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Surface-deposition and distribution of the radon-decay products indoors

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ABSTRACT

The exposure to radon-decay products is of great concern both in dwellings and workplaces. The model to estimate the lung dose refers to the deposition mechanisms and particle sizes. Unfortunately, most of the dose data available are based on the measurement of radon concentration and the concentration of radon decay products. These combined measurements are widely used in spite of the fact that accurate dose assessments require information on the particle deposition mechanisms and the spatial distribution of radon decay products indoors.

Most of the airborne particles and/or radon decay products are deposited onto indoor surfaces, which deposition makes the radon decay products unavailable for inhalation. These deposition processes, if properly known, could be successfully exploited to reduce the exposure to radon decay products. In spite of the importance of the surface deposition of the radon decay products, both for the correct evaluation of the dose and for reducing the exposure; little or no efforts have been made to investigate these deposition processes. Recently, two parallel investigations have been carried out in Rome and at Universidad Nacional Autónoma de México (UNAM) in Mexico City respectively, which address the issue of the surface-deposited radon decay products. Even though these investigations have been carried independently, they complement one another. It is with these considerations in mind that it was decided to report both investigations in the same paper.

1. Introduction

The exposure to radon-decay products is of great concern both in dwellings and workplaces. Extensive efforts have been done in epidemiological studies to estimate the effects of the exposure to radon-decay products in dwellings (Cavallo, 2000). Together with epidemiological studies, dosimetric models have been developed. These models to estimate the lung dose refer to the deposition mechanisms and particle sizes. Unfortunately, most of the dose data are based on the measurements of radon concentration and the concentration of radon-decay products. These combined measurements are widely used in spite of the fact that they do not give any information on the particle deposition of various radon progeny inside the lung and on the spatial distribution of radon-decay products indoors.

Most of the particles are deposited on indoor surfaces (plate-out) that makes the radon-decay products unavailable for inhalation (Tommasino et al., 2010). Plate-out processes, if properly modeled, could be successfully exploited as mitigation techniques to reduce the exposure to the radon-decay products. In spite of the great importance of the radon-decay product surface deposition, both for a correct evaluation of the dose and to reduce exposure, little or no efforts have been made in the past to investigate deposition processes.

2. Indoor surface-deposition of radon-decay products

For a given radon concentration, some authors have reported that the extent of the particle deposition on surfaces depends strongly on surface-to-volume ratio (being hundreds of times larger outdoors than indoors), on the electro-statically accumulated on persons and objects, and air movement (Miles, 1986; Swerdlow, 2004). In a report by NRPB in 2004 (Swerdlow, 2004), it is stated that “Although radon gas concentrations are generally a factor of five larger indoors than outdoors, deposition rates of the decay

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products can be about ten times higher outdoors than indoors". This is mainly because of turbulence but is also affected by the fact that for a given radon concentration there are typically twice as many decay products in outdoor air as there are in indoor air. The total deposition indoors and outdoors would be roughly equal for someone who spends ten times as much time indoors as outdoors.

However, it is important to state that the differences in the surface-depositions may be by far larger than the correspondent differences induced to the dose (Scott, 1983; Knutson et al., 1992). In order to measure the indoor surface deposition of radon-decay products, two different methods have been used. These methods make it possible to obtain respectively the short-term (namely 3 h, i.e. the deposition-time needed to achieve radioactive equilibrium) and the long-term measurements (a few months) of the surface deposition of radon-decay products.

3. Experiments and results from two different laboratories

3.1. Short-term-measurement of the surface-deposition of radon-decay products

The measurements of the surface-deposition of the radon-decay products are difficult because the activity is spread over a large area, thus, the activity per unit area is small. The few existing investigations have been carried out by using sheets of different materials with surface areas identical to that of the sensitive-window of the monitor used (Scott, 1983; Knutson et al., 1992). In order to obtain a sufficient large response with said small deposition-areas, exposures have been carried out only in test chambers or in closed environments with exceptionally large radon concentrations (Porstendorfer and Mercer, 1978; Scott, 1983; Bigu, 1987; Knutson et al., 1992).

It is with these considerations in mind that a new sampling method has been recently developed for measuring the surface-deposition activity of radon decay products at typical indoor levels (Tommasino and Tommasino, 2009).

In this new method, the sampling element (hereafter referred to as sampler) is characterized by a collecting surface (about 1000 cm^2) much larger than the area of the sensitive detector-window and a surface density (g/cm^2) much less than the range of the beta particles to be detected.

Once exposed, this large-surface sampler can be packed into a stack, having a surface suitable to match the sensitive detector window and any predefined thickness, the maximum value of which is given by the maximum range of the beta particles in said stack. For samplers made of a thin plastic film (≤ 1 mg/cm^2), the stack is made by folding it over itself many times until it does cope with predefined thickness and area. The use of a stack is possible since all the sampling elements are made of materials with low atomic number, thus ensuring that less than 10% of the beta particles are "retro-diffused" (Tommasino and Tommasino, 2009).

After the exposure, these samplers become sources of radiations, of which the beta particles, emitted by ^{214}Pb and ^{214}Bi, have maximum (endpoint) beta-energies of 1.024 and 3.27 MeV respectively.

These relatively high energies are attractive since they make it possible to use stacks with large thickness thus ensuring a large response for beta counting. The stack is counted with a large area beta-contamination monitor, namely a pan-cake Geiger–Muller counter. A typical sampler for the collection of radon (^{222}Rn and ^{220}Rn) decay products (RD) is a thin metalized Mylar™ (Du Pont de Nemours) film, which is held in a picture-like frame for in free-air exposure to allow deposit on both film surfaces.

Measurements have been typically carried out with a Mylar film with an area of about 1000 cm^2 and a surface density of 0.3 mg/cm^2, metalized on both sides by about 100-Å-thick aluminum-layer. In order to determine the vertical profile of radon decay products (RD), measurements in the center of a small room have been carried out by a long aluminized film (30 cm wide). The results in arbitrary unity are reported in Fig. 1 which shows substantial gradients in concentration of surface-deposited radon decay products, with the highest occurring at about 1 m height, i.e. at the breathing-zone. These results must necessarily be taken under consideration for the correct evaluation of the exposure to radon decay products (and/or to other airborne particles) for different height groups of the population.

Similar results on the vertical concentration-profiles of airborne particles in a room have been obtained, by using an optical system (Micallef et al., 1998). Said monitoring system, in addition to be too complex, makes it possible to measure only micron-sized particles, while the largest contribute to the health effects is due to the nanometer-sized-particles (Nazaroff and Cass, 1991; Thatcher et al., 2002). The long-film sampler makes it finally possible to assess the distribution of the concentration of the radon decay products, simply by a pancake G.M. counter.

3.2. Long-term measurements of surface-deposited radon decay products

Due to the variations of both radon and radon decay products indoors, correct dose evaluations require the measurements of the long-term radon decay surface-deposition. To this end the plastic-based Nuclear Track Detectors are the most suitable (Abujarad, 1988; Toohey et al., 1984).

Extensive investigations have been recently carried by using bare CR-39™ (Lantrack®) detectors in a room with controlled microclimate conditions, located in Mexico City. The temperature 20 °C average value, the relative humidity 55%, the atmospheric pressure 798–800 mbar, and average radon gas concentration value of 710 ± 26 Bq/m^3; these environmental parameters are constant during the three months experiment, as shown in Fig. 2 (measured with AlphaGUARD® dynamic system) (Espinosa et al., 2013). These unique and attractive environmental conditions are due to the fact the room is underground with little or no effect by the outside temperature and humidity. This data shows how reproducible are the environmental conditions in this room. The radon concentration is also relatively constant, since changes occurred only at the time the gate was open.

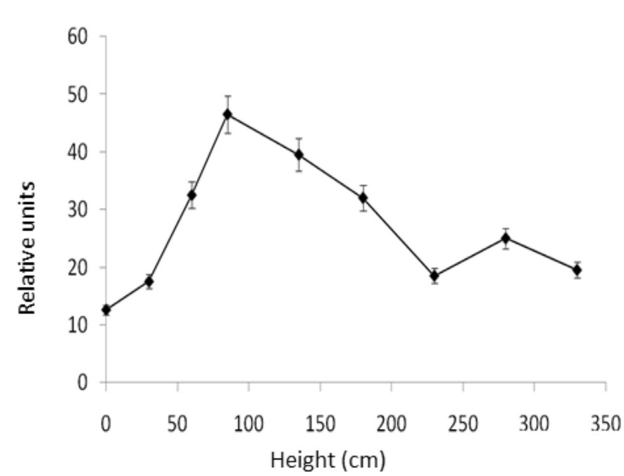

Fig. 1. Vertical distribution of surface-deposited radon-decay products, obtained by short-term measurements.