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ELECTRET ION CHAMBER-BASED PASSIVE RADON–THORON DISCRIMINATIVE MONITORS

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Electret ion chambers (EICs), commercially available under brand name E-PERM®, are widely used for measuring indoor and outdoor ^{222}Rn concentrations in air. These are designed to respond only to ^{222}Rn and not to ^{220}Rn by restricting diffusional entry area. Such radon EIC (R EIC) monitors are modified by increasing the entry area to allow ^{220}Rn, in addition to ^{222}Rn. Such modified units are called RT EIC. When a set of R and RT EICs are collocated, it is possible to discriminate and measure both radon and thoron concentrations, using appropriate calibration factors (CFs) and algorithms. The EICs come in different volumes, providing different sensitivities. The thoron CFs for 58-, 210- and 960-ml volume R and RT pairs are, respectively, 2.8-, 18.7- and 89-V drop per (kBq m^{-3} d), respectively. These provide much wider sensitivities and ranges compared to alpha track-based passive radon–thoron discriminative monitors.

INTRODUCTION

Except for the radon isotopes, the decay products of naturally occurring uranium and thorium have low mobility in the environment. On the other hand, noble radon can emanate from many materials and travel significant distances before decaying. Inhalation of radon decay products are the major component of the environmental dose of most humans. Radon gas is a known human carcinogen. The USEPA reports that nearly 10 % of all lung cancer deaths in USA are attributable to radon. Monitoring and characterising radon concentrations in living spaces is an important step in controlling this preventable risk. There are two significant isotopes of radon; ^{222}Rn, which originates from decay of ^{238}U is usually simply called radon. The other, ^{220}Rn is usually called thoron as it is a decay product of ^{232}Th. There are a large number of commercially available technologies suitable for measuring radon in air. Popular among these are passive radon monitors based on activated carbon absorption, electret ion chambers (EICs), alpha track detectors and electronic radon monitors. In most living spaces, radon contributes more to the dose than thoron as it has a much longer half-life (3.8 d) compared to thoron (1 min). However, at certain locations having high thorium content in soil and building materials, thoron can also be a problem[(1)]. Few passive technologies are available for measuring thoron. Recently, alpha track-based passive radon–thoron discriminative monitor was developed and standardised by Tokonami *et al.*[(2)] in Japan. Commercial version based on this development is also available[(1)] (RADUET). The present work describes new developments that extend the utility of popular, commercially available EIC technology to functioning as a passive technology has several advantages. The sensitivity can be selected to match the application by using chambers of different volumes and electrets of different thicknesses[(3)]. The current work investigates three different volumes (58, 210 and 960 ml) and electrets with one thickness of 1.524 mm. Other advantages include rapid readout without the need to process the sensor chemically or microscopically analyse it. The EIC method has been shown to work at low/high temperatures and low/high humidity[(3–5)]. This new development will benefit thousands of radon measurement companies that can now use EIC system to measure thoron as well as radon.

ELECTRET ION CHAMBERS

The EIC and the associated equipments are commercially available under the brand name E-PERM®. These passive devices are widely used for measuring indoor and outdoor radon concentrations. These are integrating ionisation chambers wherein the electret (a charged piece of Teflon Disc) serves both as a source of electrostatic field and as a sensor. The EIC consists of an electret mounted inside a chamber made of electrically conducting plastic. The ions produced inside the air volume of the chamber are collected by the electret causing a decrease of charge on the electret depending upon the chamber volume, the radon concentration and the exposure period. The change in charge is measured using a portable non-contact, electret voltage reader. Using appropriate calibration factors (CFs) relating change in charge to the radon concentration and the exposure time, it is possible to calculate radon concentration in air. A system consisting of electrets, electret voltage reader and appropriate algorithms is commercially available[3]. The EICs come in different volumes (58, 210 and 960 ml) and electrets come in two sensitivities. By selecting the proper combination of EIC and electret, radon measurements from 1 d to 1 year can be made indoors and outdoors. Radon diffuses passively through a filtered area that not only stops the radon progeny from outside air but also restricts the entry of thoron. Because the entry area is small, most thoron decays before reaching the sensitive volume. These are essentially radon monitors with negligible response to thoron. The method of calibration and their use for calculating radon concentration is fully described by Kotrappa *et al.*[3]. The CF is defined in units of volts drop per (Bq m^{-3} d). Electret discharge is simply divided by CF and further divided by exposure days to calculate radon concentration in units of Bq m^{-3}. The CF is not constant over the useful range electret voltages (200–750 V) as a result of changes in the uniformity and collection efficiency of the electric field over the useful range. Therefore, two electret voltage readings are taken for a measurement; the initial and the final voltage. The CF is related to the mid-point voltage (MPV) which is simply the average of initial and final electret voltage reading.

$$\mathrm{CF} = A + B \times \mathrm{MPV} \tag{1}$$

where A and B are experimentally determined constants, unique to specific combination of chamber and electret type. Radon concentration is calculated using Equation (2).

$$\mathrm{Rn} = \frac{(I - J)}{\mathrm{CF} \times D} - \mathrm{BG} \tag{2}$$

where I and J are the initial and final voltages of electret, CF the calibration factor for specific EIC, D the exposure period in days and BG the radon concentration equivalent of the gamma radiation. These detectors have been evaluated independently by many investigators[2, 4, 5]. These are known to perform well in low high temperatures and humidity usually found in indoor and outdoor environments.

ELECTRET ION CHAMBERS FOR THORON

One of the standard methods to enhance the thoron response of the EIC is to increase the diffusion area, relative to an EIC designed to measure only radon. This method has already been used in a radon–thoron discriminative detector reported by several investigators[1, 2]. The modified EIC is called as RT EIC, since it responds to both radon and thoron. Figure 1 gives a schematic of 210-ml volume RT EIC. Figure 2 gives schematic of 58-ml RT EIC. Figure 3 gives schematic of 960-ml RT EIC.

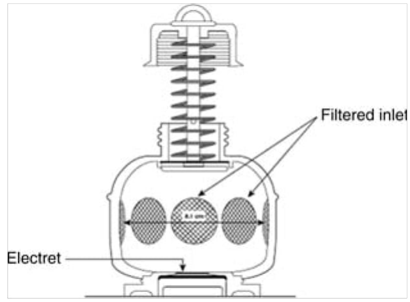

Figure 1. 210-ml RT electret ion chamber.

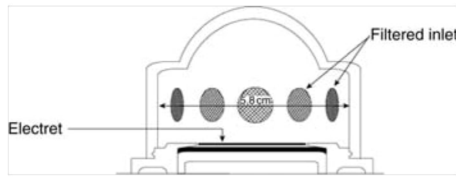

Figure 2. 58-ml RT electret ion chamber.

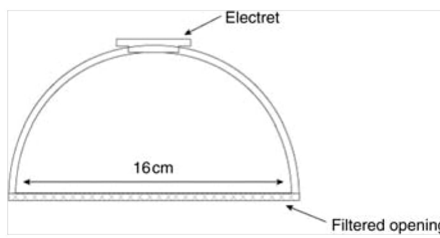

Figure 3. 960-ml RT electret ion chamber.

Respective radon (R) chambers do not have such filtered openings. The openings are covered with carbon-coated Tyvek™ sheet, which is known to be transparent to water vapour and radon. The 58-ml RT chamber has 12 openings of 1 cm diameter, the 210-ml RT chamber has 11 openings of 1.8 cm diameter and 960-ml RT chamber has one large opening of 16 cm diameter. All openings are covered with 0.06-mm thick carbon-coated Tyvek™ (Figures 1–4).

MATERIALS AND METHODS

Commercially available EIC (E-PERM®) components are used in this work. The electret reader used is commercially available electret reader (SPER1A). These components and their use for measuring radon are fully described by Kotrappa *et al.*[3]. It may be noted that 210-ml R and RT chambers have on/off mechanism to enable these to be shipped for reading, if necessary. The initial calibration of 210-ml R and RT combination was done

Figure 4. 58-, 210- and 960-ml R and RT pairs.

at thoron test facility located at CANMET, Elliot Lake laboratory, Mining Research Laboratory, Elliot Lake, Canada. The scintillation cell was used for standardisation and Pylon ^{228}Th was used as thoron gas generator. Both R and RT were fully described elsewhere[6]. R and RT EICs of different voltages are exposed to known thoron concentration for known period of time. The differential response is uniquely related to thoron concentration as given in Equation (2). Equation (3) gives the equation to calculate CF. R chamber responds to radon and ambient gamma radiation. RT chambers respond to thoron, radon and ambient gamma radiation. The differential response is uniquely related to thoron concentration as given in Equation (3).

$$\text{Tn} = \frac{(I - J) - (K - L)}{\text{CF} \times D} \qquad (3)$$

where I and J are the initial and final electret voltages of RT monitor, K and L the initial and final electret voltages of R monitor, D the exposure period in days, Tn the thoron concentration in units of kBq m^{-3} and CF the calibration factor in units of volt drop per (kBq m^{-3} d).

The CF can be calculated using Equation (3), since all the parameters are known except CF. The CF and MPV results are correlated by regression analysis, to arrive at the calibration equation as a function of MPV. This method is also similar to that used for radon[3], for arriving at such equation for radon. The current calibration is essentially similar to the one described by Kotrappa *et al.*[6] for 210-ml R and RT combinations, but uses a 40-l exposure chamber supplied with thoron from an external source using gas mantles. A fan inside the chamber and an external circulating pump insures uniform thoron concentrations within the chamber. A desiccant module in the external source circulating system insured stable and low humidity needed by the thoron monitor. An electronic radon/thoron discriminating monitor based on alpha spectroscopy (Niton RAD7) is used as the reference device for thoron concentrations. The RAD7, used as a reference device by many researchers, is connected directly to the chamber with short tubes to insure little thoron loss during monitoring. The thoron concentration in the chamber proved to be quite constant over exposure periods of several days.

Equation for CF as a function of MPV

It is well known that CF for an EIC varies with the MPV. In any random measurement, the MPV may be different from the MPV at which calibration is done. It is important to derive an equation that relates the CF to MPV. Such relationships are unique to the type of chamber used. Table 1 gives the experimentally determined CFs for different R and RT combinations of EIC chambers as a function of MPVs. Last column gives the CF for MPV of 500 V and can be taken as average CF for respective chamber volumes. On the assumption that a 20-V drop is measurable with an uncertainty of about 10%, the respective measured concentrations may be considered as the sensitivity. Table 2 gives the calculated sensitivities. These are arrived at by dividing 20 V by respective CF and further by the stated number of days. Electrets are recommended to be used between 200 and 750 V for functioning as true ionisation chambers. This range of 550 V is considered as dynamic range. Dynamic range is obtained by dividing 550 by CF. Calculated dynamic ranges are given in column 4 of Table 2. This means that a fully charged electret used with 58-ml chamber can measure at the most 200 kBq m^{-3} d. In other words, concentration as high as 550 Bq m^{-3} is measurable over 1 year.

Table 1. Equations for CFs for R and RT EICs of different volumes.

Chamber volumes (ml)	Equations for CFs	Average CF
58	2.6618+0.00009×MPV	2.8
210	15.9828+0.00548×MPV	18.7
960	76.0302+0.0257×MPV	88.9

CF is in units of volts drop per (kBq m^{-3} d).

Table 2. Calculated average sensitivities and dynamic ranges for different R and RT EICs.

Chamber volumes (ml)	Sensitivity for 1 d measurement kBq m^{-3}	Sensitivity for 7 d measurement kBq m^{-3}	Dynamic range
58	7.1	1.00	196
210	1.1	16	29
960	0.22	0.032	6

Dynamic range in units of kBq m^{-3} d.

Equation for CF as a function of MPV

If I and J are initial and final electret voltages of RT EIC and K and L are the initial and final voltages of R EIC, Equation (4) is used for calculating the thoron concentration

$$\mathrm{Tn} = \frac{(I - J)}{\mathrm{CF}(I, J) \times D} - \frac{(K - L)}{\mathrm{CF}(K, L) \times D} \quad (4)$$

where CF(I, J) is the CF corresponding to the initial I and final F electret voltages and D is the exposure period in days. The analysis of paired EICs leads to correct thoron concentrations irrespective of the presence of radon, because the signal from radon and gamma radiation is subtracted.

Mixture of radon and thoron

As pointed out in the previous section, thoron concentrations calculated using Equation (4) is correct irrespective of the presence of radon. The assumption that R EICs responds only to radon and not for thoron is not completely correct and a correction for thoron needs to be made for accurate radon determination using the R chambers. The thoron response can be measured in a pure thoron atmosphere using the procedure similar to that used in the present work. Kotrappa *et al.*[6] found the response to be about 2–4 % for 210-ml R EIC, relative to radon. Sorimachi *et al.*[5] found it to be about 2.5 % when exposed in the NIRS thoron test chamber in Japan. Thoron-corrected radon concentration is calculated using Equation (5), assuming the relative response is 3 %. Rn measured is the radon concentration as measured by standard procedure for an R EIC and Rn corrected is the thoron-corrected radon concentration using the Tn measured by an RT EIC. This procedure will make a significant difference when measuring radon in a high thoron environment.

$$\mathrm{Rn\ corrected} = \mathrm{Rn\ measured} - (0.03 \times \mathrm{Tn}) \quad (5)$$

DISCUSSION

The principle of discriminative radon–thoron monitor is the same whether one uses alpha track detector (AT) technology or EIC technology. Because of ease in measurement of short-term or long-term radon measurement, this is currently one of the most used technologies in USA for indoor radon measurement, whereas AT is used mainly for long-term measurement. Table 1 gives average CFs. The most sensitive R and RT combinations have CF of 88.0. This means such a combination gives a voltage drop of 88.8 V for 1 kBq m^{-3} in 1 d. From Table 2, the most sensitive combination can measure the thoron concentration as low as 32 Bq m^{-3} in 7 d.

Radon measurement companies using EIC system can easily adopt this method to extend their services.

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