Dose evaluation of indoor thoron progeny in some areas in China

Q. Guo [a,1], J. Cheng [b], Y. Chen [b]

[a] *Department of Technical Physics, School of Physics, Peking University, Beijing 100871, China*
[b] *Department of Engineering Physics, Tsinghua University, Beijing 100084, China*

In order to evaluate the risk from thoron progeny indoors in China, measurements of thoron progeny have been performed by 24 h integrating measurement in Beijing (13 dwellings) and Zhuhai (54 dwellings) areas, whereas in Guangdong (220 dwellings) and Fujian (204 dwellings) provinces 10 min filter sampling was adopted. The highest average EEC_{Tn} was 4.0 ± 2.3 Bq m^{-3}, which was found in Zhuhai city, the thorium-rich area, some 3 times higher than that of Beijing city. The range of mean EEC_{Tn}/EEC_{Rn} ratio was 0.07–0.10 in all the areas, the dose ratio of thoron progeny to radon progeny being 0.31–0.47 accordingly. It is suggested that attention should be paid to the exposure from the inhalation of thoron progeny in thorium-rich areas in China. Elevated indoor radon progeny levels were also found in Zhuhai areas.

1. Introduction

Compared with radon (^{222}Rn) and its progeny, thoron (^{220}Rn) and its progeny have not been well studied in the natural radiation fields, and our knowledge on thoron and its progeny in the environment around us is very limited. In recent years, however, high contributions of thoron and its progeny to the total exposure of radon, thoron and their progeny have been reported in some areas in the world [1–3]. It was reported in China that the national average of thorium (^{232}Th) concentration in soil is 49.1 ± 27.6 Bq kg^{-1} (area weighted) according to the nationwide survey of environmental radioactivity level which was carried out from 1983 to 1990 [5], which is 1.6 times higher than the world average 30 Bq kg^{-1} [4]. The provinces or regions with average soil ^{232}Th concentrations higher than 50 Bq kg^{-1} are shown in Fig. 1. Thorium concentrations in soil in the South are generally higher than those in the North of China just as Fig. 1 shows. In some provinces of the heavily populated South such as Fujian,

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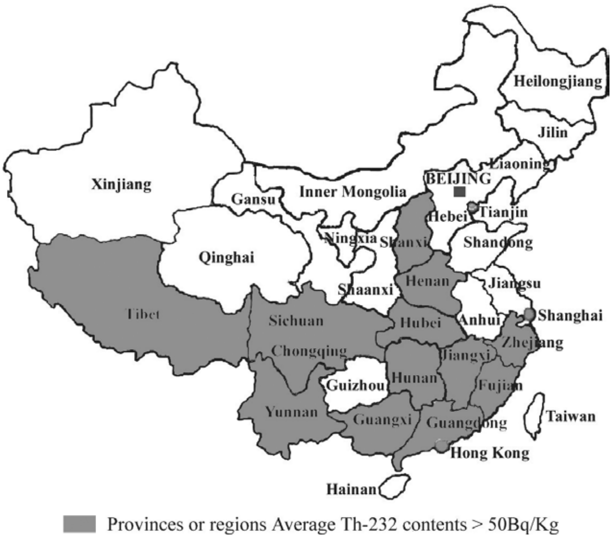

Fig. 1. The geographical distribution of Th-232 contents in soil in China.

Guangdong and Guangxi, the ^{232}Th concentrations in soil are significantly higher than the national average value.

The main building material in both urban and rural areas in China is brick. Most kinds of bricks are baked from soil. Adobe, the sun-dried mud brick, is still widely used as the building material in some rural areas. In some provinces such as Gansu and Shanxi provinces in north-western China, about 30% of the population lives in cave dwellings with soil or mud walls. It is speculated that the elevated natural thorium concentrations, the building materials widely used with high ^{232}Th concentrations, and the special building structure, like cave-dwellings in some areas, should be essential factors affecting the levels of thoron and its progeny in dwellings in China.

The purpose of our study is the estimation of thoron exposure to the public in China in different kinds of dwellings, and in different areas. For a more precise assessment of the exposure from thoron, direct measurements of thoron progeny are desirable because of the different spatial distribution pattern between thoron gas and its decay products [6]. Even though there are several reports on thoron gas measurements in China, especially in cave-dwellings, this paper only summarizes the preliminary results of local surveys on thoron/radon progeny which were carried out in recent years in China. The annual effective dose due to thoron progeny is also evaluated.

2. Materials and methods

2.1. *Integrating measurement of radon/thoron progeny*

An instrument for measuring the equilibrium equivalent of ^{222}Rn and ^{220}Rn concentrations with allyl diglycol carbonate (CR-39) plastic detectors [7] was adopted during our surveys in both the Beijing and Zhuhai areas. The monitor gives the average equilibrium equivalent of ^{222}Rn and ^{220}Rn concentrations (EEC_{Rn} and EEC_{Tn}) during sampling intervals. The detection efficiencies of the alpha particles were calculated by the Monte Carlo method. The lower limits of detection for EEC_{Rn} and EEC_{Tn} are estimated to be 0.57 and 0.07 Bq m^{-3} for 24 h continuously sampling at a flow rate of 0.8 L min^{-1}. The instrument was improved on and manufactured in the author's lab and was adopted for the local survey in Beijing and Zhuhai areas.

2.2. *Short time sampling and measurement of radon/thoron*

The filter method was adopted for sampling in the survey of Guangdong [8] and Fujian [9] provinces, the sampling time being 10 min in all the surveys. Determination of ^{218}Po, ^{214}Bi, ^{214}Pb and ^{212}Pb was carried out by total alpha particle counting. The flow rate being 30 L min^{-1} during the measurement in Guangdong province, the collection efficiency of the membrane filter was 0.7 including self-absorption; the detection efficiency was 32.5% using a uranium standard source. While in Fujian province, airborne radon and thoron progeny were collected on glass fiber filters at 60 L min^{-1}, and a piece of ^{241}Am standard source was used for the calibration of alpha particle detection.

2.3. *Protocols of local surveys on radon/thoron progeny*

Beijing city and Zhuhai city, located in the North and South of China, respectively, were chosen as survey areas for the comparison of ^{222}Rn/^{220}Rn progeny levels in the areas in which ^{232}Th concentrations are quite different. The monitor which could give the average EEC_{Rn} and EEC_{Tn} during sampling intervals (24 h with flow rate of 0.8–1.0 L min^{-1}) was adopted in the surveys of the two cities.

Guangdong and Fujian are the two provinces with both large population and high ^{232}Th concentrations in soil located in the Southeast of China. Their geological structure is mainly formed by Mesozoic igneous rocks, and granite is widely distributed. The filter method for short time measurement was adopted both in the biggest city Fuzhou of Fujian province, as well as in the biggest city Guangzhou and the Yangjiang area of Guangdong province. Sampling was principally conducted 1.5 m height above the floor/ground surface.

The outline and information in detail of the local surveys in the areas mentioned above is shown in Table 1.

3. Results and discussion

Measurements have been performed in 13 dwellings, including 9 apartment building rooms and 4 single flat houses around the authors' university in Beijing city for one year, at a frequency of twice monthly. The measurements are still going on. The building materials of both the apartment building and flat houses were red-brick. The walls of the apartments were well painted or decorated, in flat houses, however, they had a floor slab or brick with almost no decorations.

Table 1
The outline and information of the local surveys reviewed in this paper

Areas	Measuring period	Number of dwellings	Soil ^{232}Th contents (area weighted) ($Bq\,kg^{-1}$)	Sampling & measuring
Beijing	Apr. 2001–Mar. 2002	13	34.1 (17.0–63.0)	24 h sampling flow rate: 0.8–1.0 $L\,min^{-1}$
Zhuhai	Mar.–Apr. 2001	54	159.9 (21.7–263.0)	CR-39 detector
Fujian province	Jun. 1993–Aug. 1994	204	96.3 (19.5–260.1)	10 min sampling flow rate: 60 $L\,min^{-1}$
Guangdong province	July 1984–July 1986	220	57.2 (1.0–152.7)	10 min sampling flow rate: 30 $L\,min^{-1}$

Table 2
Measurement results of radon/thoron progeny in Beijing and Zhuhai areas

Area and type of dwelling	Number of dwellings	EEC_{Rn} ($Bq\,m^{-3}$) (arith. mean ± SD)	EEC_{Tn} ($Bq\,m^{-3}$) (arith. mean ± SD)	EEC_{Tn}/EEC_{Rn} (mean)
Beijing area				
Apart. building	9	10.4 ± 5.9	0.7 ± 0.5	0.07
Flat house	4	16.3 ± 8.9	1.5 ± 0.7	0.09
Total	13	12.8 ± 7.2	1.0 ± 0.7	0.07
Zhuhai area				
Sealed room	31	72.2 ± 36.9	4.5 ± 1.6	0.06
Ventilated room	23	25.0 ± 31.3	3.2 ± 3.0	0.13
Total	54	52.9 ± 39.1	4.0 ± 2.3	0.08

In Zhuhai city, 54 dwellings were measured during a 2 weeks survey in the spring of 2001. According to the ventilation conditions, 54 dwellings were classified into 31 sealed rooms and 23 ventilated rooms.

The measurement results for Beijing and Zhuhai areas are shown in Table 2. It is seen that the levels of both EEC_{Rn} and EEC_{Tn} in Zhuhai, the thorium, radium-rich area, were 52.9 ± 39.1 and 4.0 ± 2.3 $Bq\,m^{-3}$, respectively, some 3 times higher than in the Beijing area, namely 12.8 ± 7.2 and 1.0 ± 0.7 $Bq\,m^{-3}$ for EEC_{Rn} and EEC_{Tn}, respectively. It is necessary to carry out an investigation in more detail in the thorium-rich areas in the South of China in future according to the results. It was quite like radon progeny that EEC_{Tn} was higher in flat house than in the apartment dwellings, and the EEC_{Tn} of sealed rooms was higher than that of ventilated rooms. It is worth mentioning that in the Zhuhai area when comparing the levels between sealed rooms and ventilated rooms, for EEC_{Rn} it was 3 times higher in sealed rooms than in ventilated rooms, but for EEC_{Tn}, it was not so different. It was suggested that the influence of ventilation on indoor levels of thoron and its progeny was quite minor relative to that on radon and its progeny.

Table 3 presents the results of short-term measurements of indoor EEC_{Rn} and EEC_{Tn} carried out in Guangdong and Fujian provinces, both thorium-rich areas located in the Southeast of China. There were 220 dwellings measured in Guangdong province, with average EEC_{Rn}

Table 3
Short-term measurements of EEC_{Rn} and EEC_{Tn} in Guangdong and Fujian provinces

Area	Number of dwellings	EEC_{Rn} (Bq m^{-3}) (arith. mean ± SD)	EEC_{Tn} (Bq m^{-3}) (arith. mean ± SD)	EEC_{Tn}/EEC_{Rn} (mean)
Guangdong province	220	10.6 ± 3.8	1.1 ± 0.8	0.10
Fujian province	204	12.9 ± 5.9	0.9 ± 0.5	0.07

Table 4
Estimated annual effective dose (E) in each area

Areas	Rn progeny		Tn progeny		Dose ratio of Tn progeny/Rn progeny
	EEC_{Rn} (Bq m^{-3})	E (mSv)	EEC_{Tn} (Bq m^{-3})	E (mSv)	
Beijing	12.8	0.77	1.0	0.27	0.35
Zhuhai	52.9	3.20	4.0	1.08	0.34
Guangdong	10.6	0.64	1.1	0.30	0.47
Fujian	12.9	0.78	0.9	0.24	0.31

and EEC_{Tn} 10.6 ± 3.8 and 1.1 ± 0.8 Bq m^{-3}, respectively. The results for Fujian province were 12.9 ± 5.9 and 0.87 ± 0.5 Bq m^{-3} for average EEC_{Rn} and EEC_{Tn}, respectively.

No differences of both indoor EEC_{Rn} and EEC_{Tn} levels between Beijing city and Guangdong or Fujian province were found in comparing Tables 2 and 4. The limited number of dwellings in Beijing area and the different methods adopted for the surveys should be considered as interfering factors, and further investigations are necessary.

All the mean indoor EEC_{Tn}/EEC_{Rn} ratios shown in both Tables 2 and 3 were from 0.07 to 0.10, which is higher than the range (0.02–0.04) report by UNSCEAR in 2000 [4].

4. Dose evaluation

A brief calculation of exposure from the inhalation of radon/thoron progeny was applied as follows, according to the preliminary results of the surveys above:

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

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

where the conversion factors f_{Rn} and f_{Tn} were adopted as 9 and 40 [nSv/(Bq h m^{-3})] for radon and thoron, respectively [4]; The exposure time T is 6720 h for an occupancy factor indoors assumed to be 0.8. The results are shown in Table 4. The exposure from the inhalation of Rn/Tn progeny was evaluated to be 1.04–4.28 mSv in the areas above, and the dose ratios of Tn progeny to Rn progeny were around 1/3, which were significantly higher than the value given by the UNSCEAR 2000 report [4].

5. Conclusions

To obtain an outline of the exposure from the inhalation of thoron progeny in China, this paper reviews 4 primary local surveys carried out in different areas by both 24 h integrating sampling and 10 min short term sampling. High levels of EEC_{Rn} and EEC_{Tn}, of 52.9 ± 39.1 and 4.0 ± 2.31 Bq m^{-3}, respectively, were found in 54 dwellings in the survey in Zhuhai city, the radium/thorium-rich area, by 24 h integrated measurements. This was 3 times higher than that of Beijing city. It is suggested that a detailed investigation of the levels of thoron progeny in thorium-rich areas is necessary. The range of mean EEC_{Tn}/EEC_{Rn} ratio was 0.07–0.10 in all the areas examined, the dose ratio of thoron progeny to radon progeny being 0.31–0.47.

From these limited data, the levels of thoron progeny appear to be somewhat higher than the typical value in the UNSCEAR 2000 report. This suggests that attention should be paid to the exposure from the inhalation of thoron progeny in some thorium-rich areas in China. Further work has to be done on the study of thoron and its progeny, where integrated measurements of thoron, especially of thoron progeny, are necessary for a precise assessment of radiation exposure.

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