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Deposition fractions of ^{218}Po in diffusion chambers

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Abstract

After radon gas diffuses into a diffusion chamber, ^{218}Po will be formed. Due to its short half-life, a fraction f of ^{218}Po decays before deposition onto available inner surfaces of the chamber, and the deposition fraction $(1-f)$ represents the part which decays after deposition. In the present work, f has been experimentally determined for six diffusion chambers with different materials and dimensions using the radial distribution of track density on the LR115 detectors inside the diffusion chambers. For all the six studied diffusion chambers, f was found to be ~ 0.4. Therefore, the deposition fraction does not depend on the shape and dimensions of the diffusion chambers, the surface to volume ratios or the internal surface materials of the diffusion chambers.

Keywords: Natural radioactivity; Radon; LR115 detector; Detector sensitivity

1. Introduction

One of the most common techniques to measure the concentration of radon (^{222}Rn) in air is to use solid state nuclear track detectors (SSNTDs). In practice, a piece of SSNTD, such as the CR39 or LR115 detector, is placed on the bottom of a diffusion chamber, which is covered at the top with a filter paper to stop radon progeny from getting inside.

After ^{222}Rn diffuses into the chamber, it will decay to form ^{218}Po. Due to its short half-life (3.05 min), a fraction f of ^{218}Po is expected to decay before deposition onto available inner surfaces of the chamber, and the deposition fraction $(1—f)$ represents the part which decays after deposition.

The progeny decaying in air and those decaying whilst deposited on the inner surfaces have different irradiation geometries to the SSNTD on the bottom. Therefore, the behavior of ^{218}Po inside the diffusion chamber is an important factor affecting the sensitivity of SSNTDs to radon. On the contrary, the progeny preceding the second alpha emitting progeny, ^{214}Po, have much longer half lives, so ^{214}Po can be considered to be completely deposited before decaying.

There have been very few attempts to determine f. McLaughlin and Fitzgerald (1994) applied Jacobi's model for radon progeny in the diffusion chamber and obtained $f \sim 0$. Nikezic et al. (1993) experimentally identified a sensitivity peak at a particular radial distance on the LR115 detector placed inside a diffusion chamber, which they attributed to the deposited ^{218}Po. By comparing the theoretical and experimental peak heights at this radial distance, they estimated $f \sim 0.4$.

More recently, based on the dependence of the radial distribution of track density on the SSNTD on the partitioning between the radon progeny in the air volume and those on the inner surfaces of the diffusion chamber (Nikezic and Yu, 1999), Koo et al. (2002) proposed procedures to experimentally determine the value of f. The objective of the present work is to study the possible effects on f of the materials and dimensions used for the inner surfaces of the diffusion chambers. The LR115 detector was adopted in this work because it was not affected by the plate-out effect, i.e., the effect

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caused by radon progeny depositing onto the detector itself.

2. Methodology

Six different diffusion chambers (A–F) have been employed in the present study (see Table 1 for the description on the materials and dimensions, with R_1 as the bottom radius, R_2 the top radius and H is the height). The chambers can be broadly divided into two groups according to the shape: chambers A–C are cylindrical or very close to cylindrical, i.e., $R_1 \approx R_2$, while chambers D–F are conical. Among the cylindrical chambers, we have two plastic chambers A and B, with the dimensions of B approximately scaled up from those of A. The inner surface of chamber C is coated with tin foil. Among the conical chambers, chamber D is a commercial radon diffusion chamber. Chambers E and F were fabricated in our own laboratory with dimensions close to those of chamber D, but made of acrylic resin and aluminum, respectively. With these features of chambers, we can identify effects on f due to the shapes, sizes, surface to volume ratios and materials of the chambers. As a comparison, the diffusion chamber employed as an example in a previous study (Koo et al., 2002) was also conical but with a much larger height, with $R_1 = 2.35$ cm, $R_2 = 3.75$ cm and $H = 8$ cm.

The information relevant to the determination of f in the diffusion chambers in the present work is the radial distribution of sensitivity from the center of the detector. The idea is to compare the theoretical curves and the experimental data for the radial track densities. This involves two main steps, and the procedures follow those proposed by Koo et al. (2002).

The first step aims to experimentally determine the track density distributions on the LR115 detectors. A circular LR115 detector was placed to cover the entire bottom of each chamber. The LR115 films were purchased from DOSIRAD (Type 2, Non-Strippable, 12 μm red cellulose nitrate on a 100 μm clear polyester base, Catalog number 500 9535). The top of each diffusion chamber was covered by a piece of filter paper.

In order to show clearly the effects, if any, from the materials and dimensions for the inner surfaces of the diffusion chambers, we had to eliminate possible effects from inter-exposure and inter-etching variations. Therefore, all the six diffusion chambers were simultaneously exposed in an exposure chamber (Yu et al., 2002) with a ^{222}Rn exposure of 260900 ± 2200 Bq m^{-3} h. The conditions inside the exposure chamber were: temperature = 20°C, relative humidity = 83% and pressure = 1007 hPa.

After exposure, the LR115 detectors were simultaneously etched in a 10% aqueous solution of NaOH at temperature of 60°C until the thickness of the removed layers were 6.7 μm. A transparent template with concentric circles was used to measure the radial track density on the LR115 detector under the optical microscope (Koo et al., 2002). The distance between adjacent concentric circles is 1 mm. The circular LR115 detector was placed on top of the template in such a way that the center of the detector coincided with the center of the concentric circles, and they were then affixed to a movable stage attached to the optical microscope. By moving the stage, one can scan the complete area in a particular stripe (area between two concentric circles) visually without interruption. The total number of tracks in the stripe was counted. For stripes with small radius, the total numbers of counts were small due to the small areas of the stripes. To improve the statistics, the numbers of tracks were counted and combined for every two stripes.

For standardization, only the tracks that completely perforated the sensitive layer of the detector during etching were taken into account. By dividing the number of tracks by the radon exposure, the track density (in m) at a particular radial distance from the center can be determined.

The second step generates expected track densities on the LR115 detectors at different radial distances from the center for the chambers through Monte Carlo calculations (Nikezic and Baixeras, 1995; Nikezic and Yu, 1999; Koo et al., 2002). The basic idea is that ^{218}Po

Table 1
Materials and dimensions for the inner surfaces of the diffusion chambers

Chamber	A	B	C	D	E	F
Material	Plastic	Plastic	Tin foil	Plastic	Acrylic	Al
R_1 (cm)	2.9	3.7	3.65	2.35	2.5	2.5
R_2 (cm)	3.1	3.9	3.65	3.3	3	3
H (cm)	8.3	10.2	7.6	4.8	5	5
SV ratio (cm^{-1})	0.9	0.7	1.2	1.1	1.1	1.1

R_1: bottom radius; R_2: top radius; H: height. Also shown are the ratios (SV ratios) between the total internal surface areas and the volumes of the diffusion chambers.

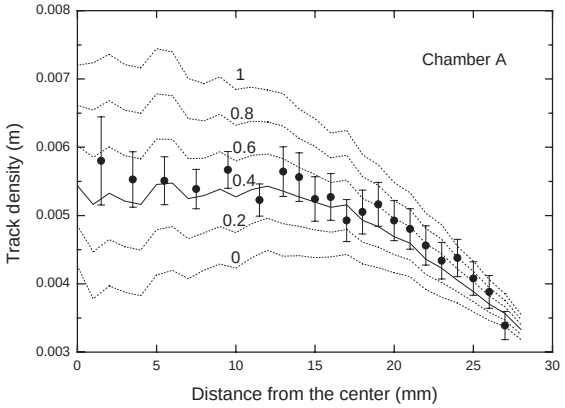

Fig. 1. Experimental data (error bars represent ± 1 SD) together with a set of Monte Carlo curves (with different f values as shown) for the radial distribution of track densities for chamber A. The percentage uncertainty for the values given by the Monte Carlo method are 1%, and are negligible compared with the errors of the experimental data. The curve for $f = 0.4$ (in bold) is the best fit to the experimental data.

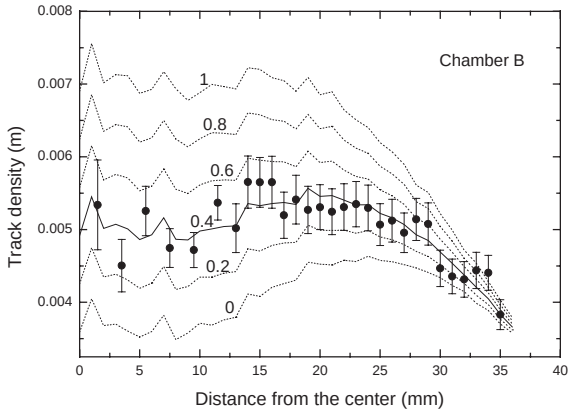

Fig. 2. Same as Fig. 1, but for chamber B.

in air and ^{218}Po deposited on inner surfaces have different irradiation geometries and thus different sensitivities for the LR115 detector on the bottom of the diffusion chamber. This property leads to differences among the curves for different values of f and enables the determination of f. The differences are more prominent for tall diffusion chambers (Nikezic and Yu, 1999). Diffusion chambers which are too thin and too short, e.g., $R_1 = R_2 = H = 2$ cm, are not sensitive to f and are thus unsuitable for the determination of f.

Again, for the Monte Carlo simulations, the circular detector surface was divided into circular stripes with widths of 1 mm bounded by concentric circles. The numbers of alpha particles hitting different circular stripes were determined to deduce the radial distribution

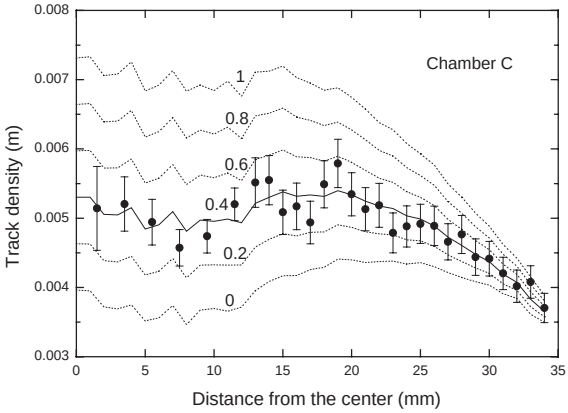

Fig. 3. Same as Fig. 1, but for chamber C.

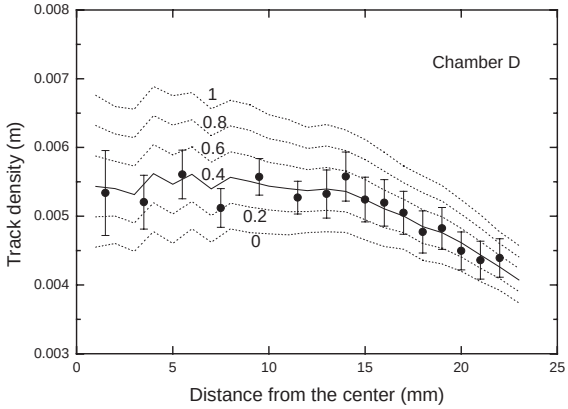

Fig. 4. Same as Fig. 1, but for chamber D.

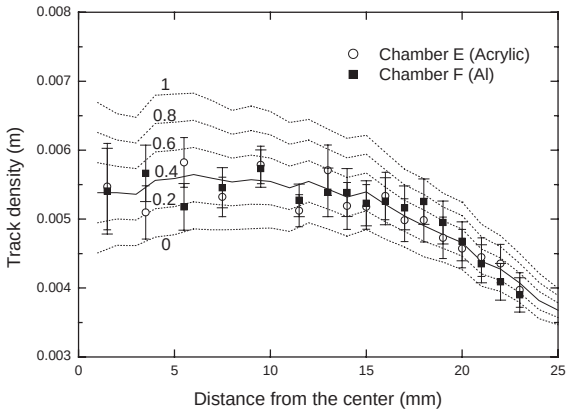

Fig. 5. Same as Fig. 1, but for chambers E and F.

of sensitivity. In order to match the experimental conditions, the calculations were made for a removed layer of 6.7 μm of LR115 detector after etching, and

only the tracks that completely perforated the sensitive layer of the detector during etching were taken into account.

3. Results and discussions

The experimental data together with sets of curves (with different f values) generated from Monte Carlo simulations are shown in Figs. 1–4 for chambers A–D, respectively, and in Fig. 5 for chambers E and F. For the Monte Carlo simulations, the uppermost curve is for $f = 1$ (i.e., all ^{218}Po atoms decay in air before deposition), while the lowest curve is for $f = 0$ (i.e., all ^{218}Po atoms decay after deposition on the inner surfaces). It can be observed that the pattern of the radial distributions of track densities obtained experimentally and those from Monte Carlo calculations agree very satisfactorily with each other for all the chambers. These good agreements give strong support to both the Monte Carlo technique (Nikezic and Yu, 1999; Nikezic and Baixeras, 1995) and the present experimental methodology for the determination of the track densities.

The theoretical curve best fitting the experimental data was determined by minimizing the quantity $C = \sum(E_i - O_i)^2/\sigma_i^2$, where E_i is the experimental track density measured at the ith distance from the center with a corresponding uncertainty of σ_i, while O_i is the value on a particular Monte Carlo curve at the same ith distance from the center. Interestingly, the best f values were found to be 0.4 for all six cases. Therefore, the deposition fraction does not depend on the shape and dimensions of the diffusion chambers, or on the materials of the internal surface of the diffusion chambers. The f values obtained in the present work also coincide with the previous value of 0.4 (Koo et al., 2002) obtained for another conical plastic chamber using the current methodology.

The result that $f = 0.4$ is in contrast to the finding of McLaughlin and Fitzgerald (1994), by using the Jacobi's model for the progeny in the diffusion chamber, that $f \sim 0$. On the other hand, although Nikezic et al. (1993) only used the sensitivity peak in the LR115 detector at a radial distance of 1.9 cm from the center, their estimated fraction f of 0.4 coincides with the present result. Apparently, the experimental results are not adequately modeled by the theoretical approach of McLaughlin and Fitzgerald (1994). It is also noted that using the entire radial distribution of track densities to infer f is more reliable and desirable than using the track density at a single radial distance.

In Table 1, we have also shown the ratios (SV ratios) between the total internal surface areas and the volumes of the diffusion chambers. The SV ratios range from 0.7 (chamber B) to 1.2 (chamber C). When the SV ratio increases, the surface available for deposition of ^{218}Po will also increase. The result that f does not vary with the SV ratio shows that the available surface is not a limiting factor for ^{218}Po deposition under normal circumstances.

In this work, the aerosol concentrations have not been monitored; these concentrations may affect the deposition behavior of ^{218}Po inside the diffusion chambers, but detailed information regarding the influence of this parameter on f is still unknown. Its possible effects will be studied in future works.

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