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Monte Carlo simulation experiments on box-type radon dosimeter

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ABSTRACT

Epidemiological studies show that inhalation of radon gas (^{222}Rn) may be carcinogenic especially to mine workers, people living in closed indoor energy conserved environments and underground dwellers. It is, therefore, of paramount importance to measure the ^{222}Rn concentrations (Bq/m^3) in indoors environments. For this purpose, box-type passive radon dosimeters employing ion track detector like CR-39 are widely used. Fraction of the number of radon alphas emitted in the volume of the box type dosimeter resulting in latent track formation on CR-39 is the latent track registration efficiency. Latent track registration efficiency is ultimately required to evaluate the radon concentration which consequently determines the effective dose and the radiological hazards.

In this research, Monte Carlo simulation experiments were carried out to study the alpha latent track registration efficiency for box type radon dosimeter as a function of dosimeter's dimensions and range of alpha particles in air. Two different self developed Monte Carlo simulation techniques were employed namely: (a) Surface ratio (SURA) method and (b) Ray hitting (RAHI) method.

Monte Carlo simulation experiments revealed that there are two types of efficiencies i.e. intrinsic efficiency (η_{int}) and alpha hit efficiency (η_{hit}). The η_{int} depends upon only on the dimensions of the dosimeter and η_{hit} depends both upon dimensions of the dosimeter and range of the alpha particles. The total latent track registration efficiency is the product of both intrinsic and hit efficiencies. It has been concluded that if diagonal length of box type dosimeter is kept smaller than the range of alpha particle then hit efficiency is achieved as 100%. Nevertheless the intrinsic efficiency keeps playing its role.

The Monte Carlo simulation experimental results have been found helpful to understand the intricate track registration mechanisms in the box type dosimeter. This paper explains that how radon concentration from the experimentally obtained etched track density can be obtained. The program based on RAHI method is also given in this paper.

1. Introduction

Radon (^{222}Rn) is an alpha emitting radioactive inert gas produced by traces of radium (^{226}Ra) present in indoors and outdoors environments [1]. Epidemiological studies show that inhalation of radon gas may cause cancer especially among the people living in closed indoor energy conserved environments, underground dwellings and uranium mine workers [2]. It is, therefore, of paramount importance to measure the ^{222}Ra concentrations in indoors environments. Ion track detectors such as CR-39 have been widely employed for environmental radon measurements and dosimetry [1,3,4].

Modeling and Simulation has become an alternate of doing experiments in science, engineering and in particular to determine the efficiency of radiation detectors including ion track detectors [5–8]. Since alpha decay from radon is a stochastic phenomenon, the application of Monte Carlo technique is the most pertinent to model and simulate a box type dosimeter [9,10]. Monte Carlo simulation gives the results just like doing the real experiments. The response of any radon dosimeter is usually given as the calibration factor in track density rate per unit integrating radon concentration (tracks/cm^2-h/Bq/m^3) [11–13]. In this research, latent track registration efficiency is the fraction of the number of radon alphas reaching the ion track detector surface out of the total radon alphas emitted within the volume of the box type dosimeter. If latent track density is determined by modeling and simulation then one can find the radon concentration (Bq/m^3) and eventually the radiological hazards.

This research is purporting to understand the intricate radon latent alpha track registration mechanisms through the use of Monte Carlo simulation experiments. Two self developed Monte Carlo simulation models have been developed to simulate box type radon dosimeter.

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2. Monte Carlo simulation models

In this research two Monte Carlo simulations methods were developed. The methods are given under the rubric of (a) Surface Ratio (SURA) method and (b) Ray Hitting (RAHI) method. The models in this research assumed two conditions: (i) at time $t=0$, the radon (^{222}Rn), in secular equilibrium with its short lived progeny mixed in air, enters into the volume of the box type radon dosimeter and fills up the space with the known radon concentration C (Bq/m^3) and (ii) it is assumed that all radon alphas falling on the ion track detector (CR-39) are registered as latent tracks.

Parametric studies were carried out by changing the size of box type radon dosimeter and range of alpha particles. Total latent track registration efficiencies were computed using all the two independent methods. Monte Carlo simulation experiments were found very useful to study the behavior of the box type dosimeter for latent track registration efficiency and for dosimeter design optimization.

This paper explains the two methods proposed by the authors in the following.

2.1. Surface ratio (SURA) method

Once entering the dosimeter, the radon gas emits alpha particles within the space of the dosimeter. Fig. 1 shows a box type radon dosimeter. Here 'a', 'b', and 'c' are the width, length, and height of the box type dosimeter, respectively. The ion track detector (CR-39) is place in xy-plane.

If from a randomly chosen point, (shown in Fig. 1) radon alpha is emitted then what is the probability that alpha particle will move to any particular side of the box type dosimeter? This radon alpha may move towards the ion track detector (CR-39) with a probability:

$$P=\frac{ab}{2(ab+bc+ca)} \tag{1}$$

where 'ab', 'bc' and 'ca' are the areas of the surfaces of the box type radon dosimeter (Fig. 1).

Monte Carlo simulation decides which alpha is moving towards the detector using pseudorandom numbers on digital computers [14,15] by generation a number 'ξ_i' between $0 \le \xi_i \le 1$. If $\xi_i \le P$ then the alpha particles move towards the detector ($N\alpha_{\mathrm{MTD}}$) otherwise they will move towards either of other five surfaces. This process is continued for 'n' randomly selected alpha particles emitted in the volume of the box type dosimeter. Therefore, n is the radon concentration C(Bq/m^3) multiplied by exposure time t (s). The intrinsic efficiency (η_{int}) is thus computed using Monte Carlo simulation technique as:

$$\eta_{int}=\frac{1}{n}\sum_{i=1}^{n} N\alpha_{\mathrm{MTD}(i)} \tag{2}$$

The intrinsic efficiency is the fraction of the number of radon alphas moving towards the detector out of the total alpha particles (n) emitted within the volume of the detector.

However, all alpha particles moving towards the detector may not reach the detector because of the limitation of the range of alpha particle R_α in air. If the distance 'd' from the random point of emission to a random point on detector surface (shown as open circles in Fig. 1) is greater than the range of alpha 'R_α' in air (for example 3.987 cm for ^{222}Ra) [11], the alpha particle will not reach the detector to be registered by CR-39 ion track detector as latent track. In order to simulate this situation, a point P_p (x_p,y_p,z_p), as shown in Fig. 1, is chosen at random in the volume of the dosimeter using Monte Carlo simulation technique as:

$$\begin{aligned} x_p &= a\xi_1 \quad 0 \le \xi_1 \le 1 \\ y_p &= b\xi_2 \quad 0 \le \xi_2 \le 1 \\ z_p &= c\xi_3 \quad 0 \le \xi_3 \le 1 \end{aligned} \tag{3}$$

where 'a', 'b', 'c' and 'ξ_i' are the dimensions of the box-type radon dosimeter and random numbers, respectively.

Moreover, random points P_s (x_s, y_s,z_s) are generated on the surface of the detector where the alpha particle may hit (as shown in Fig. 1) as given in the following Eq. (4):

$$\begin{aligned} x_s &= a\,\xi_4 \quad 0 \le \xi_4 \le 1 \\ y_s &= b\,\xi_5 \quad 0 \le \xi_5 \le 1 \end{aligned} \tag{4}$$

The distance from point 'P_p' to the point 'P_s' is computed as:

$$d=\sqrt{(x_p-x_s)^2+(y_p-y_s)^2+(z_p-0)^2} \tag{5}$$

Then the distance 'd' is compared with the range of alpha 'R_α'. If it is found that

$$d < R_\alpha \tag{6}$$

then alpha-particle will reach the detector (hit) and get registered as latent track. The fraction of the number of alpha particles

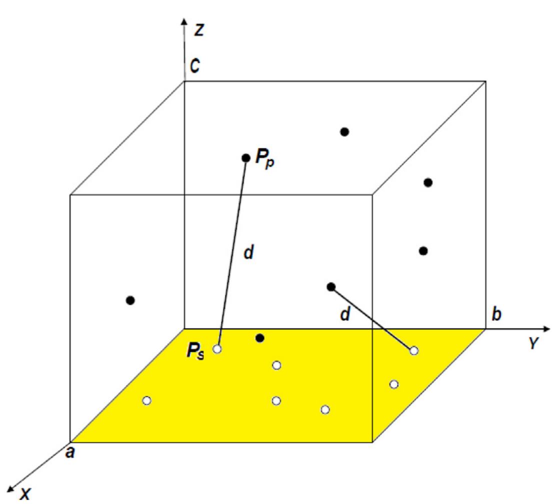

Fig. 1. The detector is shown at the bottom surface of a box-type dosimeter. The arrows show the distance 'd' from point of emission of alpha to points where the alpha may hit arbitrarily. The filled circles show the points in the volume where radon alphas are emitted and open circles represent the points on the detector where the radon alphas may fall.

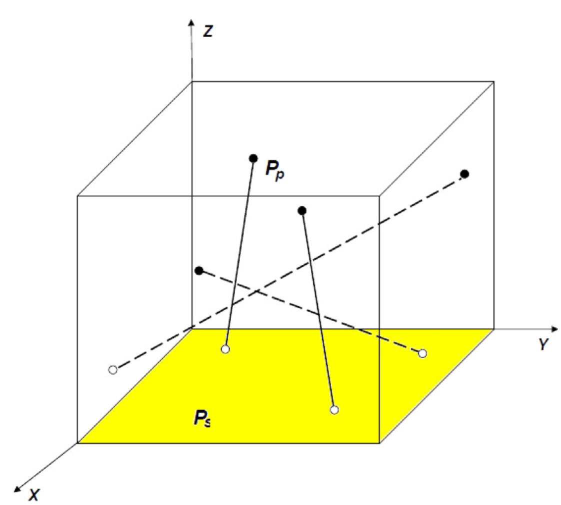

Fig. 2. This figure shows the RAHI method. Random lines are chosen by Monte Carlo simulation. Radon alphas particles moving on solid lines may hit the detector as shown by solid lines and alphas travelling along the dotted lines will not hit the detector.