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MEASUREMENT OF POTENTIAL ALPHA ENERGY CONCENTRATION OF RADON AND THORON DAUGHTERS USING AN ELECTRET DOSEMETER*

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Abstract — An electret dosemeter consisting of an electret loaded into a 60 ml chamber has been used earlier for quantitative measurement of gamma radiation. The chamber was modified to hold an air sampling filter paper at the bottom and air was sampled through it. It was shown that nearly 20% of the energy of alpha radiation emitting from the filter paper was dissipated in the volume of the chamber. This energy in turn produced ion pairs which were collected by the electret resulting in a measurable change in charge status of the electret. By taking an air sample of known volume and allowing the registration of alpha energy, not only during sampling but also for three hours after sampling, a direct measure of the potential alpha energy concentration of radon daughters could be calculated in easily interpretable working level units. By proper choice of the thickness of the electret and the total flow, it was possible to measure radon daughter concentrations down to milli working level units. The field measurements carried out by this method compared well with those obtained by established methods. The procedure was particularly useful for measuring time-averaged concentrations needed for effective survey of a mine area or for personal dosimetry.

For thoron decay products, it was shown that the alpha energy concentration measured during sampling and up to a period of 7.7 hours post sampling, time being reckoned from the mid-time of sampling, yielded 33% of the potential alpha energy concentration due to thoron daughters. An air sample collected and measured in this way registered all of radon daughter alpha potential energy and one third of thoron daughter alpha potential energy, thus providing an equivalent radon daughter concentration. This procedure is suitable for evaluating any mixture of daughter products without consideration of whether they originated from radon or thoron.

INTRODUCTION

The inhalation of daughter products of radon constitutes an occupational risk in mining of uranium ores. The alpha radiations emitted by the daughter products of radon, deposited in the lung, irradiate the basal cells of tracheobronchial and pulmonary epithelia. These cells receive doses not only from the deposited daughter products, but also from alphas emitted by decay products formed after their deposition. This has led to the concept of relating the inhalation hazards to the ultimate or potential alpha energy concentration of airborne daughter products instead of just the alpha energy concentration. One working level (WL) is defined as the potential alpha energy concentration of the decay products of radon, equivalent to 1.3×10^5 MeV per litre or 2.08×10^{-5} J per m^3 of air. ICRP publication 32[1] recommends the limits of annual intake and the derived air concentrations of decay products of radon (Table 1). The purpose of the present paper is to demonstrate a new method for measuring the potential alpha energy concentration of airborne daughter products of radon.

The procedure adopted until now has been based on the method described by Kusnetz[2] or some variation of the same[3]. The method consists of collecting a known volume of airborne radon daughter products on a filter and subjecting the filter sample to programmed alpha counting after the end of the sampling to calculate the potential alpha energy concentration of WL or in $J.m^{-3}$. The

Table 1. Recommended annual limits of intake (ALI) and the derived air concentrations (DAC) for radon daughters[1]

Type of limit	Unit	^{222}Rn (Rn) daughters	^{220}Rn (Th) daughters
ALI	Potential alpha energy	0.02 J	0.06 J
DAC*	Potential alpha energy concentration	8.3×10^{-6} Jm^{-3} or 0.40 WL	2.5×10^{-5} Jm^{-3} or 1.2 WL

* Assuming a mean breathing rate of 1.2 m^3h^{-1} during a working period of 2000 h per year.

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proposed method attempts a direct determination of such concentration (without having to do programmed alpha counting) using an alpha electret dosemeter.

ELECTRET DOSEMETER

An electret[4] is a piece of dielectric material such as teflon exhibiting a quasi-permanent electrical charge. It can be made easily in any laboratory[5] and characterised in terms of surface charge using a simple electrostatic charge reader[6]. A teflon electret of 5 cm diameter loaded into a cylindrical chamber forms a simple electret dosemeter[7]. The electret in such a dosemeter shows a decrease of charge linear with gamma dose (like an ionisation chamber) over a certain range of charge of the electret. Such a dosemeter has been shown to measure quantitatively X or gamma radiation[7]. Since electrets retain their charge for a long time even under unfavourable atmospheric conditions[8] (65°C, nearly 100% relative humidity), long term cumulative dose is measurable without loss of information.

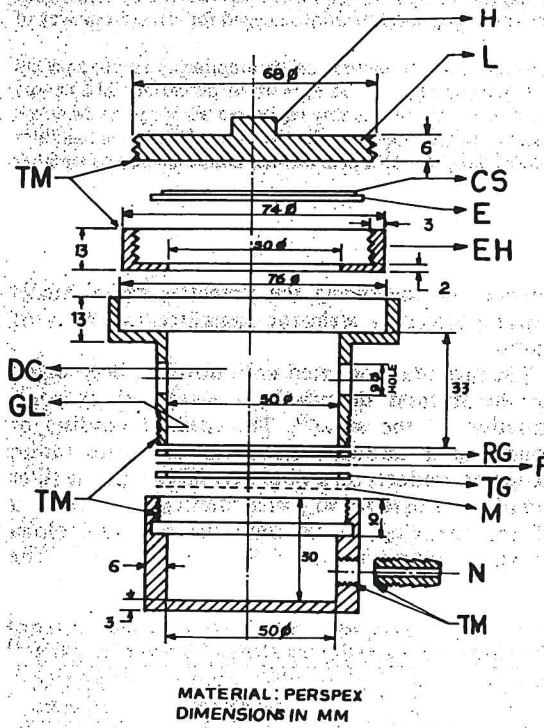

Figure 1. Exploded view of dosemeter and electret holder. Dimensions are in mm. H: Handle for lid; L: Perspex lid to screw into H, the electret holder; CS: graphite coated conducting surface of electret E; DC: Dosemeter chamber; GL: Thin graphite layer; TM: Threaded to match; RG: Rubber gasket; F Filter; TG: Teflon gasket; M: Wire mesh; N: Nozzle. Hatched parts are made from perspex.

ALPHA ELECTRET DOSEMETER FOR RADON DAUGHTER MEASUREMENTS

The dosemeter described earlier was modified to accommodate a filter at its bottom surface. The alphas emitted from the decay products of radon ionised the air in the dosemeter and the ions were collected by the electret. Figure 1 shows an exploded view of the alpha electret dosemeter suitable for measuring the alpha radiation emitting from a filter surface on which an air sample was collected. Figure 2 shows a schematic of the assembled unit. The bottom portion of the chamber was connected to an air sampling pump to draw air through the filter paper. The procedure includes the following steps: (1) measure the charge on the electret and make sure that it is within the useful range (see next section), (2) draw a known volume of air through the filter paper — the electret in the chamber collects ions during the period of sampling, (3) allow the electret to continue collection of ions formed for at least three hours after the end of sampling of ^{222}Rn daughters, (4) measure the charge on the electret and make sure that it is within the useful range (see next section). The post collection delay of three hours, being close to six half-lives of radon daughters, allows almost complete dissipation of radiation emitted by the radon daughters collected on the filter paper. Knowledge of the change in charge and the volume of air sampled yields the needed concentration in

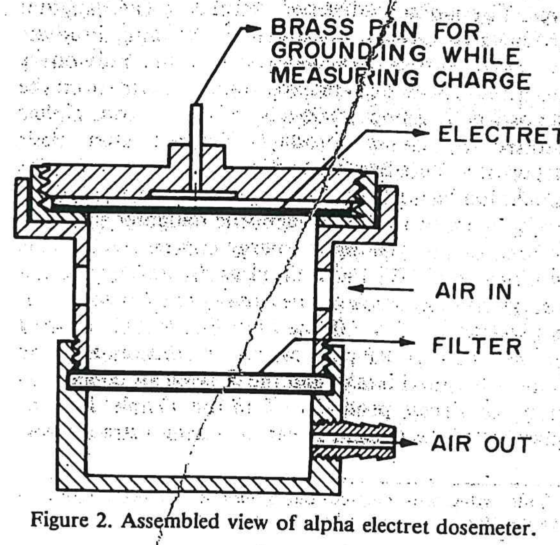

Figure 2. Assembled view of alpha electret dosemeter.

working level units due to ^{222}Rn daughters. It is clear from the procedure described above that the total potential alpha energy from a known volume of sample is measured since the alpha radiation is measured during sampling as well as during the time needed for complete decay of all the significant decay products of ^{222}Rn daughters. Similarly to measure the potential alpha energy concentration of ^{220}Rn daughters, one has to leave the electret in the dosemeter for a period of about three days. This aspect will be discussed later.

FRACTIONAL ALPHA ENERGY DISSIPATION

The sensitivity of the alpha electret dosemeter depends upon the fractional energy dissipated in the sensitive volume. This was calculated on the following assumptions; (a) only 50% of the alphas originating from the filter paper enter the sensitive volume, (b) each of the alphas emitted from the filter paper dissipates its energy over a path length of 3.6 cm, which is the distance between the filter and the electret.

The following equation[9] gives the energy dissipated (ΔE) by an alpha particle over a small distance (ΔX).

$$\Delta E = \frac{(1.3739 \ln (6.8466\, E)) \cdot (\Delta X)}{E}$$

where ΔE is the loss of energy in MeV during its passage over a small path length of ΔX cm and E is the initial energy of an alpha particle in MeV.

The above equation was used to calculate the energy loss over a small length of 1 mm with an initial energy of alpha radiation. The energy loss over the next mm was calculated using the initial energy as the energy used in the earlier calculation minus the loss in energy in the first mm. The calculations were continued to arrive at a total energy loss over a distance of 3.6 cm. Calculations were done for all the alpha energies of interest associated with daughter products of radon and thoron. After giving appropriate weighting for alphas of radon daughters and thoron daughters, the fractional energy dissipation of alphas of radon daughters was calculated to be 0.3995 and that for thoron daughters was calculated to be 0.4257. Since the difference between these two was not significant, a single value, 0.4126, could be assumed to provide a fractional energy loss applicable for both radon and thoron daughters. Considering that only 50% of the alphas deposited on the filter paper enter the sensitive volume, the overall fractional energy dissipated in the sensitive volume could be taken as 0.2063.

COMPUTATION OF POTENTIAL ALPHA ENERGY CONCENTRATIONS FROM DOSEMETER READINGS

The charge reader used in the present work has already been described in our earlier work[7]. The readout is in terms of volts. For an electret of 0.3 cm thickness, a charge reader reading of 1 V corresponds to a total charge of 8.265×10^{-10} coulombs when the electret is loaded and measured in a standard holder. For an electret of a different thickness, 1 V corresponds to a different charge. The reading of the charge reader is referred to as the *dosemeter reading*[7] in volts. It is shown that the response of the dosemeter is linear for gamma measurements over a range of dosemeter readings (5 V to 20 V). Such a range is referred to as the *useful range of the dosemeter*[7]. An alpha electret dosemeter showed a slightly different useful range (8 V to 23 V) because the distance between the top and bottom was 36 mm instead of 32 mm in the gamma dosemeter.

Let the dosemeter reading before sampling radon decay products be V_1 volts and let the dosemeter reading be V_2 volts three hours after sampling, that is, after registering all the potential alphas of radon decay products originating from the sample on the filter paper. Let F be the total volume of air sampled by the filter paper in litres. Equation 1 gives the concentration of radon daughters in WL units present in the air.

$$C = [(V_1 - V_2) \times 8.265 \times 10^{-10} \times 35.5 \times 10^{-6}] / (1.6 \times 10^{-19} \times 1.3 \times 10^{5} \times 0.2063 \times F) \qquad (1)$$

$$C = 6.8388\,(V_1 - V_2)/F \qquad (2)$$

where C is the radon daughter concentration in WL units:

8.265×10^{-10}	is the conversion factor between dosemeter reading and coulombs for a 0.3 cm thick electret. (coulombs.volt^{-1});
1.6×10^{-19}	is the charge of an ion (coulomb per ion pair);
35.5×10^{-6}	is the energy needed (MeV) per ion pair;
F	is the total volume sampled (litres)
1.3×10^{5}	is the conversion factor (MeV per litre per WL)
0.2063	is the fractional energy dissipation of alpha radiation in the sensitive volume.

For electrets of 0.1 cm thickness, the conversion factor between dosemeter reading and coulombs is 21.7127 (Coulombs.volt^{-1}).

Therefore, Equation 2 reduces to Equation 3 for such electrets.

$$C = 17.966\,(V_1 - V_2)/F \qquad (3)$$

Table 2. Comparison of radon daughter concentrations determined by Kusnetz's method and by electret dosemeter method. ($V_1 - V_2$) : Change in dosemeter reading in V; F : Total flow in litres; C : daughter product concentration in WL units.

Location		Electret dosemeter			C by Kusnetz method at same location	Deviation in percent from Kusnetz method
		$(V_1 - V_2)$	F	C		
1	Room 20	2.2	782	0.0191	0.0182	+4.95%
2	Room 20	6.32	782	0.0553	0.0546	+1.26%
3	Room PP	7.29	260	0.1912	0.1879	+1.75%
4	Room PP	3.37	260	0.0887	0.0834	+6.32%
5	Room PP	5.02	260	0.132	0.1296	+1.90%
6	U-mine (500 m level depth)	1.75	138	0.0871	—	
7	U-mine (434 m level depth)	1.52	201	0.0518	—	
8	U-mine (370 m level depth)	3.22	162	0.1354	—	
9	U-mine (132 m level depth)	10.02	120	0.5696	—	
10	U-mine (Adit 5)	10.00	96	0.7139	—	

THE PERFORMANCE

Table 2 gives some of the measurements carried out using the alpha electret dosemeter. The first five experiments were done in a room having a relatively high radon daughter concentration.

The procedure consisted of the following steps: (1) the electret was read (V_1) and loaded into the dosemeter; (2) an air sample was taken and the volume sampled (F) was noted; (3) the electret was allowed to remain in the dosemeter for a period of at least three hours after sampling; (4) the electret was read (V_2). Equation 2 was used to calculate the potential alpha energy concentration since the electrets used were of 0.3 cm thickness.

The concentration of radon daughters was also estimated by an alpha counting method. The filter paper in the dosemeter holder was taken out for a short period after a known delay after sampling. During this period the alpha disintegration rate was determined in a standard alpha scintillation counting system. Immediately after counting, the filter was loaded back into the electret dosemeter for the registration of alpha energy from it. The concentration of radon daughters in working level units was determined by standard methods[2,3] from a knowledge of sampling duration, the volume of air sampled and the alpha count rate at a specific post sampling time.

It could be seen that the same sample was analysed by two methods. The electret dosemeter lost some alpha energy during the short period (usually 2 to 3 mins) when the sample was taken out for counting in the scintillation counter. This loss was expected to be less than 2% of the total alpha energy dissipated in the dosemeter over the sampling and post sampling period. The results of measurements by the two methods were in good agreement with each other (Table 2). It was noted that the electret method gave a slightly higher value compared to the alpha counting method. This could be due to the combined effect of the contribution from radon gas, the beta radiation and wall deposition of some unattached decay products. However, the differences are within the experimental uncertainty.

Having established the accuracy of the method, the dosemeter was taken into an operating Indian uranium mine at Jaduguda, Bihar. The dosemeter was carried by a health surveyor and the sample was continuously drawn by a battery operated personal air sampler. The dosemeter weighed about 100 g which together with the air sampler weighed about 500 g. The surveyor walked through typical working areas. After collecting a known volume of sample, the air sampler was turned off; the electret was taken out from the dosemeter after a delay of three hours and was read. The net change in electret reading and volume of air sampled was used for calculating the radon daughter concentration in working level units. Room 20 (Table 2) was a room near the uranium mines built out of granites from that area.

Table 3. Sensitivity analysis.

Electret thickness in cm	Minimum volume (litres) of air to be sampled to determine the respective working level 1 WL	0.1 WL	0.01 WL	0.001 WL	Useful Range* WL - litres
0.3	6.84	68.4	684	6840	103
0.1	17.97	179.7	1797	17970	270

Assumption: A difference of 1 volt in dosemeter reading can be recorded without any uncertainty.
* Useful range is defined as the range of dosemeter reading over which the response in linear. This range (15 volts) is the difference between the upper limit (23 volts) and the lower limit (8 volts)

Ventilation was stopped for some time before sampling was done. Room PP had a source of radon in the room. The second part of Table 2 gives results of such measurements made in different areas of the mine. A few spot measurements, carried out using Kusnetz's[2] method, agreed generally with those listed in Table 2 for mine measurements.

THE SENSITIVITY

Even though the charge reader can resolve dosemeter readings down to 0.01 V, we can take 1 V as the practical limit for recording without uncertainty. Table 3 gives the sensitivity analysis. It is seen that one has to take a sample of at least 6840 litres, if one is interested in measuring a concentration of 1 mWL, whereas it is enough to take 68.40 litres for measuring concentrations of the order of 0.1 WL, the level usually found in uranium mines. This method is too sensitive for measurements in mines. The sensitivity can be reduced by a factor of about 2.6 by using an electret of 0.1 cm thickness. The useful range also increases correspondingly. The useful range is limited by the upper and lower limits of readings in volt. These are 23 V and 8 V respectively. Thus the maximum useful range corresponds to electret charge change of 23-8 = 15 volts. For example, a fully charged dosemeter (0.3 cm thick electret with a dosemeter reading of 23 V) could be used for about 17 hours at a sampling rate of $60\ l.h^{-1}$ before needing recharging at a concentration of 0.1 WL. For a similar concentration and sampling rate, a 0.1 cm thick electret can be used for 45 hours. Further reduction of sensitivity is possible by reducing either the sampling rate or the electret thickness or both.

THORON WORKING LEVELS

The procedure adopted for measuring the ^{222}Rn daughter concentration could be adopted for measuring ^{220}Rn (Th) daughter concentrations by simply registering the alpha energy up to the end of the decay of all the daughter products which would take about three days. Since it takes such a long time to arrive at the results, this method is not considered practical. Further it becomes difficult to resolve the radon daughter concentration and the thoron daughter concentration if a mixture is present in the working atmosphere. To overcome this deficiency a unified approach is suggested in the next section.

UNIFIED APPROACH FOR MEASURING RADON AND THORON DAUGHTERS

From Table 1, it is clear that a concentration of 1.2 WL of thoron daughter products causes the same inhalation hazard as that of 0.4 WL of radon daughter products. This comes about mainly because of the fact that all the potential alphas from radon decay products dissipate their energy in the lung, whereas only a part of the potential alphas from thoron decay products dissipate their energy in the lung when biological clearance mechanisms set into action.

When both radon and thoron decay products are present in an atmosphere, the concentration of thoron daughter products in WL units can be reduced by a factor of 3 and added to the concentration of radon daughters in WL units to arrive at an equivalent radon concentration for comparison with derived air concentration (DAC) standard for radon daughter products. In other words, one third of the thoron daughter potential energy concentration can be called equivalent radon daughter concentration.

Suppose we have an instrument that records all the potential alpha energy of radon daughter products and one third of the potential alpha energy of thoron daughters, then such an instrument can be said to give a single result in terms of equivalent radon daughter concentrations. The alpha electret dosemeter described in this paper has the capability of measuring such equivalent radon daughter concentrations.

We have seen that the alpha electret dosemeter when read three hours after sampling gives the radon daughter concentration in working level units. Suppose we choose another time (larger than 3 hrs.) for reading the dosemeter such that one third of the potential alpha energy due to thoron daughters is recorded by that time, then the dosemeter should read the equivalent radon daughter concentration.

Table 4. Time (t) needed to record 33% of the potential alpha energy from thoron daughters. Time, t, is reckoned from the end of sampling and t_s is the sampling time. Time t_o is calculated by subtracting the mid-sampling time from the mean biological life time of Th-B in the respiratory tract (7.7 h)

t_s(h)	t(h)	$t_o = 7.7 - t_s/2$ (h)
1	7.26	7.2
2	6.77	6.7
3	6.28	6.2
4	5.80	5.7
5	5.33	5.2
6	4.86	4.7
7	4.39	4.2
8	3.93	3.7
9	3.48	3.2
10	3.03	2.7

This time can be calculated theoretically (see the next section). Such a time depends also upon the sampling duration. Table 4 gives the results of such theoretical calculations. For instance, if sampling is done for a period of 4 hours, then the electret has to be left in its dosemeter for a period of 5.80 hours after sampling to read equivalent radon daughter concentration. It can be seen from Table 4 that the procedure holds good for a sampling period of up to 10 hours. Thereafter, the dosemeter will start recording more than one third of the thoron daughter concentration and will no longer give equivalent radon concentration.

However, in such cases the equations in the next section can be used to compute thoron and radon working levels independently using a programmed two measurement method similar to the one described by Stranden[3] for alpha counting. This method has to be used if a sampling period is more than 10 hours.

CALCULATION OF THE TIME DELAY AFTER SAMPLING NEEDED TO REGISTER ONE THIRD OF POTENTIAL ALPHA ENERGY FROM THORON DAUGHTERS

Equations 4 to 6 can be derived from fundamental principles.

Equation 4 gives the total alpha activity (A_s) formed up to the end of sampling time (t_s), Equation 5 gives the total alpha activity (A_t) formed up to time t from the end of sampling and Equation 6 gives the total alpha activity (A_∞) formed up to infinity.

Notations: t_s is the sampling time;
t is the delay time reckoned from the end of sampling;
Ø is the collection rate of Th-B atoms from air;
B and C are the decay constants of ThB and ThC.

$X(t) = (1 - e^{-\lambda_B t})$
$Y(t) = (1 - e^{-\lambda_c t})$
$B(t_s) = (1 - e^{-\lambda_B t_s})$
$C(t_s) = (1 - e^{-\lambda_c t_s})$
f is defined by Equation 7

$$A_s = \phi \left[t_s + \frac{\lambda_B C_{(t_s)}}{\lambda_c (\lambda_c - \lambda_B)} - \frac{\lambda_c B_{(t_s)}}{\lambda_B (\lambda_c - \lambda_B)} \right] \quad (4)$$

$$A_t = \phi \left[\frac{\lambda_c B(t_s) \times (t)}{(\lambda_c - \lambda_B) \lambda_B} - \frac{\lambda_B C(t_s) Y(t)}{(\lambda_c - \lambda_B) \lambda_c} \right] \quad (5)$$

$$A_\infty = \phi t_s \quad (6)$$

$$f = (A_t + A_s)/A_\infty \quad (7)$$

Equation 8 follows from the earlier equations. Equation 9 is an approximation of Equation 8 for practical situations.

$$f = 1 - \frac{1}{t_s(\lambda_c - \lambda_B)} \left[\frac{\lambda_c B(t_s) e^{-\lambda_B t}}{\lambda_B} - \frac{\lambda_B C(t_s) e^{-\lambda_c t}}{\lambda_c} \right] \quad (8)$$

$$= 1 - \frac{1}{t_s(\lambda_c - \lambda_B)} \left[\frac{\lambda_c B(t_s) e^{-\lambda_B t}}{\lambda_B} \right] \quad (9)$$

Table 4 gives values of t for various sampling times required to record 33% of the alphas in relation to the total potential alphas from thoron decay products. Equation 9 was used for preparing this Table.

BIOLOGICAL INTERPRETATION OF UNIFIED PROCEDURE

The biological half life of daughter products in lungs is about 10.6 h[1]. The effective half life of thoron daughters in lungs can be calculated to be 5.4 h and the corresponding mean life is 7.7 h. It is reasonable to assume that on average, the alpha energy liberated by the deposited thoron daughters is fully deposited up to a period of one mean life (7.7 h) and the energy liberated is later translocated to other organs. This is valid for instantly deposited thoron daughters. However, if the deposition has taken place over a period of time, say 4 h, then the daughter products deposited in the early part of the deposition dissipate their energy fully only up to 3.7 h after the end of deposition whereas those deposited last dissipate their energy fully up to 7.7 h after the end of deposition. Therefore on average, the post sampling time needed for total dissipation of energy is 5.7 h.

In general this model predicts the following equation

$t_o = (7.7 - t_s/2)$

where t_s is the time during which deposition takes place;

t_o is the time reckoned from the end of sampling up to which the thoron daughters dissipate their energy fully in lungs.

Column 3 of Table 4 gives calculated values of t for various values of t_s.

The alpha electret dosemeter can be identified with the lung and the period of sampling can be identified with the period of inhalation (or deposition). Following this model we can predict the time (t_o) reckoned from the end of sampling up to which one has to continue registration of alpha radiation.

From Table 4 it is seen that t_o predicted by the biological model agrees fairly well with that predicted by the mathematical model.

MEASUREMENTS

Experiments were conducted for thoron daughters to establish the validity of these procedures. These were similar to the ones conducted for radon daughters. To generate relatively high thoron daughter concentrations air was made to flow over 10 grams of thorium hydroxide powder packed in a filter paper before entering a 150 litre drum. The flow over the thorium hydroxide was stopped for about 5 minutes to allow the decay of thoron in the drum. An Alpha electret dosemeter was introduced into the drum and a sample was taken for a period of 20 minutes at a flow rate of 9 litres per minute. The electret was read after a period of 7.4 h from the end of sampling. The potential alpha energy concentration thus calculated was multiplied by 3 to arrive at the real potential alpha energy concentration of thoron daughters. A typical sample taken for 20 minutes at a flow rate of 9 1 min^{-1} showed a change of 8.15 volts in dosemeter reading when measured 7.4 h after sampling for thoron daughters. Equation 2 leads to a concentration of 0.31 WL units which is multiplied by 3 to give the thoron daughter concentration of 0.93 WL. The filter paper was removed and counted for alpha activity after a delay of 20 hours. This data was used for calculating the thoron daughter concentration using expressions given by Stranden(3). The two values agreed within 10% of each other.

DISCUSSION

From Table 2, it is seen that there is good agreement between the working levels measured by the alpha electret dosemeter and by other methods(2,3). This close agreement between the results indicates that the assumptions made in the theory are reasonably correct. From Table 2 it is also seen that the time averaged radon daughter concentrations in Jaduguda uranium mine varies from 0.05 WL to 0.55 WL. As expected, the concentrations are higher at upper elevations since air is supplied at the bottom level and is exhausted upwards.

The advantages of using the electret dosemeter are:

(1) The sensitivity can be controlled.
(2) Being an integrating type it gives representative exposure of a worker without loss of any information.
(3) The potential alpha energy concentration is arrived at by direct measurement without any consideration of relative concentrations of daughter products, etc.
(4) It is possible to make a single measurement of equivalent radon daughter concentration without distinguishing the concentration contributions of radon and thoron daughters.
(5) The method does not require any measuring instrument (such as a charge reader) to be carried to the mine — a convenience in practice.
(6) Electrets are known to be stable against high relative humidity(8).
(7) The method has a potential of providing an inexpensive but accurate method of measuring the exposure of uranium mine/thorium workers.

The limitations of the method are the same as those described for a gamma electret dosemeter(7). These are:

(1) Electrets cannot be stored in the open because of collection of ions. They should be stored in chambers having a small gap over the electret.
(2) For measurements of low concentrations, extended over a long period, electrets have to be aged for ten days to achieve stability.
(3) If immersed in water, the information is lost.
(4) The presence of extraneous gases containing ions can affect the performance.

It should be noted that the dosemeter also responds to gamma radiation, although the response is small and can be subtracted if it is likely to be significant. A dose of 40 mrad is needed to bring about a change in dosemeter reading of 1 V for electrets of thickness 0.3 cm. Similarly a dose of about 100 mrad is needed for electrets of thickness 0.1 cm. It should also be noted that the beta radiation from radon daughters collected on the filter paper also ionises the sensitive volume of the dosemeter. It can be shown that such a contribution is negligible (<1%) compared to the ionisation caused by alpha radiation from the daughter products collected on the filter paper.

Because of the small volume of the chamber compared to the volume of air sampled, the ionisation contributed by the alpha radiation from radon gas itself is negligible. Therefore, the ionisation measured can be taken as due to alpha radiation of decay products only.

It may be pertinent to call attention to one aspect suggested in this paper, namely, that this instrument is capable of measuring the equivalent radon daughter concentration in air without any regard to whether the decay products come from radon or thoron. The procedure is justified both on theoretical grounds and on the biological model of the respiratory clearance. This method is particularly useful in measuring potential alpha energy concentrations of daughter products in dwellings where the contribution from either of the daughter products is significant.

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