft, mit besonderer Betonung auf der RaA-Beurteilung

Eine Reihe von Messmethoden für die Konzentrationen, bei denen Radon-222 Töchter in Luft wirksam sind, stehen zur Verfügung. In den meisten Fällen interessiert jedoch die Bestimmung der Intensität. Wenn die individuelle, Wirksamkeitskonzentrationen von Töchtern beurteilt werden soll, ist die RaA (^{218}Po)-Bewertung unpräzise, ausser man verwendet Spektrometrie. Bei Umgebungsüberwachungen ist die Messung von RaA wirksamkeitskonzentrationen ein zuverlässiger Indikator für Radon Wirksamkeitskonzentrationen. Im Anschluss an eine kurze Überprüfung der bekannten Methoden zur Messung der Wirksamkeitskonzentrationen von Radon-Töchtern wird eine Methode genannt, durch die mit Hilfe einfacher, transportabler Geräte Wirksamkeitskonzentrationen bis zu 0,05 pCi l^{-1} (50 pCi m^{-3}) RaA gemessen werden können. Die hier vorgeführte Methode ist auch zur Messung von RaB (^{214}Pb) und RaC (^{214}Bi) Wirksamkeitskonzentrationen und Intensitäten geeignet, und zwar bei grösserer Präzision als die bekannten Methoden.

References

Archer, V. E., Wagoner, J. K., and Lundin, F. E., 1973, *Health Phys.*, **25**, 351.

Duggan, M. J., and Howell, D. M., 1969, *Health Phys.*, **17**, 423.

Evans, R. D., 1969, *Health Phys.*, **17**, 229.

James, A. C., and Strong, J. C., 1973, in *Proc. 3rd Int. Cong. IRPA, Washington, D.C., September* 1973, USAEC CONF-730907, p. 932. (Copies available on application to the authors, NRPB, Harwell.)

Jonassen, N., and Hayes, E. I., 1974, *Health Phys.*, **26**, 104.

Kusnetz, H. L., 1956, *Am. Indus. Hygiene Assoc. Quart.* **17**, 85.

Thomas, J. W., 1972, *Health Phys.*, **23**, 783.

Tsivoglou, E. C., Ayer, H. E., and Holaday, D. A., 1953, *Nucleonics*, **11**, 40.