A RADON DAUGHTER MONITOR FOR USE IN MINES

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Abstract

A self-contained monitor for the measurement of airborne RaA, RaC and the working level, WL, in the shortest practicable time and with a minimum of calculation is described. The ratio of two gross alpha-counts gives, directly, the ratio of airborne alpha-emitter concentrations, RaC':RaA, after collection on a filter. This is achieved because the contribution from airborne RaB to the measured alpha-activity is minimised by choosing short sampling and counting times. The RaA concentration is derived from the first alpha-count, during air sampling. WL is derived from the second alpha-count. No background correction is required. Systematic errors in estimated quantities are small. With a total measuring time of eleven minutes, the limits of detection are approximately 1 pCi/litre for RaA and 10^{-4} for WL.

Introduction

A radiation hazard from the short-lived radon daughters in uranium and other metal mine atmospheres has been convincingly shown.[1] Most of the epidemiological studies made in this context have used the working level (WL) as the unit of exposure. 1 WL represents the concentration of radon daughter activity in an atmosphere, and is defined as any combination of the daughters (RaA, RaB, RaC and RaC') in one litre of air that results in the emission of 1.3×10^5 MeV of potential alpha energy in decaying to RaD. The unit is numerically equal to the total alpha-energy arising from the decay of 100 pCi/litre each of RaA, RaB and RaC, but does not depend on the state of daughter disequilibrium. Nevertheless, it is often useful to know the RaA concentration and state of daughter disequilibrium as well as the WL. The concentration of the first daughter, RaA, because of its short half-life, responds rapidly to the radon gas concentration. This information can be valuable, for example, in locating a point of injection of fresh radon and/or daughters into an airstream. With the location of such a point, corrective action can be considered. In this case, a quick, on-the-spot assessment is very helpful, as additional measurements may be indicated. For this purpose, the RaA and RaC concentrations adequately describe the state of daughter equilibrium, whilst a measurement of RaB adds only little useful information.

A prototype radon daughter monitor (RDM) has been developed with the above points in mind. We have chosen to measure only the RaA and RaC concentrations, hence the counting procedure and the calculation of results have been greatly simplified. Both sampling and measurement normally take only 11 minutes and results can be calculated using a slide rule. An important feature of the method is that electronic requirements are simple, amounting only to the scaling of gross alpha-activity.

The Radon Daughter Monitor

Fig. 1 is a photograph of the prototype monitor. The instrument is portable and **weighs 5 kg.**

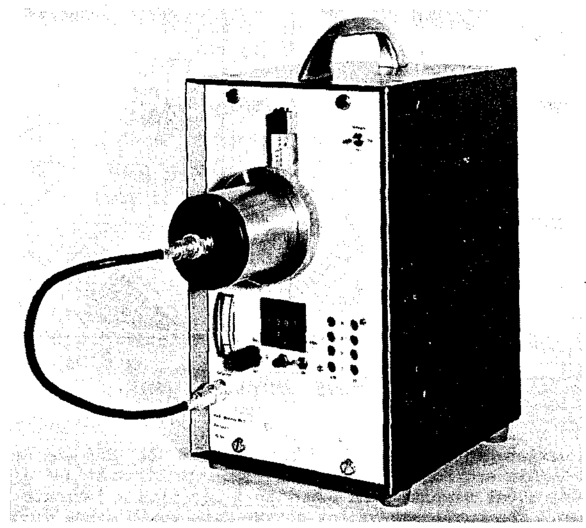

Figure 1: The Radon Daughter Monitor

Mechanical details

Air is drawn through a glass fibre filter (GF/A, Whatman UK) at 10 litres/min. The carbon vane pump (L10, Rotheroe & Mitchell UK) is battery powered. Sampling rate is monitored and all components are mounted in a sealed case.

Alpha-counting

Alpha activity on the filter is detected by a 450 mm^2 diameter surface barrier diode (ORTEC) mounted in the filter holder. The front electrode of the detector has been specially thickened to 0.5 mg cm^{-2} of gold. This reduces sensitivity to chemical contaminants that might be picked up from mine air.

Scaling

A charge sensitive pre-amplifier and an amplifier with an adjustable threshold are used. The discrimination level is set for a particle energy of 800 keV in Silicon. This effectively rejects beta-pulses from RaB and noise picked up from the pump motor. Integrated circuits and a binary display are used for two decades of scaling logic. Four higher decades are counted and displayed by a mechanical register (Landis & Gyr UK). A maximum count rate of 1000/sec is attained by this arrangement. Power for the circuitry is supplied by a battery of mercury cells, with a separate dry battery for the display bulbs.

Operation of the monitor

Operation is controlled by a single switch, the sampling and counting times being measured by a watch.

The Sampling and Counting Scheme

We have chosen a procedure that is simple to use underground. Thus, sampling times are restricted to 2, 5 or 10 minutes. Equal sampling and counting times are used. A fixed, one minute, delay between the 2 alpha-counts reduces the likelihood of timing error.

Conversion factors

Mercer's general formulation of radon daughter decay[2] was used for calculations on a digital computer. Computations were checked against published data[3,4].

Fig. 2 shows the build up of alpha-activity for equal sampling and counting times when equal airborne concentrations of radon daughters are collected on a filter. RaA contributes almost half of the total alpha-activity during sampling. At short time intervals, both during and after sampling, the contribution from RaB is small.

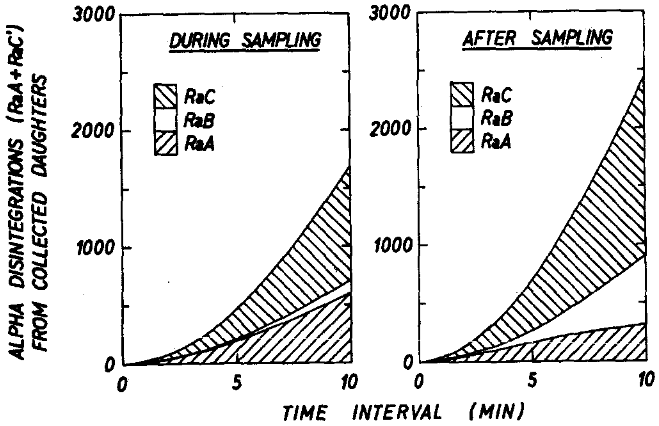

Figure 2: Alpha disintegrations from 1pCi/1. each of RaA, RaB and RaC, sampled at 10 1./min and collected on a filter. Disintegrations after sampling refer to equal sampling and counting times with a 1-minute delay in between. The envelopes of the curves give total alpha disintegrations.

In order to estimate the desired unknown concentrations, RaA and RaC, from only 2 gross alpha-counts, some assumption must be made about the RaB concentration. We have assumed that the ratio RaB/RaA is a uniquely defined function of the ratio RaC/RaA.

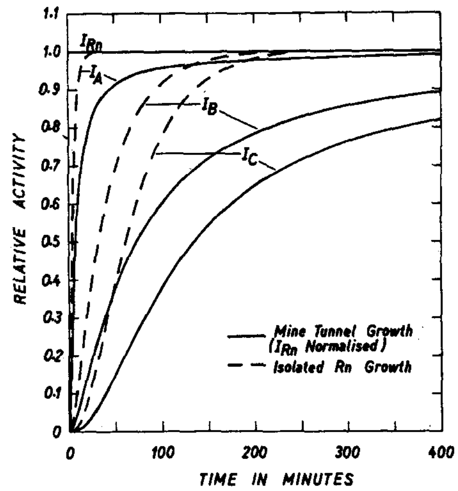

Figure 3: Relative activities of daughters and parent radon as a function of growth time, according to two theoretical models of growth.

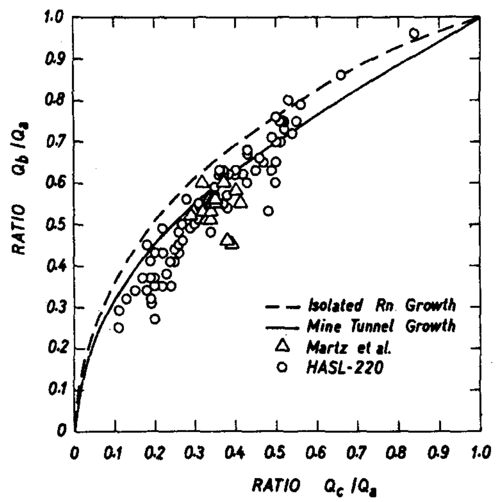

Figure 4: Ratios of radon daughter activities for two theoretical growth models. Plotted points are ratios measured in U.S. uranium mines.

The RaB approximation. Fig. 3 shows the growth of radon daughters from parent radon under 2 different conditions. The 'Mine Tunnel' model[5] describes growth during de-emanation of radon at a uniform rate from the walls of a mine tunnel. Air is moving through the tunnel, thus growth time is equated to transit time. The 'Isolated Radon' model[3] describes growth in still air. Fig. 4 shows that a different function relates RaB/RaA to RaC/RaA in the 2 models. Measured values of these ratios, from U.S. uranium mines[6,7], are also plotted in the figure. The measured values are better represented by the 'Mine Tunnel' model, but they do tend to fall below this (solid) curve. Rolle[8] found that similar, relatively small, departures from the simple model are predicted when 'young' and older air mix in a mine, e.g. downstream of a junction. Plate-out of unattached daughters on tunnel walls can also disturb the daughter equilibrium. However, the measurements plotted in Fig. 4 indicate that daughter equilibrium is adequately described by the solid curve. We have assumed this to be generally true. The curve is a good fit of the relationship[8] $RaC/RaA = (RaB/RaA)^2$.

Calculated factors. Figs. 5-7 show the factors calculated to relate equilibrium ratio, Q_C/Q_A, RaA concentration, Q_A, and WL to alpha-counts recorded by the RDM. Curves are given for both growth models. Full computer tabulations are available from the authors. These allow for the slightly lower counting efficiency observed for RaA than for RaC with GF/A filters[9]. The calculated factors have been verified by comparing laboratory measurements with the RDM and simultaneous measurements by the modified Tsivoglou method[10].

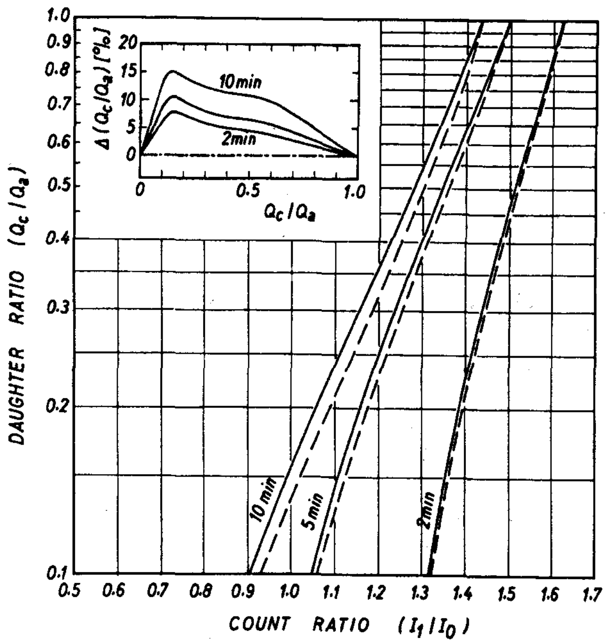

Figure 5: Curves relating the measured ratio of two alpha-counts to radon daughter ratio, Q_C/Q_A, for different sampling times. Equal counting efficiencies for RaA and RaC are assumed. Solid curves assume 'Mine Tunnel' model, dashed curves 'Isolated Rn'. Inset shows percentage systematic error in estimate of Q_C/Q_A if the wrong model chosen.

Systematic errors. The possible errors caused by departures from an assumed model are smallest for short sampling times. In Figs. 5-7, the inset figures show the magnitude of systematic errors that would arise when sampling in still air, if the 'Mine Tunnel' model were assumed to hold. These are a function of the true Q_C/Q_A. Reference back to Fig. 4 shows that similarly small errors would have been recorded for the values measured in uranium mines.

Statistical precision. Fig. 8 (a, b & c) shows the calculated coefficients of variation in estimated quantities for a range of airborne daughter concentrations. Fig. 8(a) also shows that a realistic background alpha-count of 1/min has a negligible effect on the precision of estimating Q_A. Therefore, neglecting background, the precision in an expected value, say Q_A, can be calculated as $S(Q_A = 1)/\sqrt{Q_A}$. Similarly, the minimum detectable concentrations, corresponding to a coefficient of variation of 0.5, can be calculated from these curves. For high radon daughter concentrations, the maximum counting rate of 1000/sec limits the sampling time. A two-minute sample is advised for concentrations in excess of 3 WL.

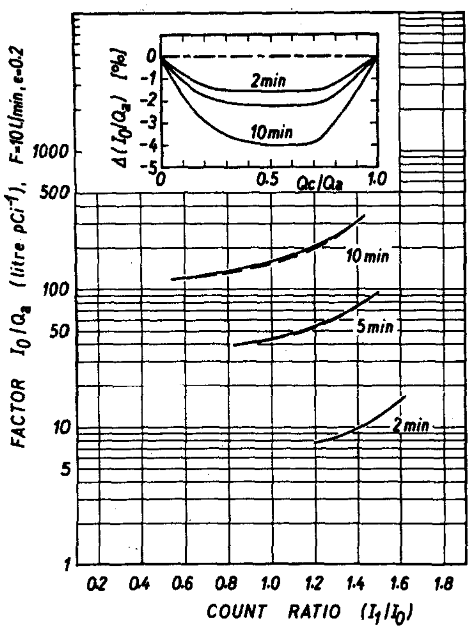

Figure 6: Factors relating count during sampling, I_0, to RaA concentration, Q_A, for different sampling times (counting efficiency 0.2). Solid and dashed curves refer to different models as in Fig. 5. Inset shows percentage systematic error arising from choice of the wrong model.

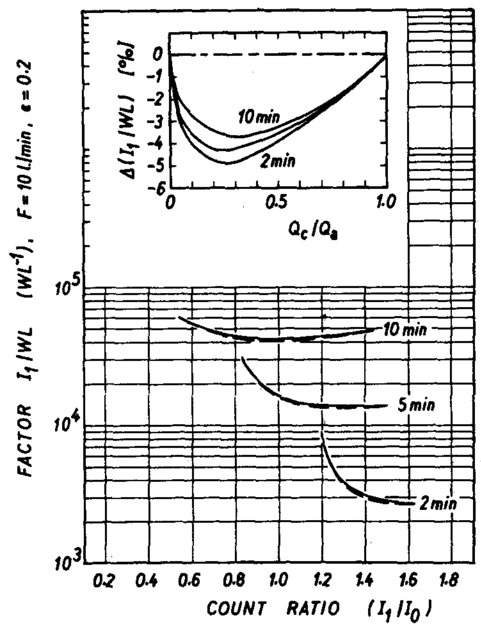

Figure 7: As Fig. 6, but showing factors relating count after sampling, I_1, to working level, WL. With a 5-minute sample and $Q_C/Q_A \geqslant 0.3$, the factor is almost constant.

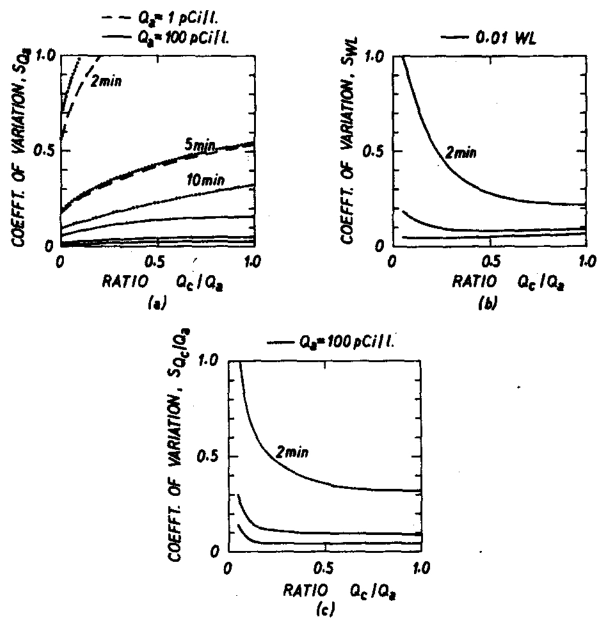

Figure 8: Statistical precision in estimates of (a) Q_A, (b) WL and (c) Q_C/Q_A as a function of daughter equilibrium for 2, 5 and 10 minute sampling times. In (a) two sets of data are given; for Q_A = 1 and 100 pCi/1. Dotted curves show the effect of 1 count/min background when Q_A = 1 pci/1.

Comparison with Other Methods

The table displays for comparison statistical precision, number of counts required for a measurement, total time and the subsequent computation for our method (RDM) and 4 established methods. Two of these methods[6,10] give individual daughter concentrations. The other two are presented as rapid methods, giving WL only: The Single Gross Alpha Measurement Procedure[11] (SGAMP) and the Instant Working Level Meter[12] (IWLM). Statistical precision for the RDM compares favourably with other methods, whilst the monitor offers significant advantages in field use. Under conditions of disequilibrium, both the RDM and SGAMP are subject to systematic errors. These are of the order of 10% for the SGAMP[11].

TABLE 1

COMPARISON OF METHODS FOR MEASURING RADON DAUGHTER CONCENTRATIONS*

	Spectrometry	Modified Tsivoglou	SGAMP (Kusnetz)	IWLM	RDM
RaA	± 5%	± 12%	-	-	± 6%
RaC/RaA	± 6%	± 12%	-	-	± 9%
WL	± 3%	± 3%	± 1%	± 11%	± 1%
No. of counts	2	3	1	2	2
Time	35 min	35 min	16 min	4 min	11 min
Computation	Simultaneous equations		Slide rule	Direct Readout	Slide rule

*Calculated coefficients of variation for 100 pCi/l. each of RaA, RaB, RaC. Sampling flow rate 10 l./min, except IWLM (3 l./min). Counter efficiency 0.2.

Field experience with the RDM

The monitor has undergone continuous development based on underground and laboratory comparisons with established methods. Development has reached the stage where the pump and counting system function reliably underground, even in very humid conditions. Good correlation has been obtained between routine measurements of WL with the RDM and the standard Kusnetz method[13].

Conclusion

The radon daughter monitor described gives a rapid, comprehensive and sensitive measurement of radon daughter activity. Ease of measurement is achieved with only small and acceptable systematic errors. The complexity of the instrument has been reduced to a minimum.

Acknowledgements

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References

1. F. E. Lundin, J. K. Wagoner and V. E. Archer, NIOSH-NIEHS Joint Monograph No. 1, June 1971.

2. T. T. Mercer, AMA Arch. industr. Hyg. and occup. Med., 10, 372-380 (1954).

3. R. D. Evans, Health Phys, 17, 229-252 (1969).

4. N. H. Harley and B. S. Pasternack, Health Phys, 17, 109-114 (1969).

5. J. W. Thomas and R. Epps, Personal communication (1970).

6. D. E. Martz, D. F. Holleman, D. E. McCurdy and K. J. Schiager, Health Phys, 17, 131-138 (1969).

7. A. J. Breslin, A. C. George and M. S. Weinstein, HASL-220 (1969).

8. R. Rolle, Health Phys, 23, 118-120 (1972).

9. A. C. James and G. F. Bradford, in preparation.

10. J. W. Thomas, Health Phys, 23, 783-789 (1972).

11. R. Rolle, Health Phys, 22, 233-238 (1972).

12. P. G. Groer, R. D. Evans and D. A. Gordon, Health Phys, 24, 387-395 (1973).

13. H. L. Kusnetz, Am. Ind. Hyg. Ass. Q., 17, 85 (1956).