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2008 J. Radiol. Prot. 28 603

(http://iopscience.iop.org/0952-4746/28/4/N02)

J. Radiol. Prot. **28** (2008) 603–607 doi:10.1088/0952-4746/28/4/N02

NOTE

Measurements of thoron and radon progeny concentrations in Beijing, China

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Received 8 April 2008, in final form 18 July 2008, accepted for publication 22 July 2008
Published 24 November 2008
Online at stacks.iop.org/JRP/28/603

Abstract
It has been reported that thoron levels in China are above the world average and may therefore make a significant contribution to the natural background radiation dose. We therefore conducted a pilot study of concentrations of both thoron and radon progeny during the spring of 2006 in the Beijing area, China. A new type of portable 24 h integrating monitor with a CR-39 detector was used during the survey. Seventy dwellings and eight outdoor sites were measured during the survey. For country houses built of red bricks and slurry, the average equilibrium equivalent concentrations (EEC) of thoron and radon were 1.02 ± 0.48 and 16.41 ± 9.02 Bq m^{-3}, respectively, whereas for city dwellings built of cement blocks and floor slabs, the results were 0.48 ± 0.47 and 11.50 ± 6.99 Bq m^{-3} for thoron and radon, respectively. For outdoor air, concentrations of thoron and radon progeny were 0.29 ± 0.28 and 7.05 ± 2.68 Bq m^{-3}, respectively. Radiation exposures from thoron and radon progeny were also evaluated; the ratio of dose contribution from thoron progeny to that of radon progeny was evaluated to be 28% and 17% in country houses and city dwellings, respectively.

1. Introduction

Thoron (^{220}Rn), a radioisotope of radon (^{222}Rn), is a decay product of natural thorium (^{232}Th). It is a naturally occurring inert gas in all rocks, soils and building materials just like radon, and can also diffuse into the indoor environment. Compared with radon and its progeny, however, we know little about the behaviour, levels and dose contributions of thoron and its progeny, and representative data on thoron and its progeny are still scarce or non-existent in some areas.

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The main reason for this is that the levels of thoron and its progeny were considered to be very low due to the short half-life of thoron (55.6 s), and the dose contribution from thoron and its progeny to the public would be ignored in the presence of that from radon and its progeny in natural radiation protection.

Thoron has been only treated as a complicating factor during radon measurements in some studies (Iida *et al* 1995, Shang *et al* 1997). In the early 1990s, however, some high thoron concentrations were reported in traditional Japanese style wooden houses made with mud/soil walls (Doi and Kobayashi 1994, Guo *et al* 1992). There were also some surveys carried out in cave dwellings in China (Shang *et al* 2000, Wiegand *et al* 2000), and quite high thoron concentrations were reported in these special dwellings. In addition, high thoron concentrations were also reported (Guo *et al* 2001) in some areas of southern China with ^{232}Th-rich soils.

The annual effective dose from thoron and its progeny was evaluated to be up to 9% of that of radon and its progeny in the UNSCEAR 2000 report (UNSCEAR 2000). It is important to know the levels of both radon and thoron progeny, and to evaluate the dose contribution from both of them, particularly in big cities in China. The purpose of this study was to investigate indoor thoron and radon progeny levels around Beijing, and to try to evaluate the dose contribution from them.

It is very important to know the level of thoron progeny (the ratio between the conversion factor from concentration to exposure dose of thoron and that of its progeny is $1/300$). In the evaluation of radon progeny doses, the equilibrium factor between radon and its progeny is often assumed; however, in the case of thoron progeny, distributions are very variable. For a precise assessment of thoron progeny exposure, integrating and direct measurements of thoron progeny are desirable.

2. Materials and methods

2.1. 24 h integrating monitor for measurement of thoron and radon progeny

For the purpose of the direct and integrating measurements of thoron progeny, a new type of portable integrating monitor with etched track detectors (CR-39[2]) was developed (Zhou and Iida 1999) and manufactured in the authors' lab, and adopted in field measurements for this study. The progeny of thoron and radon in air were collected on the surface of the membrane filter (pore size 0.8 μm). The monitor has two absorbers, one of which is sufficiently thin such that all alpha particles from both radon and thoron progeny reach the CR-39 detector, and a second, which is thick enough that only the high energy alpha particles from the thoron progeny, (^{218}Po) (8.78 MeV), reach a second CR-39 detector. The monitor sampled ambient air at a flow rate around 0.8–1 l min^{-1} for 24 h continuously, and then the average equilibrium-equivalent radon and thoron concentrations (EEC_{Rn} and EEC_{Tn}, respectively) could be obtained. The lower limits of detection for EEC_{Rn} and EEC_{Tn} were estimated to be 0.57 and 0.07 Bq m^{-3}, respectively, for continuous 24 h sampling at a flow rate of 0.8 l min^{-1}.

2.2. Integrating measurements in the Beijing area

24 h integrating measurements of thoron and radon progeny concentrations were performed in 70 dwellings in the Beijing area during the spring of 2006. Because of the possible effect of building materials on indoor thoron concentrations, all measured dwellings were classified into two kinds according to building materials. One kind, totalling 17 dwellings in this survey, was called 'country houses' or farmhouses, which were built of red bricks and slurry; they were

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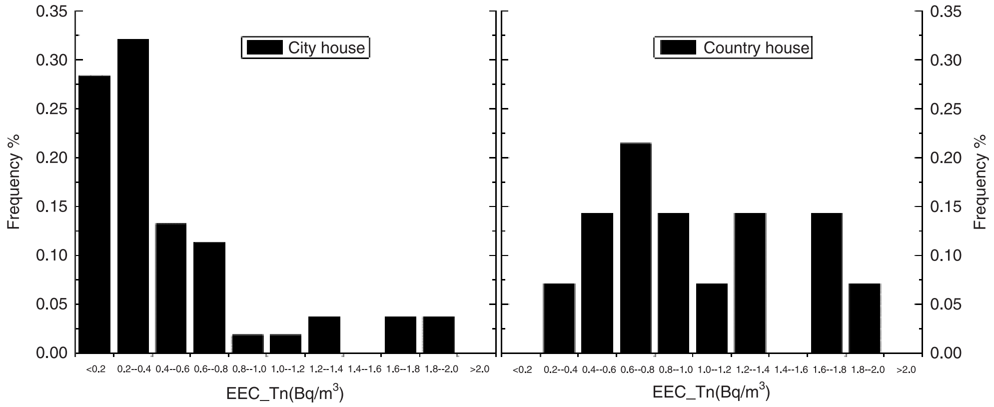

Figure 1. Frequency distribution of EEC_{Tn} of all surveyed dwellings (spring 2006).

Table 1. Concentrations of ^{220}Rn and ^{222}Rn progeny in Beijing (Bq m^{-3}). (Note: 24 h integrating measurements were carried out in spring 2006.)

Number of measurements, n	^{220}Rn progeny (mean ± SD)	^{222}Rn progeny (mean ± SD)
Indoor measurements		
City houses, $n = 35$	0.48 ± 0.47 (0.07–1.83)	11.50 ± 6.99 (2.50–35.11)
Country houses, $n = 17$	1.02 ± 0.48 (0.07–2.61)	16.41 ± 9.02 (4.83–38.20)
Outdoor measurements		
$n = 8$	0.29 ± 0.28 (0.08–0.97)	7.05 ± 2.68 (4.85–11.58)

single storey and most were located in the suburbs of Beijing city. Another kind was called 'city dwellings'—apartment buildings built of concrete blocks and cement floor slabs, and most of them were located inside Beijing city. Fifty-three dwellings of this kind were measured during the survey. Most of the measurements were performed in the living rooms and bedrooms.

Ventilation is a major factor affecting radon and thoron levels in buildings. All the measurements were carried out under natural living conditions, i.e. windows were half-opened during the day and closed at night. The temperatures during the survey ranged from 14–25 °C and the humidity was 10–40%.

In order to know levels of thorn and radon concentrations outdoors in the same area, eight outdoor sites were also measured using the 24 h monitor described above at the same time as the indoor measurements.

3. Results and discussions

3.1. Levels of indoor thoron and radon progeny concentrations

In the 17 country houses, the average equilibrium-equivalent thoron and radon concentrations (EEC_{Tn} and EEC_{Rn}) measured in spring 2006 were 1.02 ± 0.48 Bq m^{-3} and 16.41 ± 9.02 Bq m^{-3}, respectively. For city houses, on the other hand, the average EEC_{Tn} and EEC_{Rn} were 0.48 ± 0.47 Bq m^{-3} and 11.50 ± 6.99 Bq m^{-3}, respectively. The results are summarised in table 1, and the frequency distributions of all houses are shown in figures 1 and 2, respectively.

The results suggested that for thoron progeny levels the EEC_{Tn} concentration of country houses was around twice as high as that of city houses. For radon progeny levels, the EEC_{Rn}

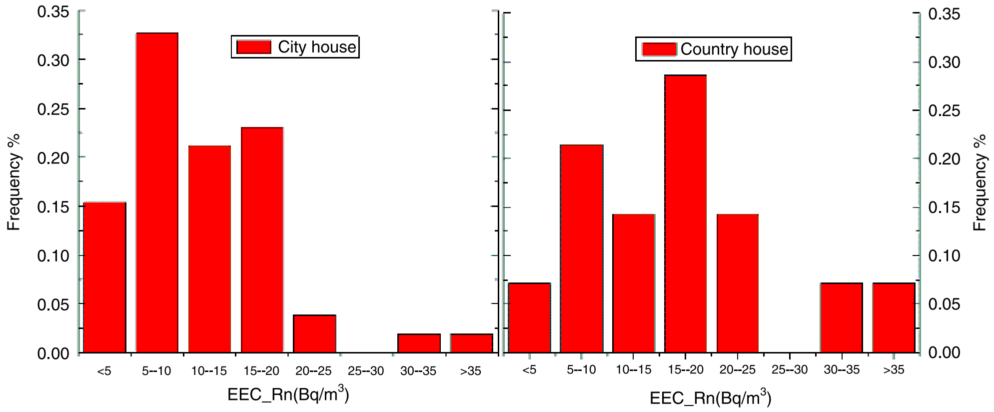

Figure 2. Frequency distribution of EEC_{Rn} of all surveyed dwellings (spring 2006). (This figure is in colour only in the electronic version)

concentration of country houses was slightly higher than that of city houses, but no obvious difference was observed between the two kinds of houses.

It seems plausible that for thoron progeny concentrations, the heterogeneity and characteristics of the building materials were an important factor determining the concentration of thoron gas because of the short half-life of thoron (55.6 s) compared with that of radon (3.85 d).

3.2. Levels of outdoor thoron and radon progeny concentrations

24 h integrating measurements of outdoor air at eight sites were also performed during the same period; the monitor was located at a height of less than 50 cm from the ground surface. The results are shown in table 1. The average concentration was 0.29 ± 0.28 Bq m^{-3}, with a range of 0.08–0.97 Bq m^{-3} for EEC_{Tn}; and 7.05 ± 2.68 Bq m^{-3} with a range of 4.85–11.58 Bq m^{-3} for EEC_{Rn}, respectively.

3.3. Evaluation of exposure dose

Radiation exposures from the inhalation of ^{220}Rn/^{222}Rn progeny were evaluated as follows:

$$E_{Rn} = EEC_{Rn} \times f_{Rn} \times T$$

$$E_{Tn} = EEC_{Tn} \times f_{Tn} \times T,$$

where the conversion factors f_{Rn} and f_{Tn} were adopted as 9 and 40 (nSv (Bq h m^{-3})$^{-1}$) for ^{222}Rn and ^{220}Rn, respectively (UNSCEAR 2000). The exposure time T was 7000 h, and the occupancy factor indoor was assumed to be 0.8. Based on the measurement results above, in country houses the average annual effective dose from ^{220}Rn and ^{222}Rn progeny to an occupant would be 0.23 and 0.83 mSv a^{-1}, whereas in city houses the results would be 0.11 and 0.58 mSv a^{-1}, respectively.

The ratio of the exposure from EEC_{Tn} to that of EEC_{Rn} in the Beijing area was 28% in country houses and 19% in city dwellings, which were higher than that summarised by the UNSCEAR 2000 Report.

4. Conclusion

It was suggested by a pilot survey that EEC_{Tn} might be higher than expected in some houses, country houses for example, and building material was indicated to be an important factor determining levels of thoron and its progeny. However, since the number of houses in this survey was limited, statistical conclusions must remain imprecise.

Acknowledgment

The study was funded by the National Natural Science Foundation of China (no. 10775007).

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