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Experimental study of track density distribution on LR115 detector and deposition fraction of ^{218}Po in diffusion chamber

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Abstract

The radial distribution of track density on a solid-state nuclear track detector inside a diffusion chamber is a function of the fraction f of ^{218}Po decay before deposition. In the present work, procedures are proposed to determine f experimentally by determining the track density distribution on an LR115 detector in a diffusion chamber. First, a relatively tall diffusion chamber, with a height of 8 cm, was chosen. After exposure, the LR115 detector was etched. A transparent template with concentric circles was devised to study the radial distribution of sensitivity using an optical microscope. The distributions according to different values of f were also calculated using Monte Carlo simulations. By minimizing the deviations between these Monte Carlo curves and the experimental data, f was found to be 0.4.

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

1. Introduction

The concentration of radon (^{222}Rn) in air is often measured with solid-state nuclear track detectors (SSNTDs). The detectors are usually placed on the bottom of a cup called a diffusion chamber, which is covered with a filter paper on the top. While radon progeny are stopped by the filter, radon gas is free to diffuse through the filter into the chamber. After entering the chamber, radon atoms will decay and the freshly formed progeny atoms can deposit onto available inner surfaces of the chamber. The progeny decaying in air and those decaying on the inner surfaces have different irradiation geometry to the detector so the radial distribution of track density will depend on the partitioning between the radon progeny in the air volume and those on the inner surfaces of the diffusion chamber.

The first radon progeny ^{218}Po has a relatively short half-life (3.05 min) and it can decay before or after deposition. On the other hand, the second alpha emitting progeny ^{214}Po can be considered as completely deposited. Therefore, the main

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uncertainty arises from the unknown behavior of ^{218}Po inside the chamber.

There were some previous attempts to determine the behavior of ^{218}Po inside the diffusion chamber. McLaughlin and Fitzgerald [1] applied the Jacobi's model for the progeny in the diffusion chamber and obtained almost total deposition of ^{218}Po. Nikezić et al. [2] made the first experimental attempt to find the percentage of ^{218}Po decayed before deposition. For their diffusion chamber (bottom radius = 2.6 cm, top radius = 3.4 cm, height = 8.4 cm), they identified a sensitivity peak at a radial distance of 1.9 cm on the LR115 detector placed on the bottom, which they attributed to the deposited ^{218}Po. By comparing the peak heights at the radial distance of 1.9 cm determined theoretically and experimentally, they estimated the fraction f of ^{218}Po decay before deposition to be 0.4. More recently, Nikezić and Yu [3] investigated through Monte Carlo simulations the deposition behavior of ^{218}Po from track density distribution on the LR115 detector in different diffusion chambers. They found the radial track density distribution and the detector sensitivity were variable for different detector sizes, and estimated the uncertainty in radon measurements due to unknown f for cylindrical chambers with different dimensions.

The objectives of this work are two folds. First, procedures are proposed to experimentally measure the radial track densities on an SSNTD and then to determine the fraction f. Second, this fraction f is determined for a chosen diffusion chamber as an example. From the dimensions of this diffusion chamber, the relationship between the radial track density distribution on the LR115 detector placed on the bottom of this diffusion chamber and the deposition behavior of ^{218}Po inside the chamber is first identified. By comparing the theoretical curves and the experimental data for the radial track densities, f can be determined. The LR115 detector was considered in this work because it was not affected by the plate-out effect, i.e., the effect caused by radon progeny deposited onto the detector itself. Consideration of a detector capable of detecting the plate-out (such as the CR39 detector) would complicate the results.

2. Experimental measurements

The diffusion chamber employed in the present study was conical, having a base radius (R_1) of 2.35 cm, a top radius (R_2) of 3.75 cm and a height H of 8 cm. Nikezić and Yu [3] studied six cylindrical diffusion chambers with different dimensions which were denoted by a pair of numbers (R, H) where R (in cm) was the chamber radius and H (in cm) was the height of the chamber. In all cases the LR115 detector covered the entire bottom of the diffusion chamber. Nikezić and Yu [3] also demonstrated that the sensitivity of a thin and short (2,2) chamber is not sensitive to f, and such a chamber is therefore unsuitable for the determination of deposition behavior of ^{218}Po. For taller chambers, such as the (2,6), (3,6) and (4,6) chambers, ^{218}Po in air and ^{218}Po on inner surfaces have very different sensitivities, which caused a large difference between the curves for different values of f, and are thus suitable for determination of deposition behavior of ^{218}Po. Therefore, we have chosen a relatively tall diffusion chamber for the present study.

A circular LR115 detector was placed on the bottom of the chamber so that the centers of the detector and the chamber base coincided with each other. 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 the diffusion chamber was covered by a filter paper. The diffusion chambers were exposed in an exposure chamber [4] with an exposure of $89100 \pm 1300\,\mathrm{Bq\,m^{-3}\,h}$ of ^{222}Rn in the present experiment. The activity concentration together with the associated uncertainty inside the exposure chamber were determined using RAD7 (from Durridge Company Inc., MA) which was calibrated by the manufacturer [4]. The conditions inside the exposure chamber were: temperature = 27°C, relative humidity = 74%, pressure = 1012 hPa and maximum concentration of $^{222}\mathrm{Rn} = 7.7 \times 10^4\,\mathrm{Bq\,m^{-3}}$.

After exposure, the LR115 detector was etched in a 10% water solution of NaOH at temperature $t = 60$°C for about 3 h. The thickness of removed

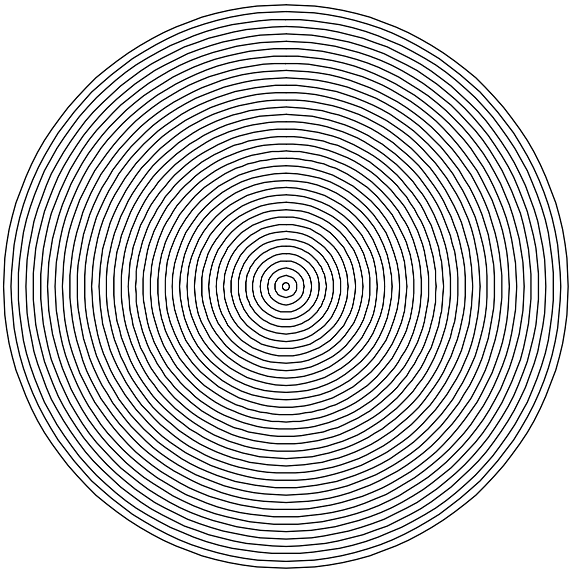

Fig. 1. The transparent template used to measure the radial track density on the LR115 detector under an optical microscope. The distance between adjacent concentric circles is 1 mm.

layer was 6.7 μm. A transparent template with concentric circles as shown in Fig. 1 was used to measure the radial track density on the LR115 detector under the optical microscope. 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 these were then affixed to a movable stage attached to the optical microscope. By moving the stage, the complete area in a particular stripe (area between two concentric circles) can be scanned visually without interruption. The total number of tracks in the stripe was counted. For stripes with small radius, the total number of counts were small due to the small areas of the stripes. To improve the statistics, the number of tracks were counted and combined for every two stripes.

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

3. Theoretical calculations

The track density per unit exposure (Bqm^{-3} h) is also termed the sensitivity ε of the detector. The sensitivity ε_i to the nuclide i in the radon chain is called the partial sensitivity. The sensitivity ε is then the sum of partial sensitivities as

$$\varepsilon = \varepsilon_{^{222}\mathrm{Rn}} + f\varepsilon_{^{218}\mathrm{Po}} + (1-f)\varepsilon'_{^{218}\mathrm{Po}} + \varepsilon'_{^{214}\mathrm{Po}} \qquad (1)$$

where $\varepsilon_{^{218}\mathrm{Po}}$ was the sensitivity to ^{218}Po from air, $\varepsilon'_{^{218}\mathrm{Po}}$ was sensitivity to ^{218}Po from inner surfaces and $\varepsilon'_{^{214}\mathrm{Po}}$ was sensitivity to ^{214}Po from inner surfaces [3]. The information relevant to the present work is the radial distribution of sensitivity from the center of the detector.

As mentioned before, the first radon progeny ^{218}Po decays partially before deposition (with fraction f), and partially after deposition (with fraction $1-f$). Other radon progeny are assumed to decay while they are staying on inner surfaces of the diffusion chamber. Monte Carlo method was employed to calculate the partial sensitivities. The circular detector surface was divided into circular stripes with width of 1 mm bounded by concentric circles. The number of alpha particles hitting different circular stripes were determined to deduce the radial distribution of sensitivity. A previously developed program of Nikezic and Baixeras [5] was used in these calculations. 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 completely perforated the sensitive layer of the detector during etching were taken into account.

4. Results and discussions

The experimental data together with a set of curves (with different f) generated from Monte Carlo simulations are shown in Fig. 2. 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).

The theoretical curve best fitting the experimental data (to the nearest 0.1 in the f value) was

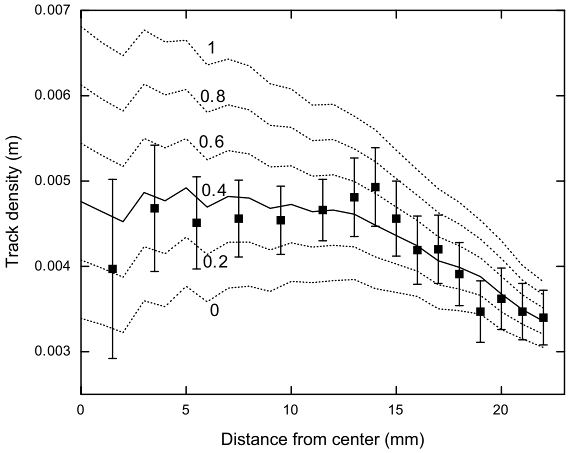

Fig. 2. Experimental data (error bars represent ±1 SD) together with a set of Monte Carlo curves (with different f values as shown) for the radial distribution of track densities. The percentage uncertainty for the values given by the Monte Carlo method are 1%, and are negligible compared with the errors of the experimental data. The curve for $f = 0.4$ (in bold) is the best fit to the experimental data (see text).

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. The values of C were 8.2, 4.0, 5.3 and 12.0 for $f = 0.5$, 0.4, 0.3 and 0.2. Therefore, 0.4 is the best f value for the present experimental data.

The result that 40% of ^{218}Po decays before deposition onto the internal surfaces of the diffusion chamber is in contrast to the finding of McLaughlin and Fitzgerald [1], by using the Jacobi's model for the progeny in the diffusion chamber, that almost all ^{218}Po deposit before decaying. On the other hand, although Nikezić et al. [2] only used the sensitivity peak in the LR115 detector at a radial distance of 1.9 cm from the center, it is interesting that their estimated fraction f of 0.4 coincided with the present result. However, it is apparent 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. For example, if only the peak sensitivity from the present results (i.e., the sensitivity at the radial distance of 1.4 cm) is used, f will be estimated to be >0.6 which is much larger than the currently estimated value of 0.4. Deviations of individual data points are expected to arise from statistical fluctuations.

Solid state nuclear track detectors are normally calibrated through exposures to high and well-known radon concentrations inside exposure chambers. It is usually assumed that the conditions for calibration are the same as those during real-life radon measurements. However, the sensitivity of the detectors will greatly depend on the deposition behavior of ^{218}Po inside the diffusion chambers. Upon decay of ^{222}Rn, ^{218}Po atoms are formed in the unattached mode. The fate of these ^{218}Po atoms, and thus the fraction f of ^{218}Po decays before deposition on the inner surfaces, may depend on the aerosol concentration, relative humidity or the presence of electric field, etc., inside the diffusion chamber, and may also on the material of the chamber itself. With the procedures established as shown in the present paper, the influence of these parameters on f can be determined in the future, and clearer pictures on the response of the detector sensitivity can be obtained.

Acknowledgements

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