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Continuous measurement of radon exhalation rate of soil in Beijing

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Abstract To understand the level of radon exhalation rate from soil surface and its variation, a continuous measurement system was developed and applied for a field measurement in Beijing from April 2012 to February 2013. For seasonal variation, It was indicated by measurement results that radon exhalation rate was higher in spring (52.9 mBq m^{-2} s^{-1} in average) and lower in winter (17.0 mBq m^{-2} s^{-1} in average). The precipitation had a strong influence on the radon exhalation rate, usually radon exhalation rate increased quickly after rain. Daily variation of radon exhalation rate was also observed in spring, usually higher at noon and lower at midnight.

Keywords Radon exhalation rate · Continuous measurement · Soil · Precipitation

Introduction

Radon (^{222}Rn) and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources [1]. It is a gaseous radioactive product by the decay of radium isotope ^{226}Ra, which is present in all terrestrial materials. It could emanate from soil and building materials and enter into the atmosphere, where it decays into a series of short-lived products. Then, they are inhaled into human lung and form inner exposure. For outdoors and most indoor environment, radon mainly comes from soil. So the measurement of radon exhalation rate of soil is quite important for estimating local radon level.

In the last decade, many measurement methods for soil radon exhalation rate have been designed. Charcoal methods and solid state nuclear track detectors as well as electrostatic method have been developed in radon exhalation rate measurement [2–4], and applied in soil radon exhalation rate survey [5, 6]. Due to the time-consuming of field survey, only limited results were obtained. In China, Guo first carried survey of the radon exhalation rate from soil in several cities in China. Wang also conducted some survey of radon exhalation rate from soil in some sedimentary and granite areas in China [7].

All those results were obtained mainly by grasp method in a short time or passive method at one point for a long time, which could only be taken as an instantaneous value or average value for a long time. However, the physical process of radon exhalation is affected by many environmental factors such as temperature, humidity, water content and so on, which change with time [8]. The radon exhalation rate of soil could hardly be constant and fluctuates with time in a large range. So, we also need continuous measurement in order to understand its relationship with many environmental factors in more details.

In this paper, a continuous measurement system of radon exhalation rate was developed on basis of the work of Hosoda [9]. This measurement system was applied to continuous measurement of the radon exhalation rate of soil in Beijing, China. Some interesting results will be presented and discussed.

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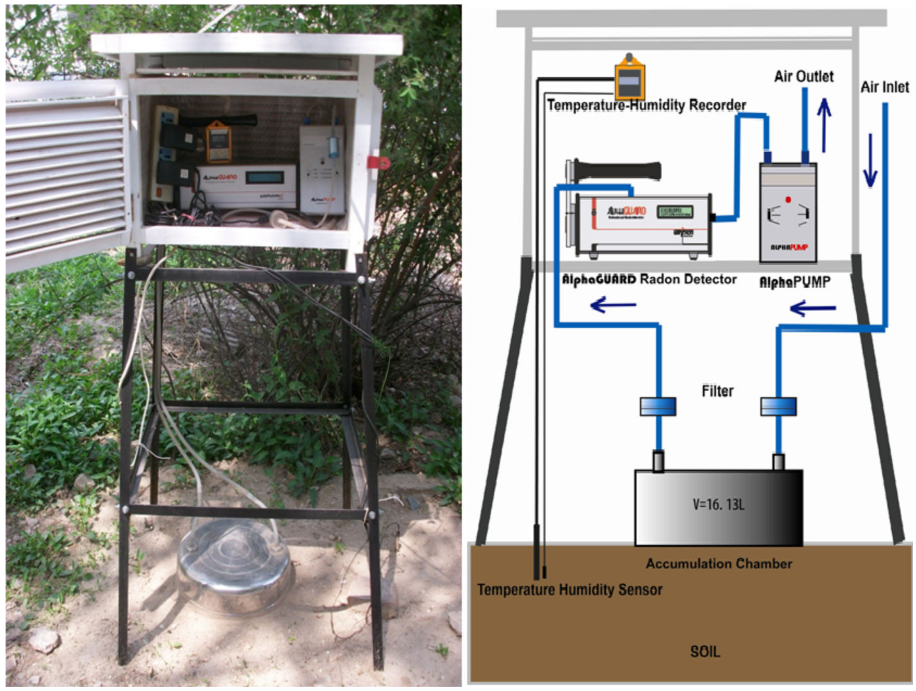

Fig. 1 The continuous measurement system of radon exhalation rate

Materials and methods

Continuous measurement system of radon exhalation rate

The continuous measurement system of radon exhalation rate is shown in Fig. 1. The picture of our system and its sketch map are on the left and right, respectively. This system is mainly constituted with an accumulation chamber with a volume of 16.13 L, a sampling pump, a radon monitor and a temperature and humidity detector for soil. Detectors of temperature and humidity were installed outside the accumulation chamber to record the variation of temperature and humidity in soil in natural condition. AlphaPUMP and AlphaGUARD PQ2000Pro produced by Genitron Instruments GmbH Company (Germany) were used as the pump and radon monitor in this system. A rather long inlet duct was selected for reducing the influence of thoron on radon measurement. Air nearly without thoron gas which inhaled at 1.5 m high at a flow rate of 0.3 L/min takes turns passing through the accumulation chamber, the radon monitor and the pump. The soil temperature and humidity are recorded every 10 min by M267221 detector (Midwest LTD Co. Beijing) with a relativity error of ±0.5 °C and ±3 % RH respectively. The accumulation chamber is built by stainless material with an open face of 0.1075 m^2. The radon concentration in accumulation is recorded by AlphaGUARD PQ2000Pro at 10 min intervals.

Theory study of continuous measurement of radon exhalation rate

Some basic assumption was made for the calculation of radon exhalation rate. First, soil is assumed to be uniform porous media and radon concentration distribution is thought to be even in the accumulation chamber. Second, due to the continuous sampling progress, we can easily assume that the radon exhalation and the ventilation are in quasi-equilibrium. Then the radon concentration in the chamber could be expressed as:

$$\frac{\mathrm{d}A_{\mathrm{Rn}}}{\mathrm{dt}} = \frac{JS}{V} - \lambda_{\mathrm{Rn}}A_{\mathrm{Rn}} - \frac{v}{V}A_{\mathrm{Rn}} \tag{1}$$

where, J is radon exhalation rate (mBq m^{-2} s^{-1}), A_{Rn} is the radon concentration in the chamber (Bq m^{-3}), λ_{Rn} is the radon decay constant, v is the sampling rate (L/min), V and S is the volume and surface area of the chamber (m^3 and m^2). Consider the quasi-equilibrium assumption, the left side of Eq. (1) is zero. Then the relationship between the radon exhalation rate and the radon concentration in the chamber could be expressed as follow:

$$J = \frac{(\lambda_{\mathrm{Rn}} + v/V)VA_{\mathrm{Rn}}}{S[1 - \mathrm{e}^{-(\lambda_{\mathrm{Rn}}+v/V)t}]} \tag{2}$$

Because v/V is much larger than λ_{Rn} and for continuous measurement $\mathrm{e}^{-(\lambda_{\mathrm{Rn}}+v/V)t} \approx 0$, then the upper equation could be sampled as follow:

$$J = \frac{VA_{\mathrm{Rn}}}{S} \tag{3}$$

So we could figure out the radon exhalation rate of soil through continuous measurement of radon concentration in the accumulation chamber.

Due to AlphaGUARD's sensitivity and the lower level detection limit are 1 cpm at 20 and 2 Bq m^{-3} respectively, the sensitivity of radon exhalation rate measurement system is 0.047 mBq m^{-2} s^{-1}/(Bq m^{-3}) and the low level detection limit is 0.093 mBq m^{-2} s^{-1}, considering 95 % confidence limits.

Results and discussion

Four continuous measurements were conducted in the last year in a small garden in Peking University. It starts from April 17th to May 30th in spring, from June 1th to July 1th in summer, from August 24th to September 20th in autumn and from November 11th to February 19th in winter separately. The average values of different seasons and the variety with 95 % confidence are shown in Fig. 2. The average value is shown as a point in the center and 95 % data is located in the rectangle box.

The average value of radon exhalation rate of soil is 52.9 mBq m^{-2} s^{-1} in spring varies from 9.8 to 110 mBq m^{-2} s^{-1}, 26.7 mBq m^{-2} s^{-1} in summer varies from 1.1 to 112 mBq m^{-2} s^{-1}, 22.5 mBq m^{-2} s^{-1} in autumn varies from 3.2 to 61.7 mBq m^{-2} s^{-1} and 17.0 mBq m^{-2} s^{-1} in winter varies from 2.7 to 41.3 mBq m^{-2} s^{-1}. Comparing with soil temperature and soil humidity, we can easily find that the soil humidity is much higher in spring than in summer and autumn, which leads the radon exhalation rate much higher in spring. Through the soil humidity is nearly

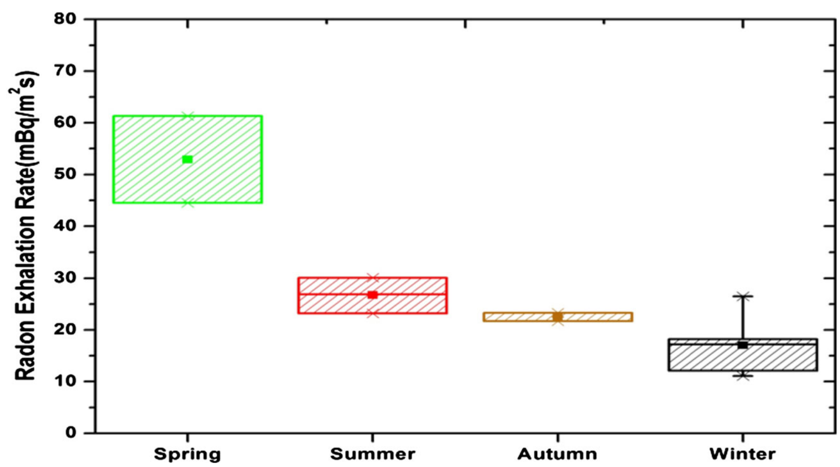

Fig. 2 The average values of different seasons and the variety with 95 % confidence

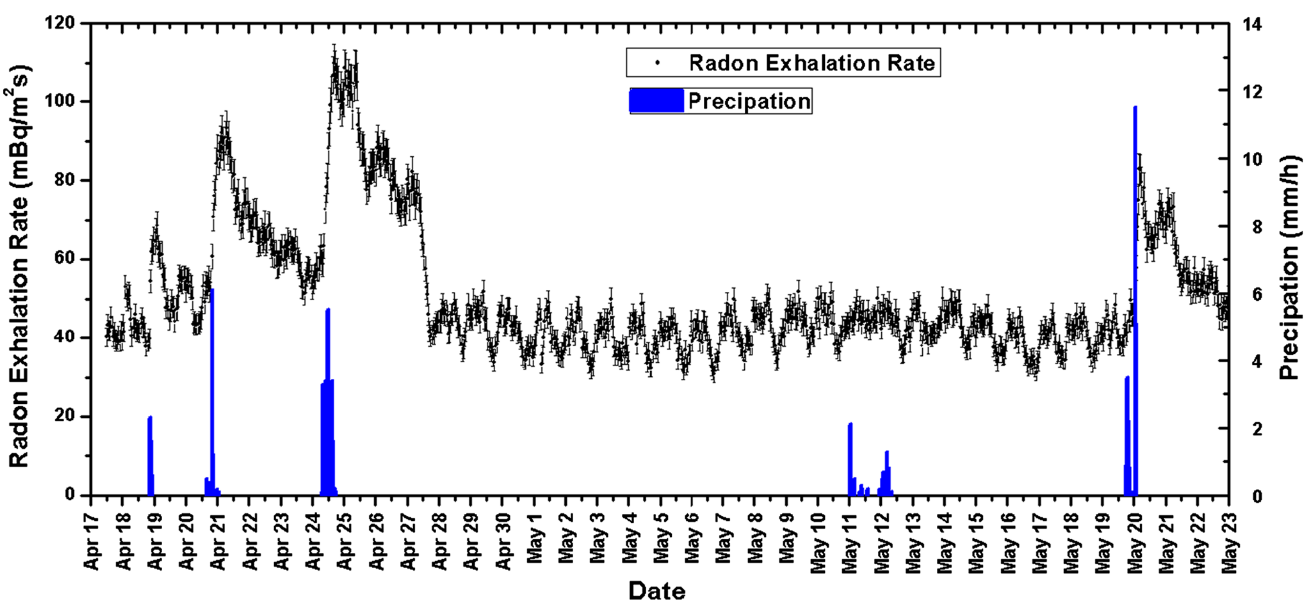

Fig. 3 Continuous measurement of radon exhalation rate in field from April 17th to May 23th

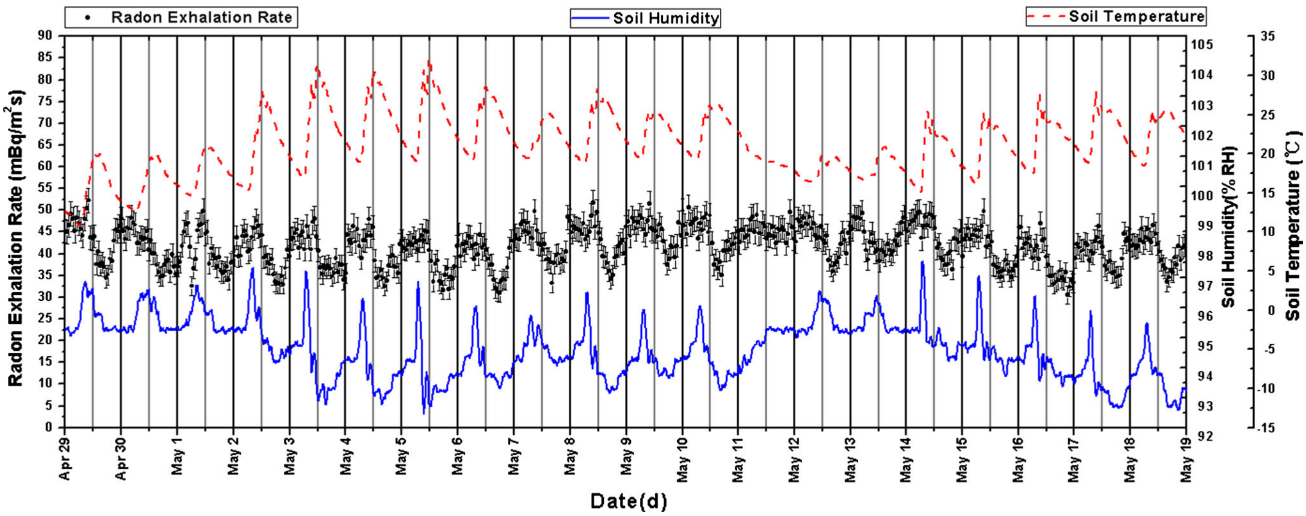

Fig. 4 Continuous measurement results of radon exhalation rate as well as soil temperature and humidity during April 29th–May 19th

99 %RH in winter even higher than in spring, the radon exhalation rate is much lower in winter probably because the temperature is below zero and the soil is frozen then the radon couldn't easily comes out. These results got in Beijing by this study were quite comparable with results reported by UNSCEAR [10], 26 mBq m^{-2} s^{-1}, the evaluated world average.

Quite interesting results were found from continuous measurement. Rainfall has a quite important influence on radon exhalation rate. To illustrate the relationship between radon exhalation rate and rainfall, the continuous measurement result from April 17th to May 23th is shown in Fig. 3. The dark point is radon exhalation rate of each hour, the blue histogram illustrate the rainfalls with different precipitation.

The radon exhalation rate changes with the rainfall. Radon exhalation rate goes up sharply after rainfall. The increase seems have positive relationship with the precipitation. The larger is the precipitation, the higher goes the radon exhalation rate.

Another interesting phenomenon is found between April 29th and May 19th, where the result is shown in Fig. 4 with soil temperature and humidity on it.

During April 29th to May 19th, the radon exhalation rate presents periodic variation with higher value in the daylight and lower in the night. Compared with the soil temperature and soil humidity results, we could find that the temperature in those days exist a periodic change and the sunshine lead a periodic change of soil humidity. Those finally lead the radon exhalation rate exist a periodic change with highest at 11:00 and lowest at nearly 18:00. Unfortunately, similar result was not found in other seasons, which probably due to the fact that the soil humidity and soil temperature did not change so largely and so periodic.

Conclusion

A continuous measurement system was developed and applied to the measurement of the radon exhalation rate of soil in Beijing from April 17th, 2012 to February 19th, 2013 in a small garden in Peking University. Results show that the average value of radon exhalation rate of soil is 52.9 mBq m^{-2} s^{-1} in spring with a variation of 9.8–110 mBq m^{-2} s^{-1}, 26.7 mBq m^{-2} s^{-1} in summer with a variation of 1.1–112 mBq m^{-2} s^{-1}, 22.5 mBq m^{-2} s^{-1} in autumn with a variation of 3.2–61.7 mBq m^{-2} s^{-1} and 17.0 mBq m^{-2} s^{-1} in winter with a variation of 2.7–41.3 mBq m^{-2} s^{-1}, which is constant with Wang's former survey. The radon exhalation rate of soil shows a large variety after rainfall, which could increase shortly, 2–3 times increase occurred in only 4 h. Attention need to be paid to this phenomenon, especially at uranium tailings where the radon exhalation rate might be quite high. A periodic variation of radon exhalation of soil was found in spring while higher in the daylight and lower in the night, which may be due to the periodic change of the soil temperature and soil humidity.

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