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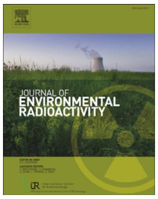

Distribution of radon concentrations in child-care facilities in South Korea

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ABSTRACT

This study was conducted to provide fundamental data on the distribution of radon concentrations in child day-care facilities in South Korea and to help establish radon mitigation strategies. For this study, 230 child-care centers were randomly chosen from all child-care centers nationwide, and alpha track detectors were used to examine cumulative radon exposure concentrations from January to May 2015. The mean radon concentration measured in Korean child-care centers is approximately 52 Bq m^{-3}, about one-third of the upper limit of 148 Bq m^{-3}, which is recommended by South Korea's Indoor Air Quality Control in Public Use Facilities, etc. Act and the U.S. Environmental Protection Agency (EPA). Furthermore, this concentration is about 50% lower than 102 Bq m^{-3}, which is the measured concentration of radon in houses nationwide from December 2013 to February 2014. Our results indicate that the amount of ventilation, as a major determining factor for indoor radon concentrations, is strongly correlated with the fluctuation of indoor radon concentrations in Korean child-care centers.

1. Introduction

Radon is a radioactive gas continuously generated from natural decay of ^{238}U in soils, rocks, and water. Several studies on people exposed toradon (^{222}Rn) confirmed that radon in homes and workplaces poses a serious health risk (WHO, 2005, 2009; ICRP, 2007; AGIR, 2009; UNSCEAR, 2009). Moreover, the risk of developing lung cancer increases for those who have experienced long-term exposure to high concentrations of radon, which causes pathological changes in the function of the respiratory system. This risk was reported to depend on the indoor radon concentration, exposure time, and building ventilation (Neuberger and Gesell, 2002; Lazar et al., 2003). The half-life (3.82days) of radon is sufficiently long for the gas to spread from its source and accumulate in enclosed indoor spaces. Thus, radon is known to potentially be the most dangerous radioisotope. Radon is released from the soil in a gaseous state and can enter buildings through cracks in concrete floor sand walls, holes in floors, drainage pumps, construction joints, and small cracks or holes in hollow block walls. When radon enters a closed space and becomes concentrated, it may reach levels hazardous to public health (Kurnaz et al., 2011). Radon and its decay products concentrate in underground mines, caves, basements, or inadequately designed buildings with poor ventilation, which may cause severe health problems. Thus, information about the radon concentration in residences is important for assessing health risks or when deciding the design of control strategies (Singh et al., 2006).

Children may be more vulnerable to environmental exposure than adults. Since children are in a growing stage, the respiration rate per unit weight in children is higher than that in adults (Patriarca et al., 2000). Accordingly, the U.S. Environmental Protection Agency (EPA) suggested that radon exposure in schools, child-care centers, and nursery facilities could be an issue, and after randomly choosing 927 schools across the United States in 1990, it has been conducting radon mitigation projects in schools and children's activity spaces (US EPA, 1993; 1994). In South Korea, however, no follow-up investigation on the state of radon concentrations in elementary schools has been carried out since the one conducted on a nationwide scale for elementary schools and government offices from 2008 to 2009. Moreover, there has been

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no government-guided survey on radon concentrations in child-care centers.

To provide fundamental data for future radon reduction and management in children's activity spaces in South Korea, this research was conducted to collect data on radon levels in child-care centers inferred from radon concentrations obtained through different methods such as government surveys on the state of radon in dwellings nationwide.

2. Materials and methods

Child-care centers for this study were randomly selected from among child day-care facilities listed in the Private Child Care Association database and the database of day-care facilities in which the 2014 indoor air quality surveys were performed by the Institutes of Health Environment in South Korea. Child-care centers were asked through phone interviews whether they would participate in this research, and those who agreed to participate were selected as target facilities for a first round of sampling.

The measurements in each targeted child-care center were taken in two selected classrooms where children would spend the day. The following principles were applied when selecting the target measurement location. 1) Two classrooms where children spend the day in the target child-care centers shall be selected as measurement locations. 2) All measurement locations shall be on the first floor or lower. However, if there is no activity space on the first floor, the second floor or higher can be examined, and if it is determined that the radon concentration on or above the second floor is high, such classrooms shall be included as measurement locations. 3) If the activity space is located in the basement, the basement activity space shall be routinely selected as a measurement location, and the ground floor (first floor) in the same building shall also be selected as a measurement location. 4) The detector shall be located at the center of the selected activity space, and if this location is in the path of air currents (from a window, ventilator, etc.), a location that is not affected by the air current shall be selected instead. In the case where it was impossible to conduct the investigation according to these principles, field researchers selected a target location that best conformed to the location selection principles.

Radon concentrations were measured using a passive radon detector, Raduet Model RSV-8 alpha track detector (Radosys Inc., Budapest, Hungary) to examine the cumulative exposure concentration for three months. One of the advantages of this detector is that it can measure both radon and thoron (^{232}Th), and thus obtain data on thoron concentrations in addition to radon concentrations. Furthermore, selecting this detector will allow future data sharing as it has been used by the Ministry of Environment of South Korea in the nationwide survey of radon concentrations in houses.

The detectors were installed between January and February 2015 and were exposed for three months before they were collected between April and May 2015. The collected detectors were sealed to prevent airflow into the detector and then transported to the National Institute of Environmental Research for analysis. The sensing elements were dismounted from the collected detectors and submitted to the pre-processing stage. The obtained track was evaluated under a microscope to calculate radon concentrations. Automated equipment (Radosys, Hungary) was used in the pre-processing and track calculation stages. The sensing elements in the detector was chemically etched in 6.25 M NaOH solution at 90 °C for 3 h and 40 min and then neutralized in 1% acetic acid solution for 20 min. After drying at room temperature for one day as a pre-processing step, the track was calculated. The track generated by alpha particles was calculated using an automatic reader and the density of the track was used to calculate radon concentrations using Eqs. (1) and (2).

$$\mathbf{RAC} = \mathbf{EXP}_{Rn} \times \frac{\frac{\mathbf{1000}}{\mathbf{24}}}{T} \tag{1}$$

$$\mathrm{EXP}_{Rn} = \mathrm{CF} \times (\mathbf{1.00} \times RnD - \mathbf{0.02} \times TnD), \tag{2}$$

where RAC is radon activity concentration (Bq m^{-3}),EXP$_{\mathrm{Rn}}$ is the exposure value for the Rn-channel (kBqhm^{-3}),T is the time of exposure in days, CF is the calibration factor provided by the Radosys QC system, RnD is the track density counted for the Rn-channel (mm^{-2}), andTnD is the track density counted for the Tn-channel (mm^{-2}).

In order to increase the reliability of the obtained results, duplicate detectors and blank detectors were installed in eight measurement locations. The duplicate detector was used to assess the difference in radon concentration levels between two radon detectors installed 30 cm apart in the same place. The blank detector, unpacked, was placed at the same measurement location as the main detector and was collected and analyzed in the same manner as the main detector; obtained values were used to correct for concentration differences. The differences in measured radon concentrations between the main detector and the duplicate detector were verified with the paired *t*-test and relative percent difference (RPD). The RPD represents the ratio of relative differences between a pair of measurement equipment values used in the duplicate measurement. It was calculated using the following equation (US EPA, 1997):

$$\mathbf{RPD}(\%) = [|x_1 - x_2|]/x_{ave} \times \mathbf{100}, \tag{3}$$

where x_1 is radon concentration of the main detector (Bq m^{-3}), x_2 is radon concentration of the duplicate detector (Bq m^{-3}),and x_{ave} is the average radon concentration of the main detector and duplicate detector (Bq m^{-3}).

As discussed above, the study was conducted at 470 sites in 235 child-care centers. However, due to the loss of detectors or errors in the analysis at 30 sites in five child-care centers, radon concentrations were ultimately obtained from 440 sites in 230 child-care centers. In addition, one of the eight duplicate detectors was lost, and thus, the results from seven duplicate detectors were used in the analysis. The buildings were classified as single type and multi-unit type. A single type building refers to a child-care center placed in a detached building or a small child-care center run by a household in an apartment unit, whereas multi-unit type refers to a child-care center located within a building complex. The year of construction was used as an indirect indicator of deterioration, and it was assumed that the older a building was, the more severe the deterioration of the building was. Mean radon concentration levels were compared by classifying the buildings into three groups based on construction year.

To identify factors affecting variations in indoor air radon concentration levels in child-care centers, the questionnaire used by the Ministry of Environment in the nationwide survey of radon concentration in houses was adapted for the child-care centers selected in the present study. The self-administered surveys were conducted by field researchers and were answered by child-care instructors or facility managers. Among the survey questions, those that were considered determining factors of indoor radon concentrations in child-care centers were selected, and the average radon concentrations was compared through Student *t*-test and analysis of variance (post hoc-Duncan analysis). In order to provide fundamental data on the reduction of radon concentrations in child-care centers, an analysis of covariance was conducted to