Available online at www.sciencedirect.com
ScienceDirect
Radiation Measurements 43 (2008) 1408–1416
Radiation Measurements
www.elsevier.com/locate/radmeas

Study of a deposition-based direct thoron progeny sensor (DTPS) technique for estimating equilibrium equivalent thoron concentration (EETC) in indoor environment

Rosaline Mishra, Y.S. Mayya*

Environmental Assessment Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

Received 30 May 2007; received in revised form 3 March 2008; accepted 16 March 2008

Abstract

A study has been carried out to examine the suitability of a passive, deposition-based technique for estimating the time-integrated equilibrium equivalent thoron concentration (EETC) in indoor environment using a direct thoron progeny sensor (DTPS). DTPS is an absorber-mounted LR-115-type nuclear track detector tuned to respond only to the 8.78 MeV alpha particles emitted from the deposited activity of ^{212}Po on the absorber surface. The study has been carried out in two steps, the first step comprising the estimation of track registration efficiency (η) and the second step comprising the estimation of effective deposition velocity of thoron progeny aerosols on the detector surface in natural and laboratory environments. The track registration efficiency is found to be 8.3% for ^{212}Po and less than 0.02% for all other alpha emitters including ^{222}Rn (radon) progeny, thereby enabling a precise discrimination of thoron progeny. The deposition velocity of thoron progeny aerosols on DTPS surface has been measured in conjunction with active air sampling techniques for different orientations of the deposition surface. The geometric mean deposition velocity was found to be $0.077\,\mathrm{m\,h^{-1}}$ having a narrow spread (geometric standard deviation of 1.35). Upon combining these factors, the overall sensitivity factor is estimated to be $0.94\,\mathrm{Tr\,cm^{-2}\,d^{-1}/EETC(Bq\,m^{-3})}$, which indicates ~ 45 times higher sensitivity as compared with conventional bare detector techniques (which register alpha particles emitted directly from air). The results obtained have been compared with currently used aerosol deposition models and progeny equilibrium models by using the aerosol number size and progeny activity distributions measured with scanning mobility particle sizer (SMPS) and low-pressure cascade impactor, respectively. The results are in good agreement with each other. A sensitivity analysis of the response characteristics of DTPS with respect to room ventilation rate and aerosol concentrations has been carried out to assess the variability of the sensitivity factor in the context of indoor dosimetry. The results are further discussed.

Keywords: DTPS; Thoron progeny; LR-115; Sensitivity factor; Activity median diameter; Deposition velocity; Attached/unattached fraction

1. Introduction

Inhalation of high cumulative levels of ^{222}Rn (radon) and, in particular, its α-particle-emitting decay products has been linked to an increased risk of lung cancer among underground miners (BEIR VI, 1999). Exposure to lower levels of residential radon has also been tied to lung cancer in some studies of radon in homes (Lubin and Boice, 1997). A recently concluded analysis of European Case control studies (Darby et al., 2005) seems to suggest an increased risk of lung cancer by about 8% (3–16%) per $100\,\mathrm{Bq\,m^{-3}}$ of ^{222}Rn concentration, which, in turn, is consistent with an estimate of 11% (0–28%) found in a combined analysis of North American studies (Krewski et al., 2005).

Contrary to multiple international investigations on the measurements of population exposures due to ^{222}Rn-progeny in the environment, very few studies have been directed on ^{220}Rn (thoron) and its progeny levels. Limited ^{220}Rn-progeny surveys indicate a mean indoor progeny level between 0.1 and $2\,\mathrm{Bq\,m^{-3}}$, with a maximum up to about $5\,\mathrm{Bq\,m^{-3}}$ (Mjönes et al., 1992; Guo et al., 1992; Reineking et al., 1992). Theoretical risk estimates project up to 4000 deaths annually due to indoor ^{220}Rn-progeny induced lung cancer in the USA (Schery,

* Corresponding author. Tel.: +91 22 25593861; fax: +91 22 25505151.
E-mail addresses: rosaline.mishra@gmail.com (R. Mishra), mayyays@barc.gov.in (Y.S. Mayya).

1350-4487/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.radmeas.2008.03.002

1990). Questions have been often raised whether thoron is as negligible an issue as it was made out to be (Steinhäusler, 1996). Thoron problem has special significance in the high background radiation areas (HBRAs) located on thorium-rich soils in Brazil, China and India (UNSCEAR, 1993, 2000) from the epidemiological perspective of finding the effects of low levels of chronic radiation exposures on human health.

In the Indian context, large variability in indoor thoron values (4–423 $\mathrm{Bq\,m^{-3}}$) has been found in the Monazite-bearing, densely populated regions in the coastal belts of Kerala (Chougaonkar et al., 2004). This region also consists of thorium and other rare earth processing industries, in the environments of which the ^{220}Rn concentration was found in the range of 56.4–448 $\mathrm{Bq\,m^{-3}}$ and that of ^{212}Pb was found to be between 2 and 20 $\mathrm{Bq\,m^{-3}}$ (Pillai and Paul, 1999). Higher thoron levels have been reported in other regions too, e.g. it has been reported that in the dwellings of South-East, India, (Hyderabad) the thoron concentrations were observed to vary between 8 and 330 $\mathrm{Bq\,m^{-3}}$ (Sreenath Reddy et al., 2004).

Although inhalation doses are predominantly due to progenies, dosimetry in the dwellings of monazite areas has essentially focused on the measurement of radon and thoron gases using twin-cup dosimeters equipped with LR-115-type (12 μm) solid-state nuclear track detectors (Mayya et al., 1998). The progeny concentrations are estimated by equilibrium factor considerations. While this is fairly justified for radon in view of the short-lived nature of the progeny as compared with the gases, this approach is beset with serious limitations in thoron-rich environments. This is because equilibrium factor is not a well-defined concept in the case of a short-lived parent such as thoron (half-life, 55 s) and a longer lived daughter product ^{212}Pb (half-life 10.6 h). In fact, large variations in thoron concentrations are expected to be near and far from walls making it almost impossible to estimate a representative concentration from one point measurements (Doi et al., 1992). In essence, there exists, as yet, no passive techniques for estimating progeny concentrations directly, especially the thoron progeny. Direct progeny measurement by passive energy discrimination techniques using suitable absorbers, which was initiated by Fleischer (1984), has established (Nikezic and Baixeras, 1996; Da Silva and Yoshimura, 2005) the feasibility of detecting individual radon progeny species using barriers placed in front of nuclear track detectors. Their application to environmental thoron progeny dosimetry has been initiated by Zhuo et al. (2000) and Tokonami et al. (2002), using CR-39 detectors covered with aluminium-evaporated plastic and a polypropylene film so as to detect alpha particles emitted from ^{212}Pb only. Tokonami et al. (2002) have carried out sample studies of progeny concentrations in HBRAS areas in Manavalakurichi, India. This development is a novel and promising approach for thoron progeny dosimetry and requires to be systematically investigated for establishing the individual factors contributing to the response of the detector system.

In the light of the above, the focus of the present work is to develop and carry out systematic studies towards standardizing an absorber-mounted LR-115 nuclear track detector system to measure solely the thoron progeny component in indoor air. This system is termed as direct thoron progeny sensor (DTPS). Since it functions on the basis of the deposition of activity on its surface, its characterization is inherently linked to environmental parameters' governing deposition. As described in the following sections, the study addresses these issues in a systematic manner by experimental measurements and theoretical modeling. Section 2 presents the details of the experimental studies on the estimation of track registration efficiencies, deposition velocities for different orientations and environmental conditions and evaluation of the sensitivity factor for the DTPS system. Section 3 presents a particle deposition model coupled with progeny attachment dynamics and compares the results with experimental deposition velocities. It also discusses the extent of variability of the sensitivity factor as a function of aerosol concentration and ventilation rate to assess the uncertainties obtained with deploying DTPS in typical but uncharacterized indoor environment.

2. Development and characterization of DTPS

The concept of DTPS is based on registering solely the alpha tracks originating from the deposited activity of ^{212}Po. Normally, LR-115 detectors are designed not to respond directly to the activity deposited on their surfaces unless an intervening absorber is placed to degrade the energy of the alpha particles below 4 MeV. Since the system is intended for use in the deposition mode, it is necessary to avoid uncontrolled static charges from affecting the deposition rates and hence aluminized polyethylene is chosen as the absorber material. A basis for the selection of thickness is provided by ensuring that the ranges of various alpha emitters of radon, thoron series, other than that of the ^{212}Po (8.78 MeV) fall within the thickness of the absorber. Taking these aspects into account, a DTPS system was developed consisting of an absorber of 50 μm aluminized polyethylene mounted on a $(2.5 \times 2.5)\,\mathrm{cm^2}$ LR-115 detector. For making the sensor system compact, the absorber is kept in close contact with the LR-115 detector rather than leaving an intervening air-gap. The DTPS strip is fixed to a metal base, which acts as a rugged support during various laboratory studies and field deployment exercises.

2.1. Estimation of track registration efficiency

Track registration efficiency (η) is defined as the number of tracks registered per unit area of the LR-115 detector to the number of alpha particles emitted per unit area from the deposition surface (aluminized mylar). Supposing N atoms of ^{212}Pb and N' atoms of ^{212}Bi are deposited on the absorber, upon their ultimate decay, $N + N'$ alpha particles will be emitted, of which 0.64 $(N + N')$ will have an energy of 8.78 MeV and 0.36 $(N + N')$ will have an energy of 6.05 MeV. η is estimated as the ratio of the number of tracks formed (due to 8.78 MeV alpha particles) to the total of $(N + N')$ alpha emissions. However, in the calibration experiments (see below) as well as in actual field conditions (see Section 2.2) N' will be far less than N due to the fact that the number of ^{212}Pb atoms in air space will be far higher than ^{212}Bi atoms. As a result, the response of