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Response of direct thoron progeny sensors (DTPS) to various aerosol concentrations and ventilation rates

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ABSTRACT

Direct thoron/radon progeny sensors (DTPS/DRPS) are absorber mounted LR115 type track detectors for measuring the time-averaged progeny concentrations. Through a large number of experiments, the sensitivity factor of these sensors in natural indoor environment was found to be nearly constant at a value of 0.94 Tr cm^{-2} d^{-1}/EETC (Bq m^{-3}) for DTPS and 0.09 Tr cm^{-2} d^{-1}/EERC (Bq m^{-3}) for DRPS. The constancy of the sensitivity factor in the natural environments is attributed primarily to the presence of large aerosol concentrations and relatively low ventilation rates in time-averaged measurements. However, detailed model calculations suggest that in extreme scenario i.e. at high ventilation rate and low aerosol concentrations, the sensitivity factor can be quite different. Such situations are likely to occur in occupational plant areas. Therefore systematic chamber experiments were carried out to using DTPS, to estimate the variability of the sensitivity factor in these extreme conditions. In the first set, the sensitivity factor of DTPS was measured in 6 different aerosol concentrations at zero ventilation rates. The sensitivity factor showed a steep decrease as the aerosol concentration increased to about 8554 particle cm^{-3}, after which it remained almost constant with increase in aerosol concentration. The second set of experiments was conducted at ~5000 particles cm^{-3} at three different ventilation rates. The sensitivity factor was found to increase with increase in ventilation rate. The results are further discussed.

1. Introduction

Due to the fact that the inhalation doses due to radon and thoron are contributed predominantly by their decay products, development of passive techniques for monitoring the decay products directly assumes considerable significance. The commonly used cup dosimeter techniques only provide information on the gas concentrations and one has to apply equilibrium factor considerations for assessing the decay product exposures [1,2]. On the other hand, if one deploys the air irradiation based bare card solid state nuclear track detector (SSNTD) system; it has a common short-coming of interference from gas concentrations [3]. On the whole, there has been a long standing need for simple direct progeny sensing systems for applications in population dosimetry in monazite areas and personal dosimetry of uranium miners and thorium plant workers. To meet this challenge, direct thoron progeny sensors (DTPS) and direct radon progeny sensors (DRPS) were developed which are deposition based systems and hence ensure that they respond only to the decay products and not to gas concentrations [4–6]. DTPSs are absorber (aluminized mylar of 50 μm thickness) mounted LR-115 type nuclear track detectors which selectively detect only the 8.78 MeV alpha particles emitted from ^{212}Po atoms, which are formed from the radioactive decay of ^{212}Pb and ^{212}Bi atoms deposited on the absorber surface. Similarly, the radon progeny sensor (DRPS) has an absorber thickness of 37 μm to detect mainly the alpha particles emitted from ^{214}Po (7.69 MeV) formed from the eventual decay of ^{218}Po, ^{214}Pb and ^{214}Bi atoms deposited on it. Alternatively, they are designed to yield the equilibrium equivalent thoron/radon concentration (EETC/EERC) (time-averaged) and not the gas concentrations.

The sensitivity factor of these systems is expressed as the track density registered for 1-day exposure to an environment containing 1 Bq m^{-3} of EETC or EERC. Two major factors that decide the sensitivity factor of the system are (a) track registration efficiency, and (b) deposition velocity of the progeny atoms on the absorber surface. The track registration efficiency of DTPS/DRPS correlates the number of deposited progeny atoms to the alpha tracks registered (upon the ultimate decay of the progeny atoms) in LR-115 and is a fixed intrinsic property of the absorber-detector combination. This was established by laboratory studies by depositing known amount of progeny atoms on the surface and counting the tracks registered. The other factor, namely the deposition velocity is an environment dependent property [7,8] that determines the rate of deposition of progeny atoms for a given air concentration. Through a series of controlled experiments in a

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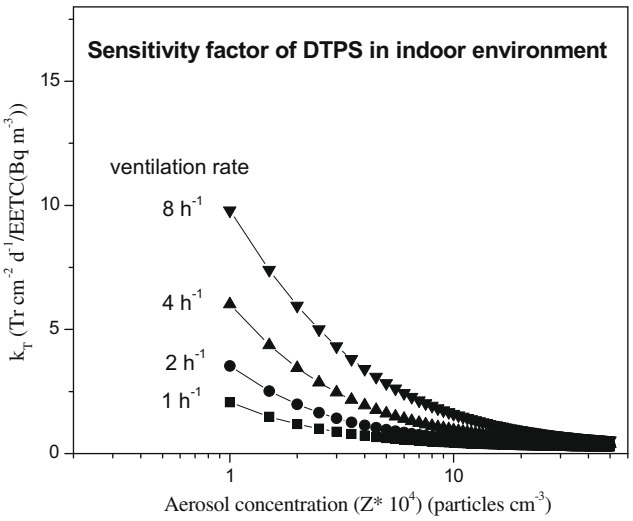

Fig. 1. Model estimate of the response of DTPS in indoor environment at different ventilation rates and different aerosol concentration.

chamber and in a test-house along with field data from more than about hundred real indoor environments, time-averaged deposition velocity of the progeny atoms was assigned [5] as 0.075 m h^{-1} for ^{220}Rn progeny and 0.132 m h^{-1} for ^{222}Rn progeny, for indoor conditions. With this a sensitivity factor of 0.94 Tr cm^{-2} d^{-1}/EETC (Bq m^{-3}) for DTPS and 0.09 Tr cm^{-2} d^{-1}/EERC (Bq m^{-3}) for DRPS was established for typical indoor environment.

Along with measurements, the deposition velocities were also modeled and closely compared with control experiments. The basic element of the model consisted of Jacobi model for progeny disequilibrium dynamics [9] and Lai–Nazaroff particle deposition models [10]. The near constancy of the indoor sensitivity factors are explained by the model as being due to the indoor ventilation rate being generally in the range of (0.5–1 h^{-1}) and aerosol concentrations generally in excess of about 30,000 particles cm^{-3}. Most of the indoor situations seem to satisfy this condition especially when long time ($\sim$ >month) averaging is involved. As a result of this DRPS/DTPS systems are considered as the best available options for indoor measurement programmes.

In view of its uniqueness, novelty, ease of deployment and high potential for use in environments other than natural, the DTPS/DRPS detection concept requires careful elucidation of possible variability due to environmental effects. Chief among these is the variation in the sensitivity factors if the environmental aerosol concentrations or ventilation rates are drastically different from typical values. In fact, Mishra and Mayya [4] extended their model computations to extreme aerosol concentration scenarios and ventilation rates varying from 1.0 to 8 h^{-1} (Fig. 1) and predicted that while the sensitivity factor remains almost independent of the ventilation rate for higher aerosol concentration ($\geqslant$30,000 cm^{-3}), it becomes increasingly sensitive to ventilation rate at low aerosol concentrations (<10^4 particles cm^{-3}). Thus, in artificially ventilated and relatively cleaner environments such as those likely to occur in plant areas handling thorium and in Uranium mines, one might have to develop different calibration factors than for typical indoor air. Since DRPS and DTPS are intended for an ambitious programme of use as eventual personal dosimeters, it becomes necessary to develop location specific calibration factors.

To this end, in order to validate the model estimates at extreme environmental conditions, systematic studies were carried out in the calibration chamber using DTPS. The variability of the sensitivity factor as a function of ventilation rate and aerosol concentrations was experimentally determined for the chamber environment and compared with those obtained from the model calculations.

2. Model prediction of sensitivity factor of DTPS

As mentioned in Section 1, the tracks registered per unit exposure time per unit area of the detector surface (T) are related to EETC through the sensitivity factor (k_T) as

$$T = k_T \cdot \mathrm{EETC}, \tag{1}$$

where, k_T is dependent on the track registration efficiency (η) and the effective progeny deposition velocity (V_{eff}) which is actually the added contribution of the fine and coarse fraction of the individual progeny species. So, k_T can be written as [4]:

$$k_T = \frac{\eta V_{\mathrm{eff}}}{0.95\lambda_2}, \tag{2}$$

where $\lambda_2 = 1.8 \times 10^{-5}$ s^{-1} is the decay constant of ^{212}Pb.

The track registration efficiency for DTPS was obtained experimentally as $\eta = 0.0832$ [4]. For the indoor environment, the effective deposition velocity of the thoron progeny atoms was measured as 0.08 m h^{-1} [5].

Theoretically the effective deposition velocity can be calculated as follows. Let, n_2 and n_3 denote the atom concentrations, and p_2 and p_3 denote the fine fractions, of ^{212}Pb and ^{212}Bi in the atmosphere respectively. Let V_f and V_c be the deposition velocities of the fine and coarse fractions. Then the flux of ^{212}Pb + ^{212}Bi atoms on a given deposition surface may be given by

$$J_T = \{p_2V_f + (1-p_2)V_c\}n_2 + \{p_3V_f + (1-p_3)V_c\}n_3. \tag{3}$$

The effective deposition velocity which is actually the ratio of the deposited atom flux to the atom concentration in the room, can be written as

$$V_{\mathrm{eff}}(\text{thoron progeny}) = \frac{\{p_2V_f + (1-p_2)V_c\}n_2 + \{p_3V_f + (1-p_3)V_c\}n_3}{n_2 + n_3}. \tag{4}$$

This may be re-expressed, in terms of the activity concentrations (Bq/m^3), C_2 (=$\lambda_2 n_2$) and C_3 (=$\lambda_3 n_3$), (where, $\lambda_2 = 1.82 \times 10^{-5}$ s^{-1} and $\lambda_3 = 1.92 \times 10^{-4}$ s^{-1} are respective decay constants), as

$$V_{\mathrm{eff}} = \frac{[0.91\overline{V_2}C_2 + 0.09\overline{V_3}C_3]}{0.91C_2 + 0.09C_3}. \tag{5}$$

In Eq. (5), $\overline{V_2}$, $\overline{V_3}$ are the species specific deposition velocities, weighted with respect to their respective fine and coarse fractions:

$$\left.\begin{aligned}\overline{V_2} &= p_2V_f + (1-p_2)V_c\\ \overline{V_3} &= p_3V_f + (1-p_3)V_c\end{aligned}\right\}. \tag{6}$$

The fine fractions p_2 and p_3 of ^{212}Pb and ^{212}Bi, are derived by using a steady-state model of Jacobi (1972) incorporating the different rate processes such as the radioactive decay (λ_2, λ_3), aerosol attachment rate (X), wall-loss rates for fine (λ_w^f) and coarse (λ_w^c) fractions and ventilation rate (λ_v), governing the concentration of the progeny species. We obtain:

$$p_2 = \frac{C_2^f}{C_2^f + C_2^c} = \frac{\lambda_2 + \lambda_w^c + \lambda_v}{\lambda_2 + \lambda_v + \lambda_w^c + X},$$

$$p_3 = \frac{C_3^f}{C_3^f + C_3^c} = \frac{(\lambda_2 + \lambda_w^c + \lambda_v)(\lambda_3 + \lambda_w^c + \lambda_v)}{X(\lambda_2 + \lambda_3 + 2\lambda_v + \lambda_w^c + +\lambda_w^f + X) + (\lambda_2 + \lambda_w^c + \lambda_v)(\lambda_3 + \lambda_w^c + \lambda_v)}, \tag{7}$$