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Calibration and optimization of a low cost diffusion chamber for passive separated measurements of radon and thoron in soil by Lexan PC SSNTD

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ABSTRACT

Background: Separate radon and thoron measurements in soil are very important in assessment of internal exposure due to inhalation of such radioactive gases. ***Materials and Methods:*** In this study, a low cost, small size, passive diffusion chamber has been developed for simple measurement of Radon-222 and Radon-220(Thoron) gases separately in soil. The diffusion chamber consists of two films and two fiber glass filters. Lexan polycarbonate films were used as Solid State Nuclear Track Detectors (SSNTDs) and optimized film to filter distance was obtained. ***Results:*** Calibration factors for the designed diffusion chamber were measured using flow through method which was 16.85[track.cm^{-2}(kBq. m^{-3}d)$^{-1}$] and 17.25 [track.cm^{-2}(kBq.m^{-3}d)$^{-1}$] for radon for the lower and upper Lexan films, respectively and 1.76 [track.cm-2(kBq.m^{-3} d)$^{-1}$] for thoron. ***Conclusion:*** The designed chamber is an economic, applicable and efficient detector for measurement of radon and thoron separately in soil.

Keywords: *Radon, Thoron, passive Detectors, SSNTD.*

INTRODUCTION

Radon and thoron are radioactive noble gases, produced in ^{238}U and ^{232}Th decay series. Inhalation of these radioactive gases leads to high natural exposure of people. The alpha particles emitted from these gases can be hazardous for human health as they can have a significant impact on cancer risk. Thus, even in this age of nuclear reactors, naturally- occurring radon is responsible for the majority of the public exposure to ionizing radiation. It is often the single largest contributor to an individual's background radiation dose, and varies significantly from location to location. Epidemiological studies have shown a clear link between breathing high concentrations of radon and incidence of lung cancer. Thus, radon is considered a significant contaminant that affects indoor air quality worldwide.

At present, the principal means used to confirm indoor radon levels involves testing buildings. Although this is likely to continue to be the main verification, soil-based investigations can help to identify land areas warranting special attention for risk communication programs, as well as site-specific decisions for radon-resistant construction. Since these gases are usually emitted from the soil, it is essential to measure the radon and thoron concentration in soil. Measuring the amount of radon in soil is one of the most important methods of radon estimation in the environment (1-3) that can help identify land areas warranting special attention for risk communication programs, as well as site-specific decisions for radon-resistant construction. Thoron has a short half-life, 55.6 s, in comparison with radon (3.82 days) and its concentration is generally lower than radon in soil (4).

Since the active methods and devices for active measurement of radon are expensive, the economic passive detectors, i. e (SSNTDs), are more preferable. Also, the passive method of radon measurement using Lexan detectors is a very simple and low cost method in comparison with the active methods (i.e. alpha guards). As the radon concentrations have hourly variations, and changes significantly over the time, the active radon measurements performed by instantaneous sampling, using alpha guard would not give an accurate estimation of the real radon concentration. The measurements performed by alpha guards are instantaneous and the measurements differ with time, while in passive measurement the data are gathered, and the average of the data is observed as the measured concentration.

The advantage of such detectors is that they are sensitive to alpha particle but not to beta and gamma, nor are they sensitive to humidity, light, and other environmental conditions (5). These qualities have made such passive detectors the method of choice for radon measurement. Most of the devices measure both radon and thoron gases, therefore, for accurate measurement, separate radon and thoron measurements are of major importance. Numerous studies have been performed in this area such as developing a ^{222}Rn-^{220}Rn discriminative passive dosimeter that can estimate both radon and thoron concentrations at the same time (6, 7), developing radon–thoron discriminative monitors (8, 9), and using (SSNTDs) based dosimeters for the survey(10).

The objective of this study is to design and optimize a small, simple and economic diffusion chamber with acceptable sensitivity and ability to measure radon and thoron separately in soil.

MATERIALS AND METHODS

Type of detector

250 μm thick (2.5cm×2.5cm) Lexan polycarbonate, Solid State Nuclear Track Detectors (SSNTDs) are used in this study for registering alpha particles. The electrochemical etching (ECE) process is used to transform latent tracks to the visible form. Electrochemical etching (ECE) is an etching technique in which the sizes of latent tracks are magnified. The aim of the etching method used in this study is to magnify the dimension of tracks so that they become visible to the naked eye. The etchant solution, PEW, consists of 15%KOH, 40% $C2H5OH$ and 45% H_2O by weight at 25^{0}C followed by the application of 32 kV/cm field strength, 2 kHz frequency and duration of 3 h (11).

Mechanism and optimization of the chamber operation

A cylindrical diffusion chamber including two filters and two films was designed for measuring radon and thoron separately. The upper film in the chamber records both radon and thoron, while the lower film records radon only. Figure 1a shows the diffusion chamber designed for separated radon and thoron measurements.

Only radon and thoron enter the diffusion chamber from the top as shown in figure 1a. Due to filters, the daughter of the radon and thoron are not able to enter the diffusion chamber.

In the upper part of the diffusion chamber radon and thoron disintegrate to their daughter products. They normally stick to the upper filter and alpha particles which are emitted will register on the upper film. Due to short half of thoron, the concentration of thoron that can pass the lower film and enter the lower part of diffusion chamber is negligible so it can be assumed only radon has entered into the lower part, after disintegration of radon, its daughter product will stick to the lower filter so the lower film will register alpha particle from radon daughter products. Polycarbonate (Lexan) with the described ECE conditions and PEW as etchant can register alpha particles with energy in the 0.5 -2 Mev range (11). To view the effect off the detector in diffusion chamber (The distance between the film and filter) films were placed at various distances. The optimal location is a place where the number of recorded track is maximum.

In such a passive method the position of the films can have a significant impact on the tracks registered on the films. To obtain the optimized positions of the upper and lower films, the registered tracks were compared for different distances (d in (cm)) between the film and filter.

Measurement of Radon/Thoron in soil

Figure 1a shows the diffusion chamber based on Lexan track detector for separate radon and thoron measurement in soil. To measure the two gasses in soil, the diffusion chamber is placed in a cylindrical tube at a sufficient depth inside the soil (see figure 1b) and the tube end is sealed with an insulator. As can be seen, radon and thoron diffuse from soil to the tube and diffusion chamber and will be measured measure in the chamber.

Calibration methods

One of the most important methods for measuring the response of the chamber is the flow- through calibration method. The schematic of calibration method is shown in figure 2 (12). Radon generated by flow-through Pylon sources model RN-1025 calibration chamber is connected to a calibration chamber with a volume of 50 liter, and model TH-1025 which connect to the calibration chamber with volume of 4 liter generated for thoron. The scintillation Lucas Cells (SLC) of a precalibrated Pylon AB-5 monitor measures the radon and thoron concentrations inside the calibration chamber. A closed loop was produced between the calibration chamber and the SLCs. To provide the different exposures, the concentrations of radon and thoron inside the calibration chambers were changed by setting different flow rates.

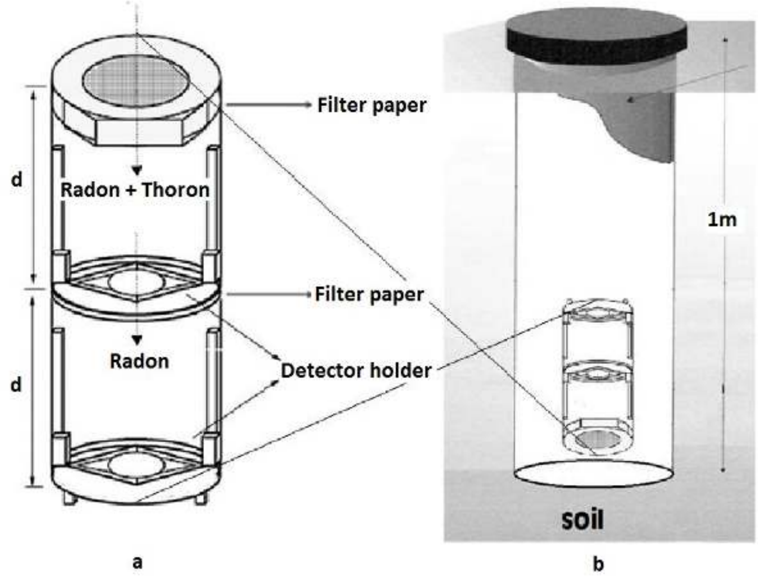

Figure 1. (a) Diffusion chamber used for radon and thoron measurements (b) A schematic drawing of a device for measuring radon/thoron in soil by SSNTDs.

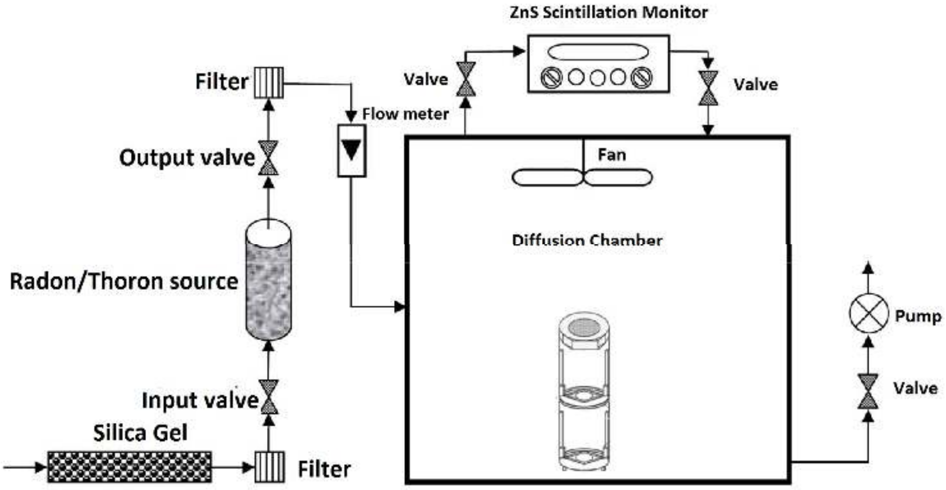

Figure 2. The flow-through calibration method used for radon and thoron measurements.

Calculation of MDL

The Minimum Detection Limit (MDL) was obtained by equation 1 (13):

$$C_{MDL} = \frac{2\sigma}{KD} \qquad (1)$$

Where, CMDL is the concentration of MDL for radon and thoron, and σ the standard deviation of net track density of unexposed Lexan films. K is the calibration factor of measurements (track density per exposure) and D is the time of exposure (days).

Calculation of Radon and Thoron concentration by detectors

The track density of upper and lower film, radon and thoron concentrations (C_{Rn} and C_{Tn}) can be defined using the track density of upper and lower film (T_U and T_L) as follows (14):

$$T_U = (C_{Rn} K_{Rn\text{-}U} + C_{Tn} K_{Tn\text{-}U})D \qquad (2)$$

$$T_L = C_{Rn} K_{Rn\text{-}L} D \qquad (3)$$

From equations 2 and 3:

$$C_{Rn} = \frac{T_L}{K_{Rn-L} D} \qquad (4)$$

$$C_{Tn} = \frac{1}{K_{Tn-U}} \left[T_U - T_L \frac{K_{Rn-U}}{K_{Rn-L}} \right] \qquad (5)$$

Where, $K_{Rn\text{-}U}$, $K_{Tn\text{-}U}$ is the calibration factor of measurements of upper film for radon and thoron and D is the exposure duration (days) of the SSNTDs detector. The calibration factor for lower film of thoron is zero.

RESULTS

The optimization results of the diffusion chamber configuration are shown in figures 3a and 3b. Figure 3a shows track density (the number of tracks per cm^2) for different distances of the film from the filter (d (cm)). The optimized position of the lower film in the chamber for radon measurements is shown in figure 3b. As is obvious from figures 3a and 3b the maximum track density for radon and thoron were found to be 5 cm.

Figure 3b shows the track density for different distances of the upper film from the filter (d (cm)). In fact, the optimized position of the upper film in the chamber for thoron measurements is observed.

The upper film inside the diffusion chamber registers tracks of radon and thoron daughter and the lower film registers tracks contributed by radon daughter only, so the difference between the signals recorded by the films inside the diffusion chamber is the thoron concentration.

Figures 4a and 4b show the response of the diffusion chamber for different concentrations of radon. Figure 4a shows that there is a linear relation between the track density and the time integrated radon concentration for the upper film. The slope of this curve (K_{Rn-U}) is 16.85 [track.cm^{-2}(kBq.m^{-3}d)$^{-1}$] .The linear relation between the track density and the time integrated radon concentration for the lower film is shown in figure4a. The slope of this curve (K_{Rn-L}) is 17.25 [track.cm^{-2}(kBq.m^{-3}d)$^{-1}$].

The calibration factor of the upper film for thoron (K_{Tn-U}) was obtained from the slope of the curve shown in figure 5, which is 1.76 [trackcm^{-2}(kBqm^{-3}d)$^{-1}$].

Figures 6a and 6b show the Minimum detection limit (kBq/m^3) of the chamber versus exposure time (day) in thoron measurements by the upper film, and radon measurements by the lower film respectively.

DISCUSSION

Almost all of the detection systems containing SSNTDs are applicable for long-term measurement of radon, but few of them are able to measure radon and thoron separately.

Moreover, many factors such as plastic material, etching process and detection geometry strongly affect the sensitivity value of a nuclear track detector which may vary from 0.67 to 5000 [trackcm^{-2}(kBqm^{-3}h)$^{-1}$]$^{(15)}$.The sensitivity value of the designed diffusion chamber for radon measurement is appropriate for area with low and high concentration of radon. Since SSNTDs with high sensitivity at a high concentration of radon in a short period of time will be saturated, for long-term measurement of radon high sensitivity is a weakness for

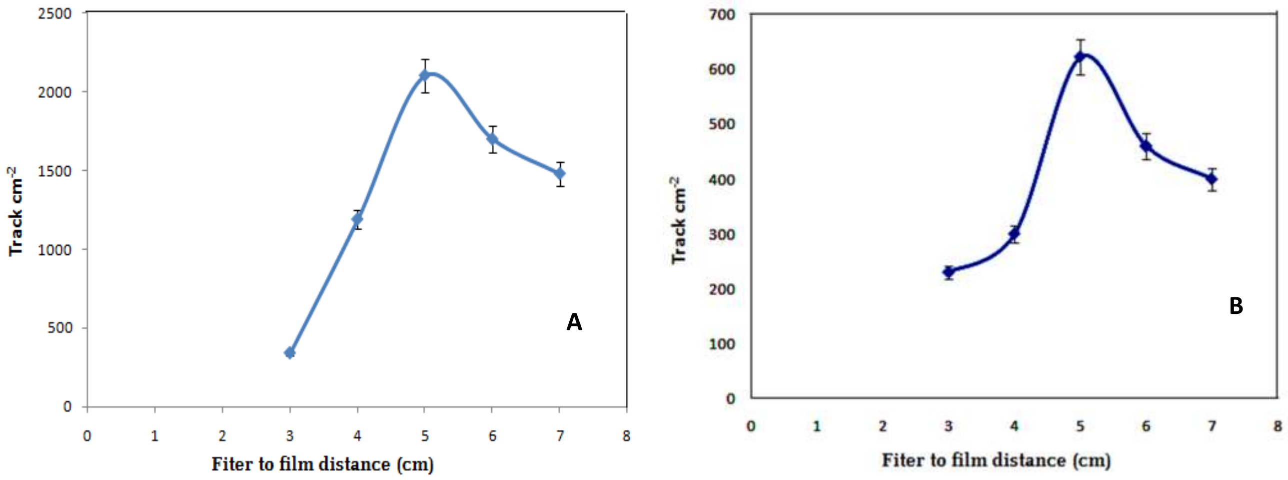

Figure 3. Optimization of film to filter position in the diffusion chamber, a: for radon b: for thoron.

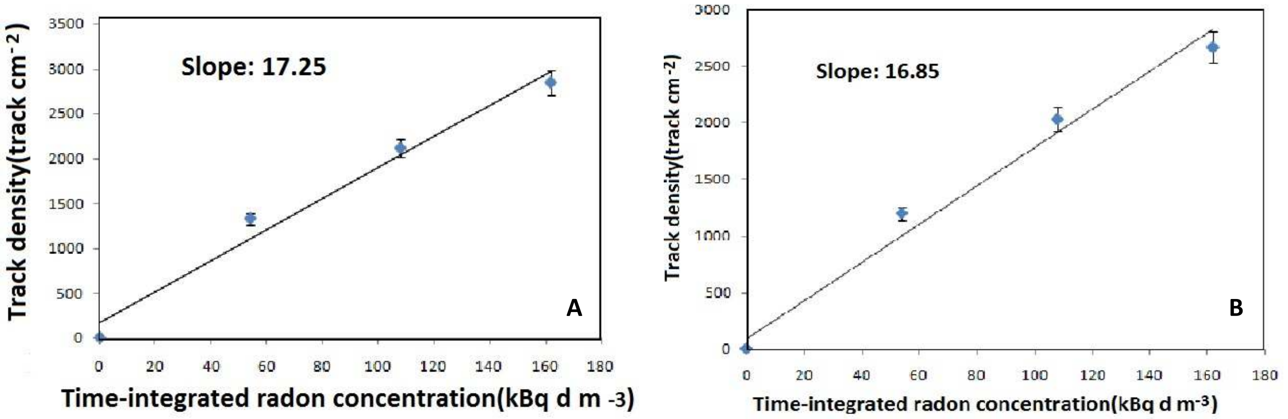

Figure 4. The radon measurement response of the designed diffusion chamber for different radon exposures by (a) the upper film and (b) the lower film (slopes of linear curves are used for obtaining the calibration factor (sensitivities)).

detector.

In the case of thoron, since the thoron measurement is based on the detection of its very short-lived daughter (Po-216), the related sensitivity is very small.

In comparison with the other detection systems containing SSNTDs, the designed detector in this research consists of two films and filters and high capability in accurate measurement of radon and thoron separately in soil. The advantage of Lexan film used in this investigation in comparison with other SSNTDs such as CR 39 and LR 115 films is that the Lexan films has low cost and can be used in situations with high concentrations.

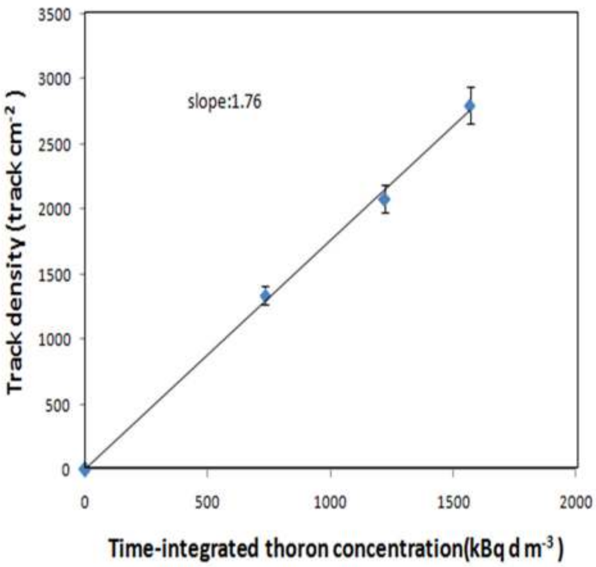

Figure 5. Track density (track per cm^2) for different exposures in thoron measurement by the upper film of the diffusion chamber. (The lower film calibration factor for thoron is zero).

CONCLUSION

In this research, a passive diffusion chamber has been developed which is low cost and small, with the ability to separate measurement of radon and thoron by Lexan polycarbonate in soil. The calibration and MDL factors were obtained for the optimized positions of the two films from filter for radon and thoron. The results of this study indicate that the diffusion chamber is sensitive to thoron gas and measures radon and thoron seperately. The design of this economic passive measurement system for radon measurements in soil with thoron separation ability could play a significant role to radon and thoron measurement programs in the country.

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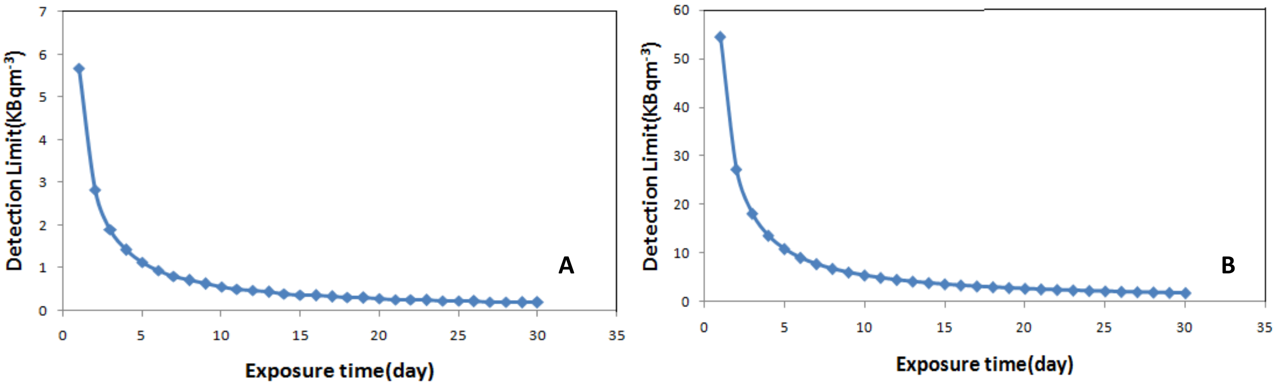

Figure 6. a) MDL factor in radon measurements by lower film in diffusion chamber. b) MDL factor in thoron measurements by upper film in diffusion chamber.

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