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# A pilot survey on indoor radon concentration in Beijing

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ABSTRACT

*Objective:* To explore the level of indoor radon concentration especially after recent 3 decades' great economic development in metropolis Beijing, so as to describe the outline of indoor radon level in Beijing.
*Methods:* A one-year integrated measurement on 800 dwellings was carried out from September 2018 to August 2019. Passive integrated radon cup monitor with CR-39 as an alpha-track detector was adopted for the survey. As a pilot study, measurement scheme was designed in detail. For measurement quality control, the background track density of CR-39 was strictly defined and controlled throughout the operation of the survey.
*Results:* The annual geometric and arithmetic mean of radon concentration of the surveyed are (39.3 ± 12.9) and (42.0 ± 13.7) Bq/m$^3$, respectively, varying from (12.1 ± 2.5) to (119.0 ± 7.8) Bq/m$^3$. Radon concentration of the ground floor dwellings is obviously higher than that of other floors. No difference of radon level is found among the dwellings of other floors. Higher radon concentration in buildings built after 2010 is obtained compared with buildings built in 1980s, 1990s, and 2000s.
*Conclusions:* There is no big change of radon concentration level in dwellings in Beijing area observed in general compared with a previous survey performed more than ten years ago. For high-rise buildings, building materials are suggested to be the main source of indoor radon. For higher radon concentration in buildings built in latest ten years, the change on building materials and indoor ventilation rate are thought to be the causes, further study in detail is needed to clarify.

## 1. Introduction

Radon is a noble radioactive gas originated from $^{226}$Ra, which is a decay product of $^{238}$U series. The half-life of radon is 3.8 d. As it usually exists as gas, it can emanate and diffuse from rocks, soils, and building materials and eventually enter into the indoor environment. Radon is a major contributor to the ionizing radiation dose received by the general population.[1] Epidemiological evidence indicates that indoor radon is the second most important cause of lung cancer after smoking in the general population,[2,3] and radon-related risk can be caused even at low level of radon exposure.[4–6] To reduce the radon-associated health burden, related international associations focus on residential radon exposure, and recommend authorities of its member states to develop comprehensive radon programmes or so-called national radon action plan, and furthermore recommended that an initial step of a radon programme is to carry out an assessment, preferably a radon survey, to obtain a nationwide representative of radon concentration.[5,7]

In China, up to now, there were twice nationwide indoor radon surveys carried out during the period of 1983–1990 last century. One was performed by the former Ministry of Health, in which 10,811 dwellings were included, the arithmetic mean of 22.5 Bq/m$^3$ with a range from the lower level detection limit (LLD) to 386.8 Bq/m$^3$ was reported.[8] The other survey was performed by former Environmental Protection Agency, in which 73% of population was covered, as a national average 24 Bq/m$^3$ (population weighted) was concluded.[9] It is noteworthy that even though a relatively consistent result of the two nationwide surveys on indoor radon concentration was achieved, grab sampling accompanied by dual-filter monitor or scintillation cell were taken as main measurement methods by the two surveys at that time of last century.

There have been great changes in China with the country-wide economic development during recent three decades, especially in housing situations for the public. Dwelling construction is booming benefit from the urbanization. High-rise buildings and large mansions are now the main style dwelling in megacities. Reinforced concrete construction replaces red-brick house. In addition, the popularization of household air conditioner is supposed to lead to an increase of indoor radon level.[10–13]

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In Beijing, there were two rather large scale surveys on indoor radon level performed in late last century and the early this century, respectively, grab sampling method and active carbon absorber were adopted for each of them.[14,15] Today from the view point of radiological protection to the public, a well-designed comprehensive national action plan is required.

To describe the outline of indoor radon level, a nationwide survey has been being planned at present. For a good representativeness, as recommended by WHO[5] and ISO,[16] passive integrated radon cup monitor with solid state nuclear track detector (SSNTD) is adopted for the survey. We chose the CR-39 as alpha track detector of integrated measurement method considering that it was widely used in previous surveys worldwide.[17–20] As a pilot study of the national survey, investigation in Beijing city was performed firstly. This paper introduces the main measurement result of the pilot study, and the strategy on measurement quality control is also highlighted.

## 2. Materials and methods

### 2.1. Descriptions on measurement site

Totally 800 dwellings were chosen randomly mainly taking account of district distribution, building density, building lays, building age of construction. All 15 administrative districts of Beijing city were covered. Monitor was set in high occupation rate places, like bedroom or living room, located on furniture's surface, making it at least 1 m away from walls or floor. Normal living condition was kept during measurement period. A field survey record form, including room decoration, air ventilation condition and start-finish time was designed and recorded for each of measurement dwellings.

### 2.2. Measurement method and radon monitor

A passive integrated radon cup monitor (model GE2014-α, Green Environment Industrial Institute, Korea) was adopted for the survey. Inside the cup, a piece of CR-39 (BARYOTRAK, Japan) is mounted in the center of bottom to record alpha particles emitted from radon and its progeny as a detector. It should be mentioned that $^{220}$Rn gas, with a half-life of 55.6 s, could hardly diffuse into the cup due to its special design. The cup monitor was calibrated at the standard radon chamber of Shanghai Institute of Measurement and Testing Technology, and the measurement sensitivity is (5.45 ± 0.38) tracks·cm$^{-2}$·kBq$^{-1}$·m$^{-3}$·h$^{-1}$. The LLD of radon concentration for the confidence level of 95% could be calculated to be 2.35 Bq/m$^3$ for a three-month measurement exposure according to the ISO formulation.[16] The background count of radon monitor was measured by putting monitors in a highly purified nitrogen gas environment.

After three-month exposure, radon detector was collected back to laboratory. CR-39 detector was then chemically etched with 7.5 N NaOH solution for 7.5–8 h at 75 °C in the laboratory. The track counting is performed automatically with Track Analysis System (STES-1, Shanghai Hapstar Mechanical & Electrical Equipment Co., Ltd, China) and double checked manually.

### 2.3. Measurement quality control

For SSNTD, determination and control of its background count are key factors for ensuring measurement quality. The initial bare background of CR-39 was determined to be (20.1 ± 8.9) tracks/cm$^2$. However, after mounting it inside a cup detector and sealing in a no-radon environment for three months, its background was evaluated to rise up to (28.8 ± 11.7) tracks/cm$^2$. The real background counts should be updated to this value to calculate radon average concentration of three months' exposure period consequently.

The preparation procedure of this study was to randomly select ten cup detectors from all prepared detectors as "background cups", put them in aluminum bags with some 1-g fresh activated carbon inside, then seal in a vacuum condition for three months. Fig. 1 shows the photo of the real objects.

During the period of the one-year field survey, confirmation on calibration factor of cup detectors was carried out twice at our radon-experiment-chamber by taking a calibrated AlphaGuard PQ2000 monitor (Thermal Fisher, France) as a reference instrument which could be traced back to national standard of Chinese Institute of Metrology.

To get reliable result, parallel-cup-monitor, accounting for 10% of total measurement, was designed as a measure of judgement. So besides the 10 cups for background determination, 880 cup monitors were setup for each measurement cycle. The follows formula was used for judgement, while $A_1$, $A_2$ and $u_1$, $u_2$ were radon concentration and its uncertainty of the parallel cup monitor setting in one dwelling, respectively.

$$K = \frac{|A_1 - A_2|}{\sqrt{u_1^2 + u_2^2}} \quad (1)$$

If $K \geq 1.96$, then the difference between $A_1$ and $A_2$ is significant, and the result is unreliable. Otherwise, the result is credible. As a result, about 94% of parallel results were estimated to be reliable and effective in our survey.

## 3. Results

As a pilot study, survey on radon concentration of dwelling in Beijing city was carried out from September 2018 to August 2019 with a measurement cycle of three months, and 800 dwellings were included. Actually, it was difficult to conduct the measurement in 800 dwellings concurrently due to the wide area and huge amount of workload. Therefore, there was some time delays among the dwellings-measurement. In this survey, the end of the latest measurement part was nearly three months later than that of the earlier part. During the survey, 17 cup monitors were missing (2.1% of total). Besides, 736 effective data were achieved after the parallel measurement evaluation described above.

The annual geometric and arithmetic mean of radon concentration were (39.9 ± 12.9) and (42.0 ± 13.7) Bq/m$^3$, respectively in general, varying from (12.1 ± 2.5) to (119.0 ± 7.8) Bq/m$^3$. There was only 1 dwelling of the survey, 0.13%, its annual average radon concentration was higher than 100 Bq/m$^3$, the lower reference level recommended by WHO.[5]

### 3.1. Radon concentration of different floors in high-rise buildings

Radon concentration of different floors of high-rise buildings was statistically analyzed as Fig. 2 exhibited the result. We can see that radon concentration of the ground floor is obviously higher than that of other floors. Meanwhile, it seems no difference among all other floors except the ground floor.

**Fig. 1.** Photos of radon cup monitor preparations.

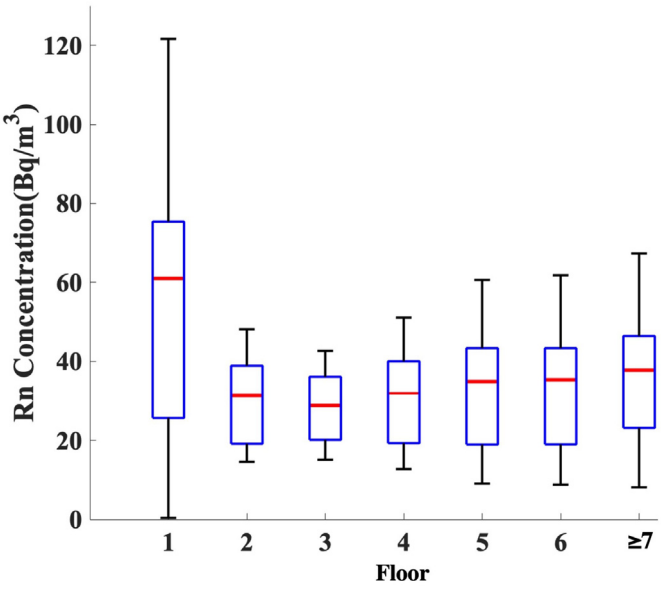


**Fig. 2.** Radon concentration of different floors of high-rise buildings.

### 3.2. Radon concentration of dwellings with different ventilation conditions

All surveyed dwellings were roughly divided into two catalogs, natural ventilation and air conditioning, according to its ventilation conditions recorded by the survey-record-form. Annual average radon concentration of the two catalogs was statistically analyzed. Unexpectedly, no difference is observed between them as showed by Fig. 3.

### 3.3. Radon concentration of dwellings of different construction age

Great changes have undergone in the construction of dwellings accompanying social reformation and economic development in recent three decades in Beijing. Most dwellings constructed before or during 1980s of last century were lower than 7 floors in height, and buildings constructed later are getting higher and higher. Changes not only have undergone in construction styles but also in building materials. Nowadays reinforced cement, parts of it made of industrial waste residue, like coal ash and slag, is most widely used for building construction.

To observe the indoor radon level of dwellings built in different times, annual average radon concentration of dwellings with different construction age was shown in Fig. 4 . The result indicated that dwellings built during 2010s might have the highest radon level compared with dwellings built before. But no difference is observed among the buildings built during 1980s, 1990s and 2000s.

## 4. Discussion

Compared with results reported by previous surveys in Beijing, one was 30 Bq/m$^3$ of grab sampling performed in 1992[14] and another one was 38.5 Bq/m$^3$ of active carbon method performed in 2006,[15] we can see an obvious increase of indoor radon concentration since last century, and no big change during the first two decades of this century. On the other hand, this result also suggests that radon level of dwellings in Beijing city is around the same level of the world average, 40 Bq/m$^3$ conclude by UNSCEAR 2000 Report.[1]

The result of Fig. 2 suggests that for the ground floor, soil of ground surface is the main contributor just as UNSCEAR concluded.[1] Nevertheless, for other floors over the ground floor, soil might not be the only big contributor to indoor radon concentration any more, indoor radon could be contributed by building materials, consequently. In big cities like Beijing in China, most of the population lives in high-rise buildings. This is also a characteristic of living condition at present. This result suggests

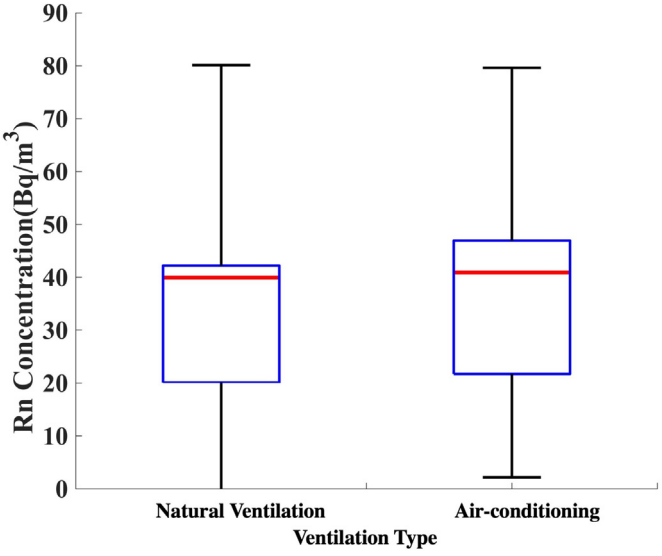


**Fig. 3.** Radon concentration of dwellings with different ventilation conditions.

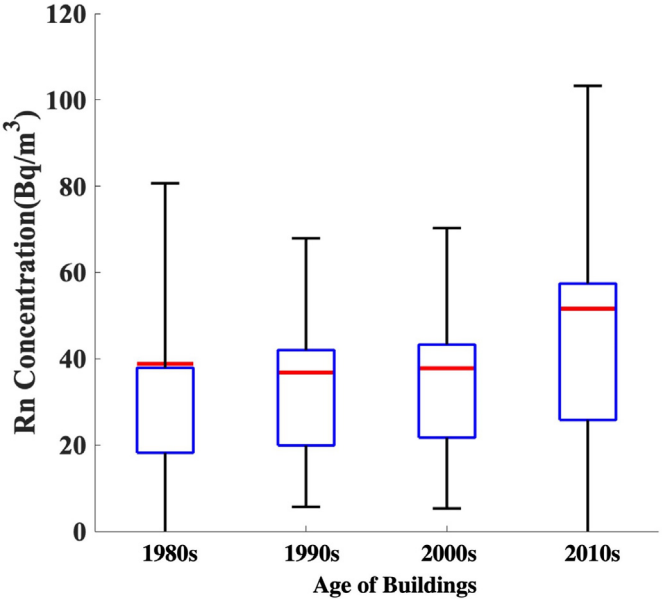


**Fig. 4.** Annual average radon concentration of dwellings built in different times.

that more attention should be paid to building materials for the control or mitigation on radon exposure in the future.

The result of Fig. 3 suggests that since ventilation condition here was not objectively cataloged by measurement data, but by householders subjectively filling-out. In this case, it is difficult to evaluate the effect of ventilation condition on annual average radon concentration according to the result.

For the result of Fig. 4, Changes on both building materials and tightness of ventilation condition are considered as possible reasons for the result, more studies are needed to confirm and clarify which one is the dominate factor.

## 5. Perspective

As a pilot study of national radon action plan, a one-year survey on 800 dwellings was performed by adopting integrated passive radon cup monitor. For measurement quality control, background count of CR-39 and operation procedure were strictly defined and controlled, and the

field survey-record-form was tested. All this experience will be referenced for national surveys in the future.

For the typical metropolis Beijing city, the annual geometric and arithmetic mean of indoor radon concentration of (39.3 ± 12.9) and (42.0 ± 13.7) Bq/m$^3$ are achieved, respectively in general, which is just around the world average level of indoor radon concentration. A higher level of radon concentration in the ground floor of dwellings is observed, indicating soil of ground surface might be the main contributor. While for dwellings of other higher floors, no difference on the level of radon concentration is observed, which suggested that soil might not be the only big contributor for high-rise buildings. Besides, a slightly higher level of radon concentration is suggested in dwellings built during 2010s.

The present observation suggests us that to get reliable and consistent measurements on indoor radon concentration for a nationwide survey in the future, standardized protocols including calibration and operation procedure should be clearly established and strictly controlled.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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