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Original Research

Measurement of Indoor Radon Concentration in Dalat, Vietnam

Huy Le Viet*, Suk Soo Dong, Son Nguyen An, Duy Tran Huu

ABSTRACT
A significant contribution to natural exposure of humans is radon gas, which emanates from the soil and may concentrate in dwellings. The level of radon exposure varies around the globe, but limited data are available on the daily variations of indoor radon concentrations. In this study, indoor radon measurements were performed continuously within one week at six different places in Dalat, Vietnam using the real time Smart Radon Detector Radon Eye+. The indoor radon behavior in a day follows a sine pattern, with peak values in the early morning and lowest values in the late afternoon. There are also some fluctuations at specific times due to different weather conditions. Indoor radon concentrations in the Dalat regions were found to exceed the recommended guidelines and thresholds; excessive radon levels warranting health concern were found (150.7-340.0 Bq/m^3). Some corrective actions to reduce indoor radon concentrations were recommended. Annual effective doses on different age categories were also calculated.
Key words: Annual effective dose, Effective dose rate, Indoor radon concentration, Radon

INTRODUCTION

Radon is a radioactive gas which presents in terrestrial soils, rocks and building materials. There are three main radioactive isotopes of radon occur naturally: Rn-222, Rn-220 and Rn-219[1]. Rn-222 has a half-life of 3.82 days and is formed from Ra-226, which is the decay product of U-238. Rn-222 is very significant for radiation exposure indoors because of the relatively high concentrations of U-238 in the ground. Rn-220 is found in the decay chain of Th-232; it has a short half-life of 55.6 seconds and can migrate a short distance before decay. Therefore, activity concentrations of Rn-220 indoors depend primarily on the emanation of Rn-220 from the surface layers of the materials of walls and floors, rather than from more distant origins. Rn-219 has a short half-life of 3.96 seconds, and is a decay product of U-235 whose low concentrations can be found in soils. Thus, the exposure from Rn-219 is negligible. Exposure from Rn-222, Rn-220 and their decay products are mainly from alpha particles and some beta particles; gamma radiation is also emitted. The basic quantity used to express radon concentration in air is Bq/m^3- the radioactivity within a volume of space[2].

There are many routes of radon to indoor areas, as illustrated in **Figure 1**. The average Rn-222 indoor concentration worldwide is 39 Bq/m^3[3]. It is quickly diluted to low concentrations in open air; there, the Rn-222 outdoor concentration is 10 Bq/m^3[3]. In the latest data, the World Health Organization (WHO) proposes a reference level of 100 Bq/m^3 to minimize health hazards of exposure indoors due to Rn-222[4]. High radon exposure to underground miners has been known for a long time, but since the 1970s, the indoor radon exposure has been realized to be quite high[5]. Then, information gathering on radon became more popular. In 2012, surveys at elementary schools in Canada showed that the average radon concentration was 56 Bq/m^3. In India, the Rn-222 levels investigated in 200 different places at 10 varying locations were found to be under the worldwide average concentration of 40 Bq/m^3[6]. According to a report in 2013 by Pristine Home Inspections, South Korea had the second highest level of radon exposure in the world[7]. Its average annual radon concentration was 124.9 Bq/m^3, not far behind the Czech Republic, at 140 Bq/m^3. South Korea's primary schools had an annual average radon concentration of 98.4 Bq/m^3 [8][8]. In Vietnam, there have also been many studies about radon. In 2017, the determination of radon and radium levels in different kinds of soil and diffusion lengths of radon in Ho Chi Minh City was surveyed by Huynh Nguyen Phong Thu et al., using alpha spectrum method[9]. The study confirmed an exponential increase in radon level with depth. The mean value was 62±8 cm. The mean radium content was 41.92±5.75 Bq/kg. In 2016, gross alpha and gross beta activities in air and rainwater were continuously monitored in Ho Chi Minh City by Nguyen Van Thang *et al.*[10]. The influences of Rn-222, Rn-220 and alpha self-absorption in the samples were considered and

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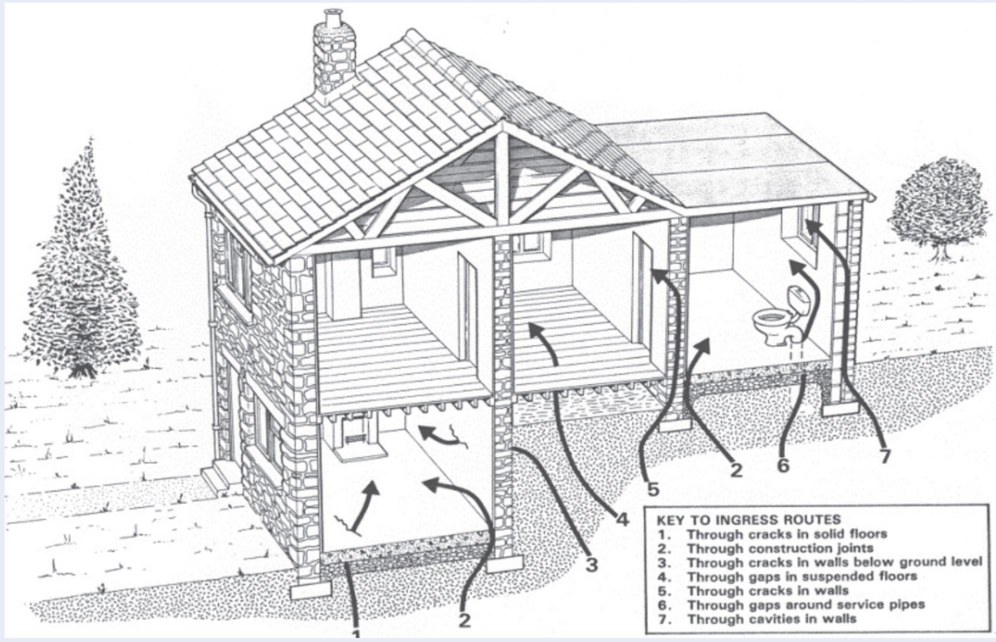

Figure 1: **Seven main access routes of radon to indoor areas (model of the building by the Building Research Establishment, United Kingdom)** [1]

corrected for activity measurement results. However, a limited data was available on the daily variations of indoor radon levels. In the present investigation, an effort is made to find the daily variation of indoor radon concentrations at six different places in Dalat.

METHODS

Theory

In terms of internal exposure, the effective dose rate from inhalation of contaminated air, E_c (nSv/h) is calculated by the following equation:

$$Ec = (P_{01}.P_{14}.P_{45})/24 \quad (1)$$

Where:

P_{01}: activity concentration (Bq/m^3)

P_{14}: breathing rate (m^3/d)

P_{45}: dose conversion coefficient for inhalation (nSv/Bq)

Table 1 indicates the breathing rates of the six age groups used by the International Commission on Radiological Protection (ICRP) [11]. The fraction of the population and the weighted rate are also indicated.

Committed effective doses per unit intake of Rn-222 were found to be 23, 5.9 and 3.5 nSv/Bq for infants, children and adults, respectively [11].

Equipment

For this study, the real time Smart Radon Detector Radon Eye+ was kept inside each surveyed place for about one week and was installed to record the indoor radon concentration with an interval of 1 hour. As such, about 168 data points were recorded from each place. The measurements were repeated at least 3 times at every place. The detection theory of Radon Eye+ is described in **Figure 2** [12].

The α-particles that are generated during the radioactive decay of radon and radon progeny create the thousands of $\pm$ charge particles by collision with air, as illustrated in **Figure 2**. These electric charge signals are usually very weak and noisy, so it is difficult to amplify the signals using a circuit with high input impedance. Radon Eye+ effectively detects these secondary charges using the dual structured built-in 200cc class pulsed ionization chamber and a special amplifier circuit developed by FTLAB's (Future Technology Laboratory, Korea) own technology. Thus, from the statistical method based on frequency, pulse counts and interval of the alpha decay, the average radon concentrations in the indoor areas can be measured with highly accurate detection. The Radon Eye+ was installed at least 50 cm apart from the wall, window and floor. The time for the first reliable data display was just within 1 hour, with less than 10% error

Table 1: Breathing rate for the world population used by ICRP [11]

Age categories	Breathing rate (m3/d)	Fraction of population	Weighted rate (m3/a)
0-12 months	2.86	0.02	21
Infants (1-2 years)	5.16	0.04	75
3-7 years	8.72	0.10	320
8-12 years	15.3	0.10	560
Children (13-17 years)	20.1	0.09	660
Adults (>17 years)	22.2	0.65	5300
Sum		1.0	6900

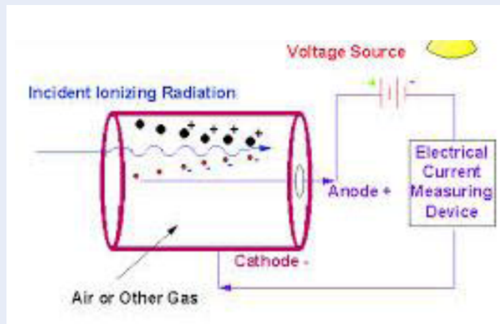

Figure 2: Detection theory of PulsedIon Chamber [12].

from the starting time of measurement. The data was updated every hour.

Six places were chosen for indoor radon concentration measurements. These areas represent various areas of Dalat, such as places located underground, places with special construction materials, offices and schools. Three places inside Dalat University were surveyed. These included the Dalat University Library (which contain a lot of gypsum in the building material), the Culture Room of the Biological Department of Dalat University (located underground, which is thought to have high radon concentration), and the Administration Building (where many staff work and where radon exposure is high and concerning). The lung of children are more sensitive than that of adults; consequently, children usually have a greater risk of developing cancer from radon irradiation than adults do. Therefore, radon surveys at schools are also very important to conduct and assure that the WHO healthcare guidelines for children are met. The Radon Eye+ was also installed in three schools with different age categories in the Dalat area: Tran Phu High School, An Duong Vuong Primary School, and Nursery No. 9 School. All the surveyed places mentioned above were located on the 1^{st} floor, except for the Culture Room of Dalat University's Biological Department.

RESULTS AND DISCUSSION

The indoor radon behavior were different at each site, as illustrated in **Figure 3.** The average values and peak values of the indoor radon concentrations were calculated and indicated in **Table 2**. Equation (**1**) was used to calculate the annual effective dose on people via inhalation. The results are shown in **Table 3**.

In this study, the analysis of daily variations of indoor radon concentration was conducted as described below. Generally, during the weekdays, the indoor radon concentration continuously decreases from the peak level in the early morning to the lowest level in the late afternoon, and then increases until the next morning. The behavior of indoor radon is due to ventilation and natural effects (sunset, dawn, cloud, rain, wind, *etc*.).

At sunset, the outdoor temperature starts to decrease, then the air pressure inside the buildings becomes higher than the outdoor air pressure since the indoor air is warmer. This causes the indoor air to be drawn

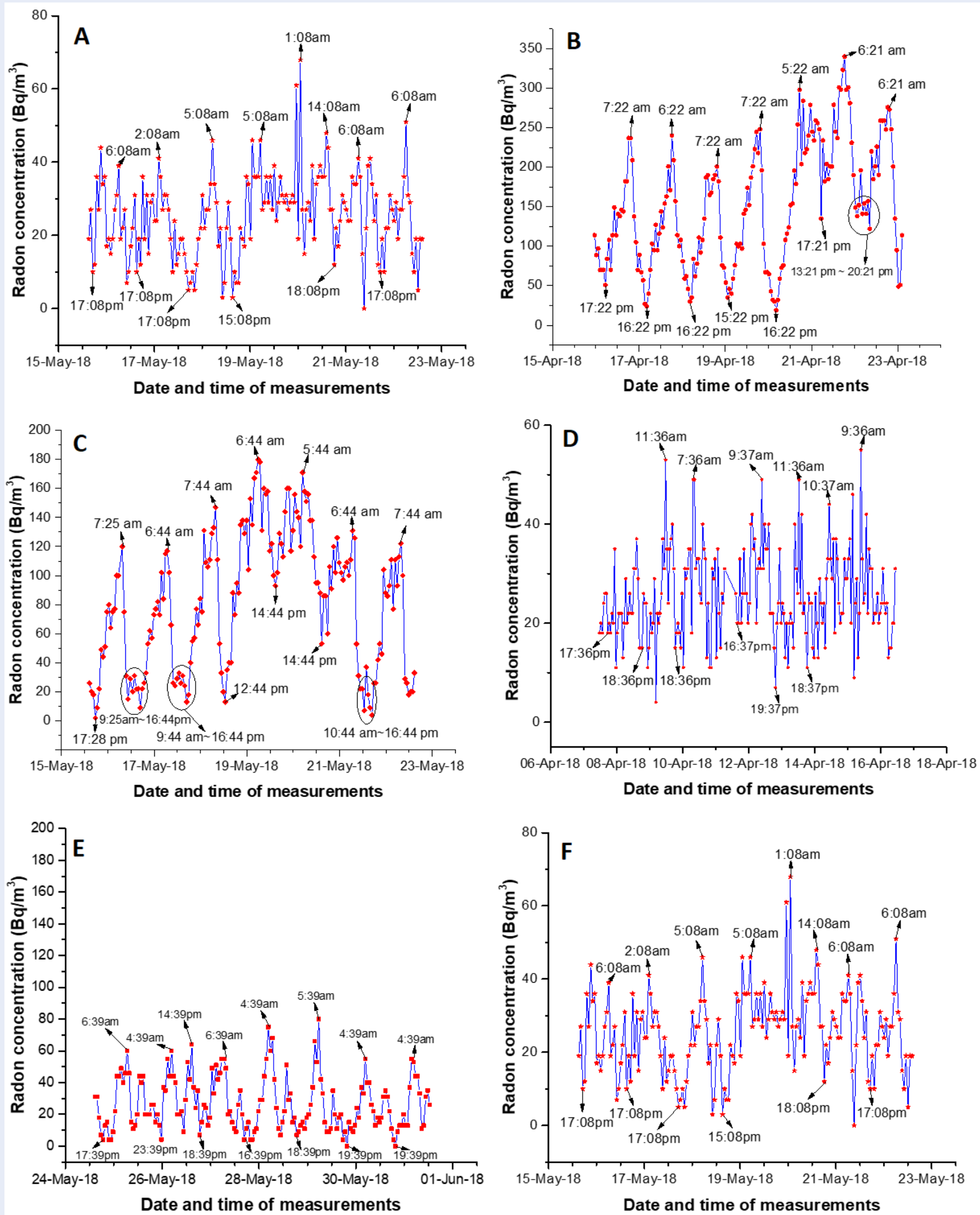

Figure 3: **Daily variations of indoor radon concentration**. (**A**) in the Library; (**B**) in the the Culture Room; (**C**) in the Administration Building; (**D**) at Tran Phu High School; (**E**) at ADV Primary School; (**F**) at Nursery No. 9 School.

to the outside, leading to a lower pressure of indoor air compared with ground pressure, since there is less dense air inside the building. Then, the air from the ground is drawn into the buildings, carrying radon with it. The access routes are gaps around pipes and cables, cracks in floors, and gaps between floors and walls. Moreover, since all doors and windows are closed by staff at non-working-times, it enables radon gas to accumulate indoor and continuously increase until it is diluted the next morning. The peak values observed were 316, 340, 180, 55, 80 and 68 Bq/m^3 in the Library, Culture Room, Administration Building, Tran Phu High School, ADV Primary School and Nursery No.9 School, at 6:49 am, 6:21 am, 5:44 am, 9:36 am, 5:39 am and 1:08 am, respectively.

At dawn, the indoor pressure is lower since the outdoor air becomes warmer, leading to the increase of dense indoor air which reduces radon from being drawn into buildings from the ground beneath. Ventilation has been demonstrated as a major factor that influences indoor radon concentration. Ventilation actions, such as opening doors and windows, can lead to the mixing of indoor and outdoor air, and thus, the radon concentration quickly decreases at about 7 am in the morning.

On the weekend, no ventilation leads to a higher radon concentration compared with that during the weekday since radon accumulates inside the room. Moreover, the indoor radon concentration is affected by natural effects. It gradually reaches its peak value at about 5 am and drops to the lowest value at about 5 pm. Sometimes, the radon value is highest at 10 am or lowest at 2 pm in a given day, depending on the weather conditions (cloudy, rainy, *etc.*).

The results in **Table 2**show that the indoor average concentration of radon in the Library and Culture Room are about 1.5-fold higher than the reference level of 100 Bq/m^3 (proposed by WHO). Radon is carried indoors through many access routes, such as cracks in solid floors, construction joints, cracks in walls below ground level, and gaps around pipes; note that the Culture Room is located underground. The Library contains a lot of gypsum in the building material. In the constructed room, concrete blocks are used extensively for internal walls as are natural gypsum plaster boards for ceilings. The air within the room contains radon which enters from the outside, together with radon from the ground beneath and from the structures. The additional radon concentration arises from the established building materials (gypsum contains concentrations of radium). Furthermore, the ventilation conditions are not good because ventilation actions are dependent on the working times of the staff. For example, at non-working times and on weekends, all doors and windows are completely closed due to security reasons and thus, there is poor ventilation.

The worldwide average annual effective dose due to inhalation is 1.2 mSv/a [1], with the range as 0.2-10 mSv/a, depending on the indoor accumulation of radon gas. In comparison, the radon concentrations in the Library and Culture Room were about 4-fold higher, at 4.81 and 4.27 mSv/a, respectively. Furthermore, the annual effective dose in the Administration Building was about 2-fold higher, at 2.32 mSv/a. The indoor radon concentrations at Tran Phu High School, ADV Primary School and Nursery No. 9 School were below the WHO limit. Indeed, the annual effective dose were also lower than the worldwide average value; they were 1.11, 0.5-0.88, and 0.48-1.1 mSv/a at Tran Phu High School, ADV Primary School and Nursery No. 9 School, respectively. The classroom structures of the three schools surveyed were similar, although there were some differences in composition of the building materials. All three schools have walls and ceilings which were made from concrete and limestone; floors are made of marble; and many holes in the wall provided good ventilation. Certainly, these can provide a good environment for students, children and infants for inside studying **Figure 3.**

Corrective actions can be designed to prevent the entry of radon from the soil into a building or to remove radon from the building. Corrective actions are described as active or passive. Passive actions are generally less costly but also less effective than active measures. However, the main drawbacks of active actions are their costs and the need for regular monitoring of proper function and long-term maintenance. There are some examples of corrective actions to reduce indoor radon concentration. Passive corrective actions can include increasing the ventilation (opening windows and doors) to mix the indoor air (that is rich in radon) with the outdoor air, thereby reducing the concentrations of radon in indoor air. Active corrective actions can include installing fans to blow air into underground spaces or to exhaust air from the underground space. Other actions are installing extractor fans (to withdrawn radon from the indoor), installing air conditioning systems (to reduce concentrations of radon by diluting the radon indoors and keeping the balance between incoming air and outgoing air), sealing all radon entry points in contact with the ground, and removing building materials with a high rate of exhalation of radon.

CONCLUSIONS

In this study, the daily variation of indoor radon concentration was analyzed. The average indoor radon concentration and annual effective dose were also calculated and compared with the worldwide average annual effective dose. As shown from the results, some corrective actions should be performed to reduce the radon concentration at two of the surveyed areas: Library and Culture Room (of Dalat University).

The effect of radon on children should be of high caution. Further study is in progress to analyze radionuclide concentrations in the building materials of the Library, as well as surveying radon concentrations at other schools in the Dalat area. The creation of a radiation map of the Lam Dong Province is also underway.

COMPETING INTERESTS

No conflict of interest declared.

Table 2: Indoor radon concentrations calculated from data obtained at the six surveyed sites

No.	Place	Temperature (oC)	Humidity (%)	Average Radon Concentration (Bq/m3)	Peak Radon Concentration (Bq/m3)
1	Library	24.64	57.10	169.70 ± 10%	316.00
2	Culture Room	26.79	52.51	150.70 ± 10%	340
3	Administration Building	24.68	65.59	81.73 ± 10%	180.00
4	Tran Phu High School	22.96	62.30	25.60 ± 10%	55.00
5	ADV Primary School	24.57	68.75	26.65 ± 10%	80.00
6	Nursery No. 9 School	25.35	63.53	25.36 ± 10%	68.00

Table 3: Annual effective dose calculated via inhalation

No.	Place	Age categories	Breathing rate (m3/d)	Dose Conversion Coefficient (nSv/Bq)	Annual Effective Dose (mSv/a)
1	Library	> 17 years	22.20	3.50	4.81
2	Culture Room	> 17 years	22.20	3.50	4.27
3	Administration Building	> 17 years	22.20	3.50	2.32
4	Tran Phu High School	15 - 17 years	20.10	5.90	1.11
5	ADV Primary School	6 - 7 years	8.72	5.90	0.50
		8 - 10 years	15.30	5.90	0.88
6	Nursery No. 9 School	1 - 2 years	5.16	23.00	1.10
		3 - 5 years	8.72	5.90	0.48

AUTHORS' CONTRIBUTIONS

Huy Le Viet proposed the measurement plan, implemented the measurement of indoor radon concentration and wrote the manuscript. Suk Soo Dong is the first advisor, who applied for the project funding. Son Nguyen An is the secondary advisor. Duy Tran Huu supported the conditions for the measurement.

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