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Performance Characteristics of Different Passive Detectors in a Radon Chamber

Key Words
Radon chambers
Plastic bag radon sampler
Envelope-type radon monitor
Permeability of polyethylene
Sensitivity coefficient
Relative humidity

Abstract

The performance characteristics of two types of passive radon monitors were studied by exposing them in the Paul Scherrer Institute radon chamber at 20 °C and a relative humidity of ~50% to three different radon levels of approximately 40, 450 and 900 kBq h m^{-3}, respectively. The monitors were a plastic bag radon sampler and an envelope-type radon sampler. The agreement between the radon concentrations measured by these two monitors with those of the Lucas cell of the chamber monitoring system was within the statistical error of ±20%. The experiment carried out at 20 °C and a relative humidity of ~90% with the radon exposure level of ~450 kBq h m^{-3} showed no appreciable decrease in the measured radon concentration compared with that of the Lucas cell.

Introduction

Measurement of radon and radon progeny have attracted much attention since the early 1980s. The variety of instruments for indoor and outdoor radon measurement may be divided into two broad groups; active and passive systems. Solid-state nuclear track detectors have proved to be very successful tools in performing radon measurements [1]. Their main characteristics include the ability to integrate over a long period of time (up to 1 year), with no need of an external power supply during sampling; the sampler is easy to activate and inactivate, and there is the possibility of storage for a long time after sampling, with the automatic reading of tracks and a low cost. These detectors have also been used successfully for screening surveys and short-term exposure periods as short as 1 week [2]. The present paper describes the performance characteristics of two types of passive radon monitors in the newly constructed radon chamber at the Paul Scherrer Institute (PSI).

Materials and Methods

The two types of radon samplers used in this study were the plastic bag and envelope-type monitors.

Plastic Bag Radon Monitor

The plastic bag radon monitor [3] consisted of a plastic right-angle prism (base 26 mm × 35 mm, height 12 mm) as shown schematically in figure 1. The cylindrical cavity (diameter 24 mm) inside

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the prism provided the diffusion chamber with a volume of ~5.43 cm³ and base area of ~4.52 cm², which constituted the exposed area for each detector. Two narrow slits, each about 1 mm wide, on the cylinder wall allowed diffusion of radon into the chamber. The two LR-115 Type II track detectors, which were separated by a distance of 12 mm, were kept in place with two rectangular covers (28 mm × 38 mm). An aluminized polycarbonate (Maylar) foil (20 μm) was used on both sides of the detectors to make their surfaces conductive, so as to remove any electric fields due to static charges (fig. 2) and to degrade the α energy to ~4 MeV, which is the upper energy detection limit for the LR-115. The device was enclosed in a heat-sealed plastic bag (8 cm × 12 cm). The polyethylene bag (40 μm thick) provided low permeability to water vapour but sufficiently high permeability to radon. Consequently, the device permits a fast sampling time, is of small size and low cost, and suffers no deformation in very cold weather. The permeability of polyethylene to radon gas for different membrane thicknesses is shown in table 1, and the main characteristics of the cup-type and plastic bag radon samplers are compared in table 2.

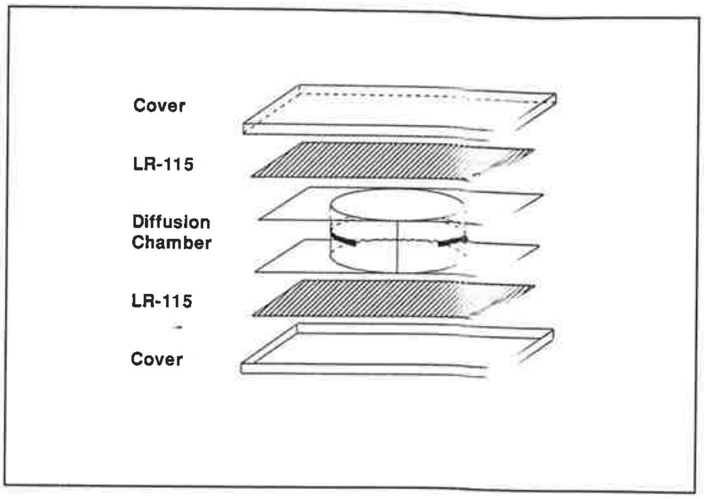

Fig. 1. Schematic view of the plastic bag radon sampler.

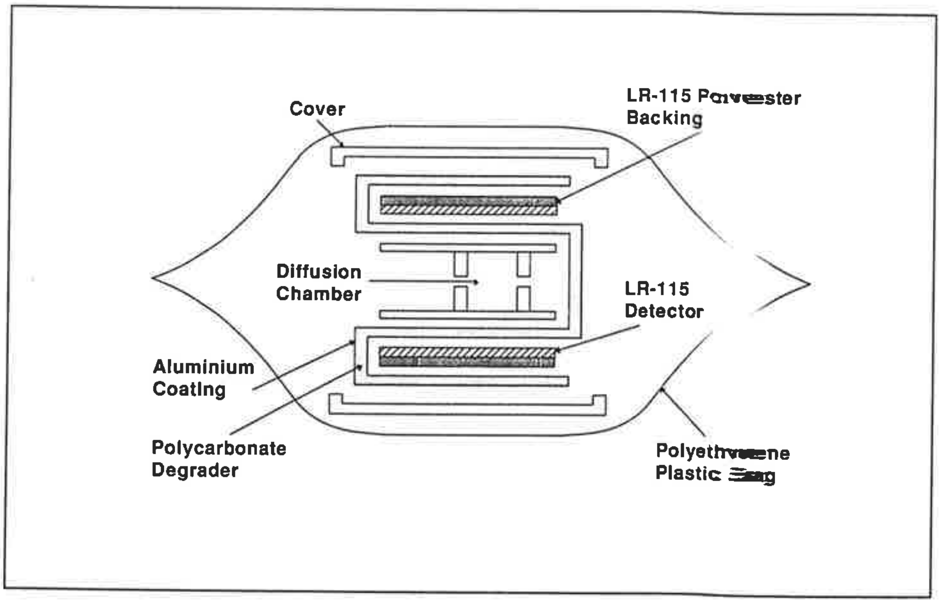

Fig. 2. Cross-section of the plastic bag radon sampler.

Table 1. Permeability of polyethylene membrane to radon gas

Thickness μm	Permeability 10^{-8} cm² s⁻¹	Reference
25	0.335	4
70	7.8	5
50	5.5	6
100	3.35	7

Table 2. Main characteristics of some radon samplers

Radon sampler	Volume cm³	Polyethylene thickness, μm	Permeation time τ_M	Reference
Terradex type	292	15	2.6 days	6
Karlsruhe type	144	100	50 min	7
Plastic bag	25	40	5 h[a]	this work

[a] Assuming the permeability of 5.5×10^{-8} cm² s⁻¹.

Table 3. Sensitivity coefficients of the bare LR-115 track detector

Etching conditions	Counting system	Sensitivity coefficient[1]	Reference
2.5 *N* NaOH, 60 °C, 170 min	microfiche reader	2.08	14
2.5 *N* NaOH, 60 °C, 70 min	microscope	2.26	15
2.5 *N* NaOH, 60 °C, 140 min	spark counter	1.3	16
2.5 *N* NaOH, 60 °C, 140 min	image analyser	2.16	17
2.5 *N* NaOH, 60 °C, 120 min	microscope	1.19	18
2.5 *N* NaOH, 60 °C, 110 min	image analyser	2.03	this work

[1] Tracks cm^{-2} per kBq h m^{-3}.

Table 4. Comparison of radon concentrations measured by three different monitors

Run No.	Temperature °C	Relative humidity %	Exposure period h	Radon concentration ± SD, Bq m^{-3}		
				Lucas cell	plastic bag	envelope-type
1	20 ± 1	51 ± 4	72	510 ± 41	-	514 ± 97
2	20 ± 1	44 ± 4	72	6,311 ± 462	5,805 ± 292	4,958 ± 1,014
3	20 ± 1	43 ± 4	72	12,467 ± 769	7,972 ± 889	7,847 ± 1,000
4	20 ± 1	52 ± 5	24	5,753 ± 337	-	4,125 ± 875
5	20 ± 1	89 ± 2	24	5,595 ± 199	-	4,042 ± 167

The principle on which the operation of the plastic bag radon monitor is based is the separation of ^{222}Rn (half-life 3.8 days) from ^{220}Rn (half-life 56 s) by a membrane, which acts as a diffusional barrier. The radon concentration inside the plastic bag (C) is the sum of the production rate due to permeation and the decay rate, and is given by the following equation [8]:

$$dC/dt = (kA/\delta V)\,[C_o - C] - \lambda C, \tag{1}$$

where λ is the decay constant of ^{222}Rn and C_o is its concentration outside the bag, *k* is the membrane permeability, and A, V, and δ are the area, volume and thickness of the membrane, respectively. If the mean permeation time is τ_M, and the ^{222}Rn mean decay time is τ_R, then the solution of (1) is in the form of:

$$C = C_o\,[\tau/\tau_M]\,[1 - e^{-t/\tau}], \tag{2}$$

where τ, the effective mean life time of ^{222}Rn inside the bag, is given by:

$$1/\tau = 1/\tau_M + 1/\tau_R, \tag{3}$$

where

$$\tau_M = \delta V/kA, \qquad \tau_R = 1/\lambda. \tag{4}$$

As can be seen from table 2, in the plastic bag radon sampler, the mean permeation time, τ_M, which depends on the type and dimensions of the membrane, is much smaller than the ^{222}Rn mean decay time, τ_R, then,

$$\tau \approx \tau_M, \tag{5}$$

and, therefore, the radon build-up concentration inside the bag is:

$$C = C_o\,[1 - e^{-t/\tau_M}]. \tag{6}$$

Thus for the exposure time $t_o \gg \tau_M$, the radon concentration inside the bag is equal to that of the outside, $C \approx C_o$. As the radon decays according to the relation

$$C = C_o\,e^{-t/\tau_R}, \tag{7}$$

if sufficient time is allowed for the ^{222}Rn to decay before opening the plastic bag, then the number of α particles registered at the end of the waiting time corresponds to C_o at the end of the exposure time t_o. It can easily be shown that even when $t_o < \tau_M$, the situation is similar [9]. The plastic bag radon monitors can then be kept in heat-sealed anti-radon packing made of plastic-coated aluminium foil, and the act of opening the packing begins the exposure.

Envelope-Type Radon Monitor

The envelope-type radon monitor is a passive dosemeter, and its principle of operation is based on the exposure of bare track detector material in air. The detector, therefore registers the α particles emitting both from the decay of ^{222}Rn and the decay products of ^{214}Po and ^{218}Po. The commercially available LR-115 Type II damage track detectors with the area of 9 cm × 12 cm were used in this radon monitor (see fig. 1 on page 356 of this issue). When the envelope is closed, the strippable LR-115 detector does not register any α-particle activity and the monitor is in the 'off' state. When the envelope is opened, only half of the LR-115 sheet is exposed to the ambient air:

the second half of the detector is protected by an aluminium foil and is used for the sheet background estimate.

It has been shown [10] that the track registration efficiency or sensitivity of the exposed LR-115 to radon gas, ε is a function of equilibrium factor F, and may be expressed as:

$$\varepsilon = 0.0444\ F^{0.0877}, \qquad (8)$$

where ε is in tracks mm^{-2} per (100 pCi Rn) h $litre^{-1}$. If follows that when the equilibrium factor is increased by one order of magnitude, the increase in the LR-115 sensitivity is about 22%. When the LR-115 detectors were exposed in the National Radiological Protection Board (NRPB) radon chamber [11], it was shown to be in agreement with this expression. However, a high dependence of the calibration coefficient (which is the reciprocal of sensitivity) on the equilibrium factor has recently been reported [12]. It has been shown that the calibration coefficient is decreased by ~ 47% when the equilibrium factor is increased by one order of magnitude. Nevertheless, it may be assumed that within experimental limits, the LR-115 material has the same efficiency for radon gas and radon daughter products.

Results

The plastic bag and envelope-type radon monitors were exposed in the newly constructed radon chamber at the PSI [13] as part of an intercomparison of several active and passive radon detectors [Schuler, Ch., PSI, 1991, pers. commun.]. The irradiations were performed at three different radon levels of approximately 500, 6,000 and 12,000 Bq m^{-3} at 20 °C with the relative humidity of ~ 50%. One experiment was also carried out with the relative humidity of ~90% at 20 °C for the radon concentration of ~ 6,000 Bq m^{-3}. At each concentration, 2 plastic bag and 4 envelope-type radon monitors were exposed, and the average radon concentration was obtained. The radon concentration measured by the Lucas cell of the chamber monitoring system was taken as the reference.

At the end of the exposure periods, the LR-115 sheets were chemically etched in the 2.5 *N* NaOH solution at 60 °C for 110 min. The LR-115 foils from the plastic bag monitors were counted by a spark counter with the electrode diameter of 19 mm, while those of the envelope-type which had larger exposed areas were counted by the Quantimet image analyser. The radon concentrations were calculated using the sensitivity coefficients of $\varepsilon = 0.73 \pm 0.19$ tracks cm^{-2} per kBq h m^{-3} and $\varepsilon = 2.03 \pm 0.07$ tracks cm^{-2} per kBq h m^{-3} for plastic bag and envelope-type radon monitors, respectively. These coefficients have been determined previously by exposures in a radon calibration chamber [2, 3]. The sensitivity coefficients of the exposed LR-115 detectors reported by others [14–18] are similar to the present value, despite different etching and counting procedures, as shown in table 3.

The results of the radon concentration measured by plastic bag and envelope-type monitors and the Lucas cell are shown in table 4. The quoted standard deviations are the random sampling errors only. The values for the Lucas cell are the mean of the daily readings.

Discussion

The results show that at the radon levels of 500 and 6,000 Bq m^{-3}, the agreement between the radon concentrations measured by the plastic bag and envelope-type radon samplers and those of the Lucas cell is to within the statistical error of ± 20%. When the radon concentration was increased from ~ 500 to ~ 12,000 Bq m^{-3}, there was a decrease of about 30% in the relative concentration to the Lucas cell. This decrease probably results from high track densities, whereby, if two tracks are very close to each other, they are counted as one feature by the counting system.

Moisture could be a major source of error in radon concentration measurements: as temperature drops, the droplets of water vapour can block the α particles and cause lower track densities. This effect was studied by exposing the envelope-type monitor in the radon chamber when the relative humidity was ~90% at 20 °C. The Lucas cell of the chamber monitoring system has a dehumidifier, and, therefore, its measurements are not affected by the humidity in the chamber. The results of these experiments showed no appreciable decrease in the radon concentrations measured with the envelope-type detectors relative to the values obtained when the relative humidity was ~ 50%. It is likely that this result was seen because there was no condensation at 20 °C.

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