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A study of daily and seasonal variations of radon concentrations in underground buildings

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Abstract

A study of daily and seasonal variations of radon concentrations in underground buildings in major cities of China was carried out. According to the data from the Model 1027 continuous monitor, radon concentrations in the underground buildings changed through two cycles each day. The first cycle was from 12:00 to 0:00 and the highest or lowest value, depending on location, was at about 19:00. The second cycle had a little change. Based on the data from solid state nuclear detectors (SSNTDs), it was concluded that the radon concentrations in underground buildings in winter were lower than in summer, which was opposite to that above the ground level. Similar to that above the ground level, the radon concentrations in spring were close to the year-round average radon concentrations.

Keywords: Daily; Seasonal; Variation; Underground buildings; Radon concentration

1. Introduction

Radon (^{222}Rn) is a radioactive gas arising from the uranium decay chain, and is the largest single source of radiation exposure to many populations (Fovt et al., 1999). Inhalation of radon and its daughter products can cause a significant health hazard when they are present in

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enhanced levels (Singh et al., 2001). Radon has the highest level in basements and underground buildings that are in contact with the soil (Anastasiou et al., 2003). Exposure to radon has become a great concern to people working in underground spaces (Shui et al., 1999; Shouming and Puling, 2004).

It has been reported that above ground level, radon concentration is the highest in winter and the lowest in summer, whereas radon in autumn is similar to that in spring and these seasons are both close to the annual average radon concentration (Xiehua, 1996; Suozhao and Yihe, 1996; Kullab et al., 2001; Dwicedi et al., 2001). To reduce the radon concentrations in underground buildings with efficient measures, it is important to know the daily and seasonal changes. However, the seasonal radon variation in underground spaces has yet to be studied in detail in China.

Solid state nuclear detectors (SSNTDs) and continuous radon monitors were used to study daily and seasonal variations of radon concentrations in underground buildings in major cities of China. Among those, data are obtained for 87 underground buildings in spring, summer and winter, and for 191 underground buildings in summer and winter. In addition, data in some sites were obtained from Model 1027 continuous monitor to study radon daily variation.

2. Materials and methods

Measurements were carried out employing CR-39 detectors made in China. The CR-39 uses allyl diethylene glycol carbonate, which is sensitive to α particles and is used widely in accumulating radon measurements. The detectors were 1×1 cm and were mounted in a detector box with a filter film to remove radon daughters. The detector boxes were hung in underground buildings at a distance of about 20 cm from any surface. Radon diffused into the detector box and decayed to its progeny. The alphas originating from radon and its progeny were registered as tracks in the detectors. The detectors were exposed in underground buildings for about three months before they were retrieved from all sites and were etched in 7 N KOH at 70 °C for 6 h.

The detector was calibrated by the Radon Laboratory, School of Nuclear Science and Technology, Nanhua University in Hengyang, China, which is the Asian regional coordination laboratory for the International Radon Metrology Program (IRMP). A density of 4.218 tracks $cm^{-2}/(kBq\,m^{-3}\,h)$ was obtained for ^{222}Rn. Track densities were obtained from the detectors using optical microscopes at a magnification of 630×. A total of 500 counts were made or the surface area for counting was about 0.25 cm^2 per detector. To measure variation, 17 sites had duplicate measurements, and the variation coefficients were less than 20%. The detection limit was 8.654 $Bq\,m^{-3}$ if the detectors were exposed for three months.

Detectors were also calibrated for ^{220}Rn in the same situation as for ^{222}Rn, and we obtained 0.159 tracks $cm^{-2}/(kBq\,m^{-3}\,h)$, which accounted for 3.8% of that of ^{222}Rn. Hence the obtained data are mainly from ^{222}Rn.

Model 1027 continuous monitor from Sun Nuclear Corporation, U.S.A., was chosen to measure the radon concentrations at some sites for over 24 h to study daily variations. The monitor is a patented electronic detecting device using a diffused-junction photodiode sensor to measure the concentration of radon gas, and has been evaluated and accepted by the U.S. Environmental Protection Agency. The monitor was calibrated by the same laboratory in Nanhua University before use.

The underground buildings studied included basements, parking garages and tunnels. The basements and parking garages were under high buildings, and people are working in them. Some tunnels were built in war as air-raid shelters and now most of them are normally closed. Some were built in peace. There are 2 construction types of tunnels: one was built in mountains and are called saps in this paper, and the other was built in soils and are called tunnels in this paper.

3. Results and discussion

3.1. The daily radon variation

In this section, we focus on tunnels and basements to discuss the daily radon variation in underground buildings. On July 2003, there were 18 underground buildings, including 3 saps, 4 tunnels and 11 basements, where radon concentrations had been measured for over 24 h using the Model 1027 continuous monitors. The saps and tunnels were closed normally. Fig. 1 shows the change of air radon concentrations within 24 h in different types of underground buildings in summer. The radon concentrations are an average of 3 saps, 4 tunnels and 11 basements.

From 12:00 to 0:00, radon concentrations in saps, tunnels and basements had varied through a cycle. Radon in saps and tunnels increased and then decreased, with a highest value at 19:00. However, radon in basements decreased and then increased, with a lowest value at 19:00. After the second 12 h, the radon in tunnels increased rapidly. This was probably due to meteorological influence that day, but the increasing trend was similar to what was during the first 12:00–19:00.

From 0:00 to 12:00, radon in underground buildings underwent a second cyclic variation, though the variation was less than before. Radon after 7:00 in saps showed a different variation, which should be studied in future.

Why did radon variation in basements have the opposite trend to that in tunnels and saps between 12:00 and 0:00? It could be explained from two aspects. First, they were different in constructive surroundings. The tunnels and saps were dug into the earth, and were surrounded by original soils and rocks. However, the basements were built after opening the above soil, and then they were covered with non-original soil. This meant that the surrounding above the basements may have been more porous than that above tunnels and saps, which would enhance radon diffusion. Second, they were used in different ways. Most of the tunnels and saps were usually closed. In contrast, most basements were used as people's working places and were normally opened during the daytime. Though the doors and windows were closed during

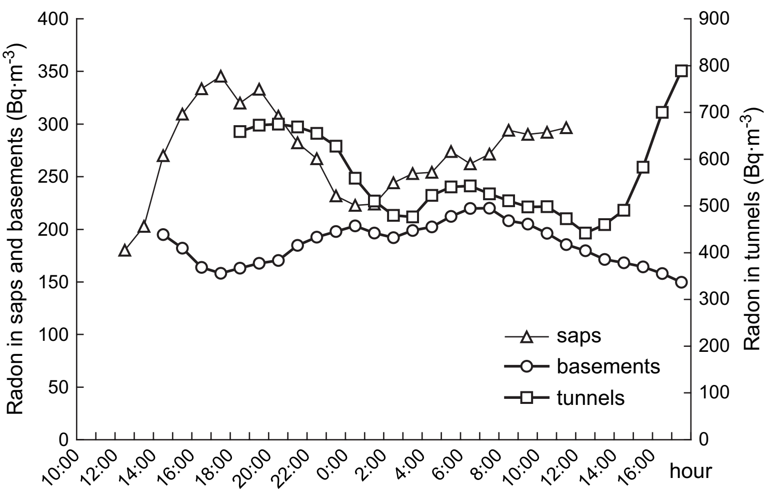

Fig. 1. The change of radon in underground space during 24 h in summer.

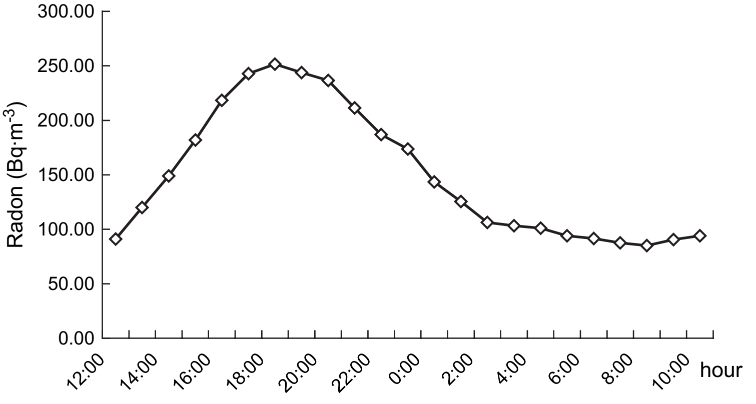

Fig. 2. Radon in saps over 24 h in spring.

the measuring period, it was inevitable that the measurements were disturbed by the people working there. In fact, from the radon variation curve of basements, it could be found that the radon decreased from 7:00 to 19:00, which was when people were working.

Fig. 2 describes the average radon variation of 5 saps on March 2003. It showed that the radon changed greatly between 12:00 and 0:00 and had the same variation trend as that in summer. In contrast, the variation was relatively smaller during the other half of the day, though it had the similar trends of that in tunnels in summer. It appears that the radon variation in underground buildings undergoes two periods with larger variation in the first period.

3.2. The seasonal radon variation

It is known that in spaces above ground level, the radon level in winter is usually higher than that in summer. In our survey, using SSNTDs, the radon concentrations in underground buildings were measured during the spring (from March to May), summer (from June to August) and winter (from December to February) of 2003–2004. Because of the loss of some detector boxes, there were only 87 underground buildings with radon data during all 3 seasons and 191 underground buildings with data in summer and winter.

The type, number of sites, geometric mean (GM) of radon concentrations and its geometric standard deviations (GSD) for 87 underground buildings in each season are listed in Table 1. The annual radon concentration of each site is obtained by averaging its radon concentrations of seasons. The radon concentrations in spring are highest and are close to the annual radon

Table 1
Seasonal variation of radon in 87 underground buildings

Type	Number of sites	Geometric mean (GSD)/Bq m^{-3}			
		Spring	Summer	Winter	Annual
Saps	45	200 (3.16)	180 (4.16)	160 (2.63)	200 (2.88)
Tunnels	9	150 (1.58)	260 (2.45)	83 (1.99)	180 (1.82)
Basements	28	72 (1.74)	55 (2.09)	50 (1.58)	63 (1.58)
Parking garages	5	61 (1.44)	39 (1.51)	45 (2.04)	51 (1.41)

Table 2
Seasonal variation of radon in 191 underground buildings

Type	Number of sites	Geometric mean (GSD)/Bq m^{-3}		Summer/winter ratio
		Summer	Winter	
Saps	69	160 (3.55)	130 (2.57)	1.23
Tunnels	31	410 (2.63)	170 (3.02)	2.41
Basements	75	78 (2.34)	62 (2.00)	1.26
Parking garages	16	59 (1.99)	50 (1.82)	1.18

concentration. Except for the parking garages, the other three types of underground buildings had higher radon concentrations in summer than in winter, which was opposite to the situation above the ground level. In tunnels, the radon concentrations in summer were especially higher than in winter.

In parking garages, the radon concentrations in summer were lower than in winter. This might be because parking garages had a similar situation as above ground level with large spaces, where parking promoted air movement. However, the number of sites of parking garages was insufficient. Saps and tunnels had higher GSD; this is because the radon concentrations between each site varied substantially because of their different geological background and other conditions.

Data of 191 underground buildings with intact radon concentrations in summer and winter are shown in Table 2. Here also, the GM radon concentrations in underground buildings were apparently higher in summer than in winter. In tunnels, the summer/winter ratio of radon concentration was 2.41. The summer/winter ratios of radon concentrations in the other three types of underground buildings were relatively lower. This seasonal variation is due to air ventilation with the air outside. In winter, the air density outside is larger than that inside, and the air outside goes into underground buildings diluting the radon concentration. In summer, the air density outside is lower than that inside and the air inside remains stable, so that it has a higher radon concentration (Bin et al., 1995; Perrier et al., 2004).

For saps and tunnels, there were differences in use. Some were not used and were closed normally, while others were used as warehouse, passage, summer resort or were unclosed. Table 3 shows the radon concentration and summer/winter ratio in different sites.

Data from Table 3 show two trends in seasonal radon variation. For closed saps and tunnels, their radon concentrations in summer were higher than that in winter. The summer/winter ratios were 1.38 in saps and 2.82 in tunnels. For unclosed saps and tunnels, the radon concentrations in winter were lower than that in summer, but the differences were small.

Table 3
Seasonal variation of radon in different situations in saps and tunnels

Type	Situation	Sites	Geometric mean (GSD)/Bq m^{-3}		Summer/winter ratio
			Summer	Winter	
Saps	Closed	27	220 (5.23)	160 (3.24)	1.38
	Unclosed	42	140 (2.40)	110 (2.04)	1.27
Tunnels	Closed	24	480 (2.57)	170 (3.24)	2.82
	Unclosed	7	230 (2.51)	180 (2.75)	1.27

In closed saps and tunnels, the air inside changed little with that outside, while in unclosed saps and tunnels, the air inside had more chance to change with that outside, similar to that in basements and parking garages. According to Perrier et al. (2004), the more the ventilation in underground buildings, the higher the summer/winter ratio. However, by comparing closed and unclosed saps and tunnels, the opposite was found. It may be that most closed saps and tunnels were characterized by larger water entry rates, which increased the summer/winter ratio of the closed underground buildings.

In summary, in underground buildings, the radon concentration in winter was lower than in summer, which is opposite to the situation above the ground level. Furthermore, the difference of radon concentrations between summer and winter in closed underground buildings is larger than that in unclosed underground buildings.

Similar to that above the ground level, the radon concentrations in underground buildings in spring were close to the annual average radon concentrations.

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