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A new pin-hole discriminated ^{222}Rn/^{220}Rn passive measurement device with single entry face

B.K. Sahoo, B.K. Sapra*, S.D. Kanse, J.J. Gaware, Y.S. Mayya

Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

HIGHLIGHTS

- A model is developed to discriminate ^{222}Rn and ^{220}Rn using pin-hole.
- Model is validated against the experimental results.
- A new pinhole discriminated ^{222}Rn/^{220}Rn passive measurement device is developed.
- The new device overcomes the limitation of the conventional twin cup dosimeter.
- Device is calibrated using standard sources of ^{222}Rn and ^{220}Rn.

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ABSTRACT

Solid State Nuclear Track Detector (SSNTD) based diffusion chambers have been widely used for residential radon measurements due to their cost effectiveness, portability and easy-to-use feature. In India, an LR-115 track detector based twin-cup dosimeter has been in use for about a decade for indoor ^{222}Rn and ^{220}Rn measurements. However, the estimation of the gas concentrations using this dosimeter was based on the assumption of the same entry rate of the gases into the two cups of the dosimeter, which may not be valid for dosimeters deployed in turbulent environmental conditions. To overcome this limitation, a new pin-hole based ^{222}Rn/^{220}Rn discriminating measurement device has been developed. The underlying discrimination technique has been established by modelling ^{222}Rn and ^{220}Rn diffusion into a pin-hole chamber and validating the same by carrying out experiments in a test chamber. The device has been calibrated at Bhabha Atomic Research Centre, Mumbai following the standard procedures to correlate the number of tracks registered in the LR-115 detector placed in the two chambers to the ^{222}Rn and ^{220}Rn concentration in the environment. Salient features of the device include (i) the pin-holes act as ^{222}Rn/^{220}Rn discriminator and eliminate the requirement of membrane filter used in the earlier twin cup design (ii) the single entrance design for gas transmission and (iii) use of multiple pin-holes of reasonably small radius minimises effect of turbulence on ^{222}Rn/^{220}Rn transmission factors so that the calibration factor is independent of indoor turbulence.

1. Introduction

Radon (^{222}Rn) and thoron (^{220}Rn) gases enter into the indoor air through exhalation from soil and building materials used in walls, floors and ceilings (Nazaroff and Nero, 1988). Poor indoor ventilation conditions result in an increase in the concentration of these gases and their decay products in rooms. It has been observed that radon is the second most important cause of lung cancer, after smoking (WHO, 2009). Epidemiological studies have provided convincing evidence of an association between indoor radon exposure and lung cancer, even at relatively low radon levels commonly found in residential buildings (Darby et al., 2005; Krewski et al., 2005). Due to the increasing concern about the risk associated with indoor radon, projects for monitoring of indoor radon are being carried out in several countries (Dudney et al., 1990; Miles, 1998; Yu et al., 1999; Srivastava, 2005; Zhang et al., 2007; Ramachandran and Sahoo, 2009).

For indoor radon survey, passive detectors (such as CR-39, LR-115) have been widely used because of their cost effectiveness, portability and easy-to-use feature. Most importantly, unlike the

* Corresponding author. Environmental & Bio-dosimetry Section, Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai 400 085, India. Tel.: +91 22 2559 2209; fax: +91 22 2551 9209.

E-mail addresses: bsapra@barc.gov.in, bijaybarc@gmail.com (B.K. Sapra).

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case of active instruments, these detectors do not require power supply and provide time integrated radon concentration encompassing both diurnal and seasonal variations. Initially SSNTD in the bare mode was used for passive measurements of radon (^{222}Rn) (Stranden et al., 1979; Ramachandran et al., 1986; Andriamanatena and Enge, 1995; Ramola et al., 1996); however, the response included the tracks from the decay products and ^{220}Rn (thoron) as well. In order to remove interference from decay products in ^{222}Rn gas measurements, a system with Solid State Nuclear Track Detector (SSNTD) enclosed in a diffusion chamber was developed (Nikezic and Baixeras, 1995; Nikezic et al., 1996; Nikezic and Stevanovic, 2007). In this system, the particulate decay products are filtered out using a suitable filter paper at the entry face, through which gases diffuse easily. However, these systems cannot distinguish ^{222}Rn and ^{220}Rn, which is a major issue in environments with elevated ^{220}Rn concentrations. This necessitates development of a discrimination technique for ^{222}Rn and ^{220}Rn so as to accurately quantify individual gas concentrations using passive detector systems.

For discriminating ^{222}Rn and ^{220}Rn measurements, twin chamber device with a diffusion barrier, which cuts off short lived ^{220}Rn but allows ^{222}Rn to pass through it, have been designed. While some systems use membranes (Eappen and Mayya, 2004; Tokonami et al., 2005), others use pinhole based diffusion barrier (Doi and Kobayashi, 1994; Sciochheti et al., 2010). In India, LR-115 SSNTD based cylindrical twin cup dosimeterusing membrane for thoron cut-off, developed by Eappen and Mayya (2004), has been widely used for measurement of ^{222}Rn and ^{220}Rn in dwellings. The detector has two entrances (facing opposite to each other), both using glass fibre filters to cut off entries of decay products. In addition, one entrance uses a cellophane membrane to cut-off ^{220}Rn transmission so that only ^{222}Rn enters into the so called ‘radon’ chamber. The other entrance allows both ^{222}Rn and ^{220}Rn into the so called ‘radon + thoron’ chamber. A subtraction technique is used to remove the contribution of radon to the tracks in radon + thoron chamber and obtain thoron concentration. However, it was observed that in some cases the track densities of SSNTD detector placed in ‘radon’ chamber exceeded the track densities of detector placed in ‘radon + thoron’ chamber, resulting in a physically unacceptable negative ^{220}Rn concentration. One possible reason for this is the different entry rates of ^{222}Rn through two entrances of the dosimeter which may arise from turbulence or air flow in one direction (as in case of one entrance facing a fan and other being opposite to it). This ambiguity of different ^{222}Rn entry in two chambers can be removed by developing a twin chamber device having a single entrance. The conventionally used dosimeter which uses membrane based ^{222}Rn – ^{220}Rn discrimination technique cannot be easily converted to a twin chamber with single entrance. However, it is possible to achieve the required design by replacing the membrane with a pin-hole based discriminating design. Though pinhole based diffusion barrier has been used in some detectors there has been no theoretical basis to decide the pin-hole dimensions for desired ^{220}Rn cut off and ^{222}Rn transmission into the diffusion chamber.

In this paper, we discuss the development of a pin-hole based ^{222}Rn/^{220}Rn discrimination technique, established by modelling ^{222}Rn and ^{220}Rn diffusion into the pin-hole chamber and validating the model predictions with the experimental observations. Based on this, a new pin-hole based ^{222}Rn/^{220}Rn discriminating device has been designed and developed. This LR-115 track detector based device has a single face for gas entry and gives time integrated measurement of ^{222}Rn and ^{220}Rn in dwellings. The optimal configuration of pin-hole dimensions was decided with the help of model predictions as well experimental measurements in turbulent environmental conditions. In order to minimise the effect of turbulence penetration of ^{222}Rn and ^{220}Rn, multiple pin-holes of reasonably small radius (0.5 mm) were used and an arrangement was made for deploying the device in a face-down condition. The device has been calibrated in a laboratory calibration facility at the Bhabha Atomic Research Centre, Mumbai to correlate the number of tracks registered in the LR-115 detector to the ^{222}Rn and ^{220}Rn concentration in the environment.

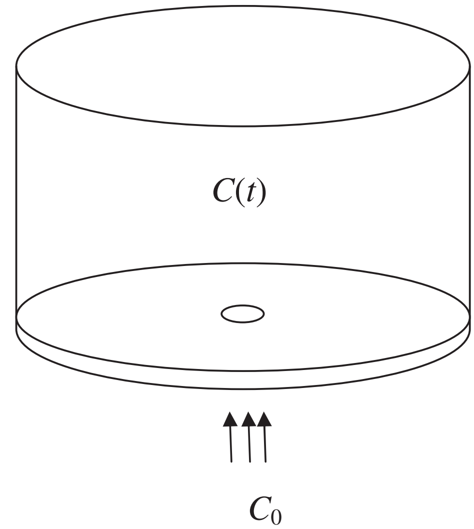

Fig. 1. Schematic of a pin-hole chamber system.

2. Model development for pin-hole based ^{222}Rn – ^{220}Rn discriminator

Let us consider a closed cylindrical chamber having a pin-hole of radius a and length d at one face (Fig. 1). It is assumed that the gas enters the chamber through pin-hole by the process of diffusion. If $C(t)$ is the average ^{222}Rn/^{220}Rn gas concentration in the chamber volume at time t, then, the non-steady state equation for $C(t)$ may be written as:

$$V\frac{\partial C(t)}{\partial t} = JA - \lambda C(t)V \tag{1}$$

where V is the volume of the chamber, J is the ^{222}Rn/^{220}Rn transmission flux through the pin-hole, A ($=\pi a^2$) is the area of the hole and λ is the decay constant of the gas (either ^{222}Rn or ^{220}Rn).

The flux J through a pin-hole is related to the difference in the concentration of the gas between the outside and inside air, by applying the Fick's law of diffusion as follows:

$$J = D\frac{C_o - C(t)}{d} \tag{2}$$

Where, C_0 is the ^{222}Rn/^{220}Rn gas concentration in the outside air at the entry face,D is the ^{222}Rn/^{220}Rn diffusion coefficient in air (hole). Substituting J from Eq. (2) in Eq. (1) and simplifying we arrive at

$$\frac{\partial C(t)}{\partial t} = \lambda_p C_0 - \lambda_e C(t) \tag{3}$$

where we denote

$$\lambda_p = \frac{AD}{Vd} \tag{3a}$$

and