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Modeling of indoor ^{222}Rn distribution in ventilated room and resulting radiation doses measured in the respiratory tract

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ABSTRACT

Most of radiation hazard of indoor radon is largely due to the radon progenies, which are inhaled and deposited in the human respiratory tract. It is therefore important to understanding the distribution of radon and their progeny in indoor environment helps in calculating the inhalation doses due to them. This paper focuses on effects of exhalation from different sources (wall, floor and ceiling) and the ventilation profile on distribution of the concentrations of radon and their progeny indoor. The radon exhalation rate from walls, floor and ceiling, and ventilation rate were measured as a part of this study and are used as input in Finite Volume Method (FVM) simulation. The findings show that the radon concentration which is distributed in a non-homogeneous way in the room is due to the difference in the radon concentration of different sources (wall, floor and ceiling). Moreover, the radon concentration is much larger near walls, and decreases in the middle of the room because of the effect of air velocity. It has also been found that the distributions of unattached and attached fraction of ^{218}Po, ^{214}Pb and ^{214}Po radionuclides are similar to that of ^{222}Rn. In addition, equilibrium fraction F and the unattached fraction (f_j) of ^{218}Po, ^{214}Pb and ^{214}Po radionuclides for different values of the attachment rate were evaluated. The committed equivalent doses due to ^{218}Po and ^{214}Po radon short-lived progeny were evaluated in different tissues of the respiratory tract of workers from the inhalation of indoor air.

1. Introduction

Radon and their decay products are present in the indoor environment since their parent nuclei radium and thorium are present in building materials and the soil. It is well known that the inhalation of radon and their decay products contributes a major part (more than 50%) of the natural background radiation dose to the humans (UNSCEAR, 2000, pp. 453–487). Further, in the indoor environment, the inhalation doses due to the ^{222}Rn are predominantly contributed from their decay product concentrations in the indoor environment. Therefore, the estimation of the behavior of ^{222}Rn and their decay products indoor is very important for assessing the radiation dose received from the inhalation of radon and their progeny.

At present, limited experimental work has been reported on radon progeny products indoor (Steinhäusler, 1996). However, these studies assumed a homogeneous activity distribution in the room. More recent studies (Rabi & Oufni, 2017; Urosevic & Nikezic, 2008) have addressed this shortcoming, using numerical simulation. But, a major limitation of these studies is not taking into account the influences the exhalation of radon from different sources (wall, floor and ceiling).

In this work, a model based on the Finite Volume Method (FVM) for the simulation of spatial and temporal distribution of the radon concentrations and their progeny in a typical Moroccan room. Computer simulation was implemented in FORTRAN software. As part of this study, algorithms are developed to allow for a detailed description of the production and attachment of the radioactive progeny products as well as their dispersion and deposition. Furthermore, the radon exhalation from walls, floor and ceiling has been measured for this room using solid state nuclear track detectors (SSNTD) technique that is widely used to measure radon/thoron, uranium and thorium in various samples (Hesham, Gehad, El-Farrash, & Hamza, 2016; Rafat, 2015; Singh et al., 2015). The annual committed equivalent doses in the tissues of the respiratory tract due to the inhalation of radon short-lived progeny by workers

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were also determined.

2. Methods and measurements

2.1. Description of room geometry

Experimental works were carried out in the room of dimensions (4 m × 3 m × 3 m) which is similar to an ordinary living room in Morocco (Fig. 1). The window is located in middle of the left wall, while the door is on the right side of the lateral wall. The door and window were kept closed; the flow of air is due to the two small openings that are open. Opening in window which is directly in contact with the outer environment is considered as air inlet and the other in high is considered output, are symmetrical with the center plane (Y = 1.50 m). Radon exhalation rate from the room surfaces (walls, floor and ceiling) are the only sources of the indoor radon.

2.2. Determination of radium activity and radon exhalation rate

The building material samples have been taken from the ceiling, floor and walls of house studied, crushed and placed within contact to solid state nuclear track detectors (SSNTD) in a plastic container for one month. During this time, α-particles emitted by the nuclei of the uranium and thorium series have bombarded the SSNTD films. After the irradiation, the exposed films were etched in a NaOH solution at optimal conditions of etching, ensuring good sensitivities of the SSNTDs and a good reproducibility of the registered track density rates: 2.5 N solution at 60 °C for 1.5 h for the LR-115 type II films and 6.25 N solution at 70 °C for 6 h for the CR-39 detectors. After this chemical treatment, these SSNTDs were washed, dried and scanned using an optical microscope (Oufni & Misdaq, 2001).

Under our experimental conditions, and assuming that there is a secular equilibrium between uranium, thorium and their daughters, thus knowing the track densities on each SSNTD used, we can evaluate the radium activities by using the following equations:

$$D_G^{LR} = 0.5\, d_s\, \Delta R_s\, \sin^2\theta'_c A_c(^{226}Ra)\left[4 + 3\frac{A_c(^{232}Th)}{A_c(^{226}Ra)}\right] \quad (1)$$

$$D_G^{CR} = 0.25\, d_s \sin^2\theta_c A_c(^{226}Ra)\left[\sum_{i=1}^{8} k_i R_{\alpha i} + \frac{A_c(^{232}Th)}{A_c(^{226}Ra)}\sum_{i=1}^{7} k_i R_{\alpha i}\right] \quad (2)$$

where D_G^{LR} and D_G^{CR} are the track density rates registered on the LR-115 type II and CR-39 (tracks $cm^{-2}s^{-1}$), $A_c(^{226}Ra)$ and $A_c(^{232}Th)$ are the radium (^{226}Ra) and thorium (^{232}Th) α-activities inside the studied material sample ($Bqkg^{-1}$), d_s is the building material sample density ($kg\ m^{-3}$), k_i is the branching ratio in %, $R_{\alpha i}$ is the range of α-particle of energy $E_{\alpha i}$ and index i inside the building material sample and it is calculated by means of the TRIM program, θ_c and θ'_c are the critical angles of etching for the LR-115 type-II and CR-39, respectively. $\Delta R_s = R_{max} - R_{min}$ where R_{max} and R_{min} are the α-particle ranges in the building material samples which correspond to the lower and upper ends of the energy window which depend on the residual thickness of the LR-115 SSNTD (Oufni, 2003).

Combining equations (2) and (3), we obtain the following relationship between the radium (^{226}Ra) to thorium (^{232}Th) ratios and track densities. Indeed, we have:

$$\frac{A_c(^{232}Th)}{A_c(^{226}Ra)} = \frac{0.5\sin^2\theta_c \sum_{i=1}^{8} k_i R_{\alpha i} - 4\gamma'\Delta R_s \sin^2\theta'_c}{\left[3\gamma'\Delta R_s \sin^2\theta'_c - 0.5\sin^2\theta_c \sum_{i=1}^{7} k_i R_{\alpha i}\right]} \quad (3)$$

where: $\gamma' = \frac{D_G^{CR}}{D_G^{LR}}$

From where one obtains the radium activity given by:

$$A_c(^{226}Ra) = \frac{2D_G^{LR}}{\Delta R_s d_s \sin^2\theta'_c\left[4 + 3\frac{A_c(^{232}Th)}{A_c(^{226}Ra)}\right]} \quad (4)$$

For the calculation of radon α-activities, we have placed the SSNTD at a distance of 9 cm above the material samples. The range for the α-particles emitted by radon and their corresponding daughters in the gas volume has been determined by the TRIM program. The radon α-activities per unit volume have been measured outside [$A_c(^{222}Rn)$] different samples by using the track densities measured on the LR-115 [$D^*(LR)$] SSNTDs given by (Oufni, 2003):

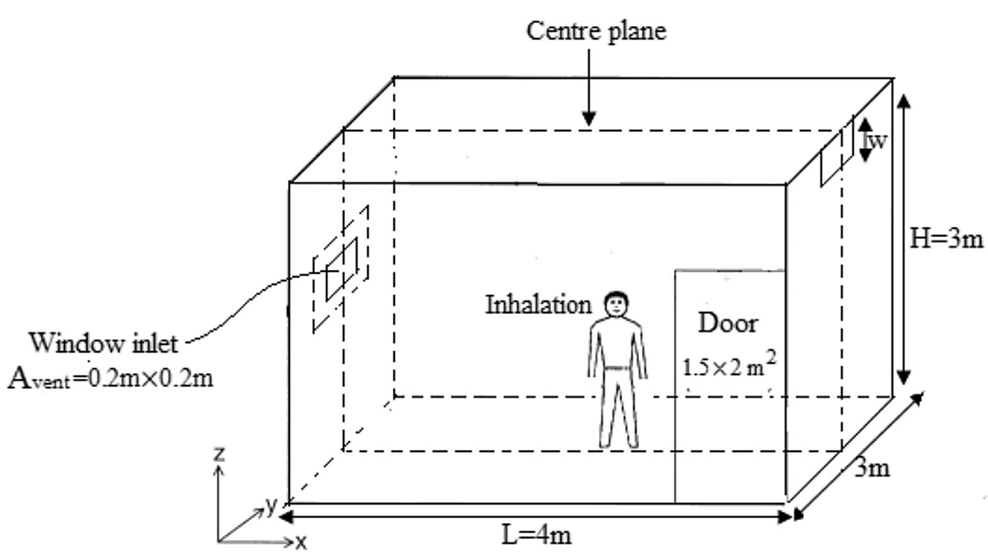

Fig. 1. Geometrical configuration of the model room, a size of screen (0.2 m × 0.2 m) is supposed for the airflow inlet and outlet.