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Mitigation of the effective dose of radon decay products through the use of an air cleaner in a dwelling in Okinawa, Japan

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ABSTRACT

Field measurements were conducted to assess the effects of an air cleaner on radon mitigation in a dwelling with a high radon concentration in Okinawa, Japan. The measurements included indoor radon concentration, individual radon progeny concentration, equilibrium equivalent concentration of radon (EECRn), unattached fraction, and size distribution of aerosol-attached radon progeny. These measurements were conducted in a 74 m^3 room with/without the use of an air cleaner. The results showed that the mean radon concentration during the measurement was quite high (301 Bq m^{-3}). The operation of air cleaner decreased the radon progeny activity concentration, EECRn and equilibrium factor by 33%, 57% and 71%, respectively, whereas the unattached fraction increased by 174%. In addition, the activity concentration of attached radon progeny in the accumulation mode (50–2000 nm) was obviously deceased by 42%, when the air cleaner was operated. According to dosimetric calculations, the operation of air cleaner reduced the effective dose due to radon progeny by about 50%.

1. Introduction

The largest part of the general population's exposure to natural radiation originates from the inhalation of short-lived radon (^{222}Rn) progeny (United Nations Scientific Committee on the Effects of Atomic Radiation, 2000). The progeny are radioactive isotopes of ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po, which are produced by ^{222}Rn. Generally, atmospheric radon progeny are classified into unattached and attached fractions. After radon decays, solid particle progeny are formed. The progeny, called "unattached fraction" (f_p), is comprised of a number of ultrafine particles and clusters. The ultrafine particles consist of a complex mixture of charged and neutral particles, which are generated from radiolysis of water molecule with a size of 0.5–5 nm (Ramamurthi and Hopke, 1989). On the other hand, clusters are formed in size range of 0.7–2 nm when the radon progeny attach polar or neutral molecules during the decay process (Květoslav, 2000). The unattached fraction of radon progeny consists mainly of ^{218}Po (80–82%), which is positively charged after its formation (Porstendörfer and Mercer, 1979; Dua et al., 1983). These atoms then attach to ambient aerosols, forming the radioactive aerosols (Porstendörfer, 1994) that make up the "attached fraction".

In all dosimetric models for the estimation of the exposure, a dominant physical parameter is the activity size distribution of radon progeny in the air. A considerable portion of the unattached atoms may be deposited in the extra-thoratic and bronchial regions, whereas the attached atoms are deposited in different parts of the pulmonary region owing to the different sizes of the aerosol particles (Shimo et al., 1981). Epidemiological studies have established that enhanced levels of radon and its progeny in dwellings can cause health hazards and may lead to serious diseases, such as lung cancer (Lundin et al., 1971; Sevc et al., 1976; Axelson, 1995; Bochicchio et al., 1998; Field et al., 2000).

Several techniques for mitigating radon have been developed to reduce indoor radon concentration and the associated health risks. The techniques can be divided into two categories: those intended to prevent soil gas entry into the living area and those intended to remove radon after it is present (Henschel, 1994). Natural or forced ventilation and the use of air cleaners are included in the latter category. Henschel (1994) reported that the use of air cleaners might result in an increase in the concentration of unattached progeny, despite a reduction in the total concentration. Because the unattached progeny may give a significant dose to the lungs, the dose mitigation effects were unclear.

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Several studies have reported on the use of air cleaners to mitigate the health effects from indoor radon progeny. Li and Hopke (1991) reported that air cleaners are effective in reducing the median dose resulting from radon progeny. Tokonami et al. (2003) pointed out that the use of an air cleaner critically enhances the dose conversion factor because the unattached fraction increases significantly as a result of the removal of aerosols. These dose mitigation studies should have included an estimation of the particle size distribution and its application to dosimetry to more completely evaluate the effects of the use of air cleaners on dose mitigation (Li and Hopke, 1991; Offermann et al., 1985).

In the present study, the concentration of radon and its decay products and the activity size distribution of attached aerosol particles were measured with and without the use of an air cleaner in a dwelling with a high radon concentration. On the basis of these measurements, this paper describes the results in terms of the effectiveness of the air cleaner on the mitigation of radon progeny and effective dose.

2. Materials and methods

2.1. Study location

Concentrations of indoor radon and its decay progeny were measured in the first-floor bedroom of a dwelling in Yomitan village, Okinawa prefecture, Japan. The study took place from 19 to 21 November 2007. The volume and surface area of the room are about 72 m^3 and 24 m^2, respectively. The walls and the floors are made from gypsum board and wood, respectively. The bedroom was selected for experiments because relatively high levels of radon concentration had been previously recorded in this room (Sanada et al., 1999).

2.2. Measurement techniques

Indoor radon concentration and equilibrium equivalent concentration of radon (EECRn) were measured continuously at every 1 h with a pulse ionization chamber (AlphaGUARD, Genitron Instruments GmbH, Germany) and a Working Level monitor (Pylon Electronics Inc., Canada), respectively.

The total activity concentration of radon progeny was measured after sampling radon progeny on a glass microfiber filter (47 mm diameter, Whatman®, England) that had been operated at a flow rate of 10 L min^{-1} for 5 min. Gross alpha particles were counted with a ZnS(Ag) scintillation detector (Ludlum Instrument Inc., USA) for a period of 40 min at 5-min intervals. The concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi were calculated with the method described by Thomas (1972).

The unattached fraction of radon progeny was measured by using an alpha spectrometry method. Unattached progeny was collected on a 400-mesh metal wire screen (40 mm diameter, TETKO Inc., USA), and they were considered as a single type for convenience. The diffusion coefficient was assigned to be 0.065 $cm^2 s^{-1}$ (Tokonami, 1999). The alpha activities were detected during and after air sampling by a continuous air monitoring PIPS detector (Model CAM1200, Canberra Inc., USA), which was set opposite to the metal wire screen (Tokonami et al., 1996). The measurement system was set up as shown in Fig. 1. ^{241}Am was used as a calibration source, and the counting efficiency was found to be 30.1 $\pm$0.5%. The detector has an active area of 1200 mm^2 (42 mm diameter) and an alpha energy resolution of about 70 keV. This resolution enables the discrimination between the alpha particle energies of 6.0 MeV from ^{218}Po and 7.8 MeV from ^{214}Po. To determine the activity concentration of unattached radon progeny (^{218}Po, ^{214}Pb and ^{214}Po), the measurements were performed in two steps. First, the alpha spectrum was acquired during a sampling period of 20 min. Second, after waiting for a period of 5 min without sampling, the alpha spectrum was measured again (during decay) for a period of 15 min. The air flow rate during the measurement was 4 L min^{-1}. From the measured alpha-counts of ^{218}Po and ^{214}Po during the sampling period and the ^{214}Po counts during the decay period, the activity concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi could be calculated by using the build-up and decay method (Cliff, 1978; Tremblay et al., 1979).

For the determination of the particle size distribution of the attached radon progeny, a Micro Orifice Uniform Deposit Impactor (Model 110 MOUDI™, USA) was used. Efficiency curves and interstage losses of the impactor stages were determined (Virgil et al., 1991). The impactor consisted of eight size fractionating stages and a back-up filter holder, and it was operated at a flow rate of 30 L min^{-1} for 10 min. The measured 50% cut-off diameters for the eight stages were 0.056, 0.10, 0.18, 0.32, 0.56, 1.0, 1.8, 3.2, and 18 μm. A 400-mesh metal wire screen was set at the top of the MOUDI to prevent invasion of unattached progeny, and the collection efficiency was estimated to be 89.1%, based on fan model filtration theory (Cheng and Yeh, 1980). After sampling, the collected activity on each impactor stage was simultaneously measured with the ZnS(Ag) scintillation detectors. The activity concentrations of radon progeny for each stage were analyzed

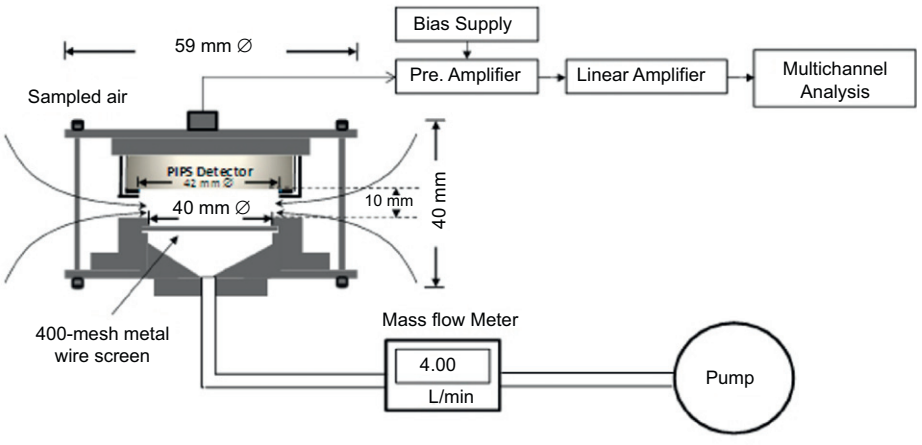

Fig. 1. The schematic diagram of unattached radon progeny measuring system.