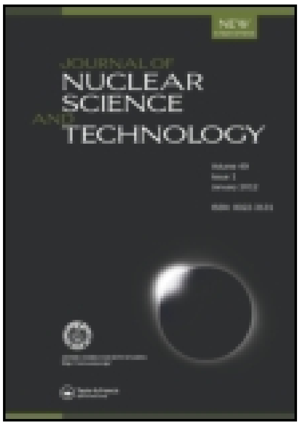

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TECHNICAL DATA

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Small surveys on thoron, radon and their progeny were carried out in four areas in China. Both high thoron concentrations near to walls and high thoron progeny concentrations were found in some dwellings through the surveys. It is suggested from the limited data that attention shall be paid to the exposure from the inhalation of thoron and its progeny in some kinds of dwellings or areas, and much works on thoron study in detail is necessary.

KEYWORDS: radon 220, thoron, thoron progeny, radon, radon progeny, natural radiation, surveys, China

I. Introduction

Radon-220, commonly called thoron, is an isotope of radon. Thoron is a natural product of thorium (^{232}Th) series, and produced in the earth's crust, such like soil, rocks and also in building materials. Thoron also can migrate to the earth's atmosphere, exist both indoors and outdoors, and can be inhaled, mainly its progeny, into our body through breath.

The international database on radon (^{222}Rn) and its progeny has improved steadily since 1970s, while representative data on thoron and its progeny are still scare or non-existent in some areas. The main reason leading to this situation is that the levels of thoron and its progeny are considered to be very low due to the short half-life of thoron (55.6s), and the dose contribution from thoron and its progeny to the public would be ignored compared with that from radon and its progeny in natural radiation protection filed. As the half-life of thoron progeny (^{212}Pb, 10.64h) is much longer than that of radon progeny, and the alpha energy emitted from thoron progeny is high (^{212}Po, 8.78 MeV), the effective dose per unit equilibrium equivalent concentration of thoron progeny is near 4.4 times higher than that of radon progeny.[1)] In the report of UNSCEAR 1993,[2)] the annual effective dose from thoron and its progeny was evaluated to be 75μSv, only 6% of that of radon and its progeny. 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 report of UNSEEAR 2000.[1)]

In the early years of 1990s, however, some high thoron concentrations were reported in the traditional Japanese style wooden house with mud/soil walls, and the potential risk of indoor thoron and it progeny was indicated.[3,4)] People begin to pay more attention to thoron and its progeny in recent years world widely. In China, as pointed out,[5)] ^{232}Th contents of both in soil and in some building materials widely used are high, and brick made of coal cinder or made of soil is still the main building materials nationwide. It is suggested that thoron and its progeny may be a significant indoor pollutant in some regions or some specific dwellings. The purpose of our study is to see the outline of thoron and its progeny levels in some special areas. This paper summarizes a preliminary results of local surveys on thoron, radon and their progeny.

II. Materials and Methods

1. Measurements of Thoron and Radon Concentrations

The measurements of thoron and radon concentrations were carried out by passive integrating Rn–Tn cup monitors with solid state nuclear track detectors (SSNTD) of CR-39. The monitors were developed by Nagoya University, Japan, and more detailed technical information on the monitors is shown in Iida *et al*.[6)] Since the distribution of thoron concentrations depends on the distance from its sources, Rn–Tn cup monitors were located in the places 5–20 cm far from walls uniformly during our surveys. After having been exposed for 3 months, the CR-39 detectors were sealed by an aluminium bag and then were etched for 5 h at 80°C in 6.25 N NaOH solution in laboratory. Thoron and radon concentrations can be calculated as follows:

$$Q_{\mathrm{Rn}} = \frac{N_{\mathrm{Rn}} - B}{CF_{\mathrm{Rn}} \times T}, \tag{1}$$

$$Q_{\mathrm{Tn}} = \frac{N_{\mathrm{Tn}} - N_{\mathrm{Rn}}}{CF_{\mathrm{Tn}} \times T}, \tag{2}$$

where N_{Rn} and N_{Tn} is etched-track densities of radon and thoron cup monitors (tracks cm^{-2}); B is the background track density of CR-39 (tracks cm^{-2}); CF_{Rn} and CF_{Tn}, the calibration factors of Rn and Tn monitors, are 4.17×10^{-3} tracks cm^{-2} (Bq·m^{-3}·h)$^{-1}$ and 0.6×10^{-3} tracks cm^{-2} (Bq·m^{-3}·h)$^{-1}$, respectively. And T is exposure time in h.

From the point of view of dose evaluation, the contribution from thoron can be ignored compared with that from thoron progeny, the integrating measurement of equilibrium equivalent concentration (EEC) of thoron is desired and enough as well for dose evaluation generally. However as for integrating measurement for investigation, only the passive integrating Rn–Tn cup monitors mentioned above was well studied and applied at the early stage of thoron research. In the other hand, thoron levels is also an important reference to know the source as well. Both thoron concentration and the concentration of its progeny were investigated in our small survey.

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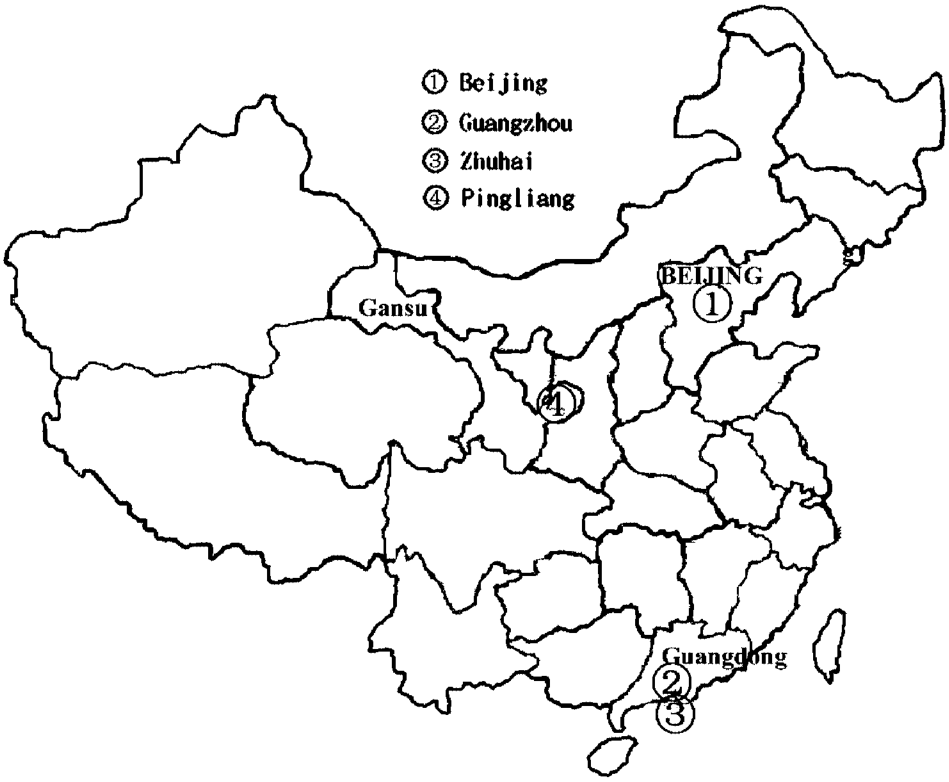

Fig. 1 The locations of the four survey areas in China

2. Measurements of Thoron and Radon Progeny

The equilibrium equivalent concentration (EEC) of radon and thoron were measured by counting all the alpha particles deposited on the sampling filter. The flow rate of sampling was 0.04 $m^3 \cdot min^{-1}$. For EEC of radon, we counted from 7 to 10 min after 5 min sampling; for EEC of thoron, we counted for 10 min from 217.3 min after 10 min sampling. The EEC of radon and thoron was calculated as follows:

$$EEC_{Rn} = (40.3 \times N_{7\text{–}10})/(13,000 \times 3.7\eta FV),$$

$$EEC_{Tn} = (94 \times N_{217\text{–}227})/(13,000 \times 0.275\eta FV),$$

where η is the counting efficiency of detector, F is the collecting efficiency of filter including self absorption, V is the flow rate of sampling, $N_{7\text{–}10}$ and $N_{217\text{–}227}$ are counts from 7 to 10 min and from 217 to 227 min after sampling, respectively.

3. Protocols of the Survey on Thoron, Radon and Their Progeny

The locations of the four survey areas of our survey are shown in **Fig. 1**. Beijing is a big city in the North of China, and Guangzhou and Zhuhai are both big cities of Guangdong province located in the South of China. Comparatively with the three big cities with large population density, Pingliang is a rural area of Gansu province in the Northwest of China, and the main style of dwellings in the area is cave. There is generally no decoration in the interior surface of walls. The building materials widely using in the area is adobe, the sun-dried mud brick.

The outline of the survey is shown in **Table 1**. For reference, soil ^{232}Th contents in each area were also shown in the table. It is necessary to point out here that there is no direct relationship between indoor concentrations of thoron or its progeny and soil ^{232}Th contents. There are some other factors affecting on thoron exhalation, such as porosity, grain size, moisture of the surface of building materials, are more important than ^{232}Th contents.

The measurements of thoron and radon progeny were performed both indoors and outdoors in Beijing, Zhuhai and Pingliang areas except Guangzhou.

III. Results and Discussions

1. Thoron and Radon Concentrations

The result of thoron and radon concentrations in Guangzhou city was shown in detail in **Table 2**. The range of radon concentrations was from 28.1 $Bq \cdot m^{-3}$ to 138.5 $Bq \cdot m^{-3}$, and the average concentration during the measuring period was 61.2±28.8 $Bq \cdot m^{-3}$. For thoron concentrations, it varied from 46.6 $Bq \cdot m^{-3}$ to 531.0 $Bq \cdot m^{-3}$, and the average concentration was 190.8±163.4 $Bq \cdot m^{-3}$, around the places 10 cm from walls.

It suggested from Table 2, in despite of the number of the dwelling measured were still very limited, that the dwellings with the brick made of coal cinder have a trend toward a higher radon and thoron concentrations than the dwellings with other building materials. Coal is the main natural resource in China, and coal cinder, as a component of building materials, is getting widely used during recycling in recent years. The representative value of ^{232}Th contents in the brick made of coal cinder nationwide was reported to be 80 $Bq \cdot kg^{-1}$[8)] in China. On the other hand, the ^{232}Th con-

Table 1 The outline of the local surveys on Tn and Rn concentrations

Areas	Measuring period	Dwellings number	Soil ^{223}Th contents in the areas ($Bq\cdot kg^{-1}$)[7)	
			Mean	Range
Beijing	July–Dec. 1998	10	34.1	17.0–63.0
Guangzhou	Nov. 1997–Feb. 1998	17	80.4	15.5–152.7
Zhuhai	Mar.–Sep. 1999	54	193.0	11.0–644.5
Pingliang	Nov. 1996–Dec. 1997	24	42.4	16.4–105.5

Table 2 Tn and Rn concentrations in different dwellings in Guangzhou city

No.	Building materials of walls	Decoration of wall surface	Concentration ($Bq\cdot m^{-3}$)	
			^{220}Rn	^{222}Rn
1	Red brick	Latex paint	52.2	46.9
2	Red brick	Calcareousness	49.4	42.8
3	Red brick	Lacquer	49.4	43.0
4	Red brick	Calcareousness	64.7	52.3
5	Red brick	Lacquer	149.6	50.1
6	Red brick	Latex paint	303.3	43.8
7	Red brick	Calcareousness	357.9	28.1
8	Red brick	Calcareousness	258.2	46.3
9	Red brick	Latex paint	46.6	56.4
10	Concrete	Wood block	122.2	63.6
11	Concrete	Wood block	46.9	84.1
12	Concrete	Wood block	50.8	51.6
13	Brick made of coal cinder	Lacquer	429.7	117.0
14	Brick made of coal cinder	Wood block	93.9	36.2
15	Brick made of coal cinder	Lacquer	208.2	75.8
16	Brick made of coal cinder	Latex paint	531.0	64.2
17	Brick made of coal cinder	Lacquer	429.7	138.5
	Average±SD		190.8±163.4	61.2±28.8

tents of brick made of clay and concrete was reported to be 63 $Bq\cdot kg^{-1}$ and 38 $Bq\cdot kg^{-1}$, respectively. It is important to notice that the wide use of coal cinder in dwelling construction is possible to enhance the exposure level from natural radiation.

Thoron and radon concentrations of the four areas is shown in **Table 3**. High thoron concentrations were found in Guangzhou, Zhuhai, where the soil ^{232}Th contents of the areas are rather high as showing in Table 1. The most highest thoron concentration was found in the cave dwellings in Pingliang area, Gansu province, whereas the ^{232}Th contents both in soil and in building materials are not high (42.4±7.6 $Bq\cdot kg^{-1}$), however. The walls of the cave dwellings in Pingliang area were made of mud or adobe, the sun-dried mud brick. As mentioned above, there was nearly no any decorating in the surfaces of walls, it may make thoron exhaling from building materials easily. This may be the reason of the high thoron concentration in cave dwellings, still there is no exhalation rate to approve it.

It is necessary to point out here that all the thoron concentrations given in Table 3 was around the places very near to walls (5–20 cm). Unlike the spatial distribution of radon concentrations in dwellings, thoron concentrations is in exponential decrease with the distance from the walls due to its short half-life.[3,4] Furthermore, for the very limited dwellings numbers, we do not think the results shown in Table 3 is the representative data of the areas. It should be careful while comparing thoron concentrations obtained in different environmental surveys.

2. Concentrations of Thoron and Radon Progeny

Equilibrium Equivalent Concentrations (EEC) of thoron and radon both indoor and outdoor air were surveyed in Beijing, Zhuhai and Pingliang except Guangzhou, and the results are shown in **Table 4**. We can see from the table that in the four areas, the levels of thoron progeny in dwellings is 3–9

Table 3 Tn and Rn concentrations of the local surveys

Areas	Dwellings number	Tn concentrations (Bq·m^{-3})		Rn concentrations (Bq·m^{-3})	
		Range	Average	Range	Average
Beijing	10	<LLD-106.5	56.4	12.6–106.1	24.6
Guangzhou	17	46.4–531.0	190.8	28.1–138.5	61.2
Zhuhai	54	25.0–827.0	127.9	16.6–245.2	60.4
Pingliang	24	<LLD-1,326.4	493.5	18.9–148.6	71.6

Table 4 Equilibrium equivalent concentrations (EEC) of Tn and Rn

Areas	Dwellings or point number	EEC_{Tn} (Bq·m^{-3})		EEC_{Rn} (Bq·m^{-3})	
		Mean	Range	Mean	Range
Indoors					
Beijing	15	0.9	<LLD-3.08	12.3	1.4–48.3
Guangzhou[9]	80	1.1	0.1–4.3	10.6	1.9–22.2
Zhuhai	14	2.7	0.3–4.7	20.4	2.2–93.2
Pingliang	8	2.0	0.4–5.9	8.6	2.7–57.0
Outdoors					
Beijing	31	0.4	<LLD-0.9	4.8	1.1–14.7
Guangzhou[9]	20	0.6	<LLD-0.8	8.8	3.9–12.0
Zhuhai	11	0.8	0.1–1.2	12.3	1.5–17.3
Pingliang	—				

Table 5 The estimated annual effective dose (E) in each areas

Areas	Rn progeny		Tn progeny		Dose radio of Tn progeny to Rn progeny
	EEC (Bq·m^{-3})	E (mSv)	EEC (Bq·m^{-3})	E (mSv)	
Beijing	12.3±8.9	0.78	0.9 ± 1.3	0.25	0.32
Guangzhou	10.6±1.3	0.67	1.9±0.1	0.53	0.79
Zhuhai	20.4±21.6	1.29	2.7±0.9	0.76	0.59
Pingliang	8.6±8.6	0.54	2.0±1.0	0.56	1.04

times higher than the world average,[1,4] 0.3 Bq·m^{-3}.

3. Dose Evaluation

(1) Exposure from the Inhalation of Thoron

The ratio of the effective dose conversion factor for thoron to that for its progeny is 3/1,000 according UNSCEAR Report 1993, so the exposure from the inhalation of thoron itself can be ignored generally. However in some special environment, for example the cave dwellings in Pingliang area, thoron concentration near walls can be as high as over 1,000 Bq·m^{-3}, and bed is often placed near walls. If a person is 8 h daily in such an environment, the effective dose caused from the inhalation of thoron gas would be 0.32 mSv·yr^{-1}. Unlike the inhalation of radon gas, the rather long half-life of thoron progeny (^{212}Pb, 10.64h; ^{212}Bi, 60.6 min) makes the exposure from the inhalation of thoron not only to bronchus and other parts of lung, but also to the other tissues or organs, like kidney, liver or born marrow.

(2) Exposure from the Inhalation of Thoron Progeny

To evaluate the radiation exposure from radon progeny, equilibrium factor between radon and its progeny is often used to estimate radon progeny. However, different procedure should be followed in the case of thoron and its progeny since the different distribution pattern between thoron and its progeny. For a precise assessment of the thoron progeny exposure, the data obtained from direct progeny measurements are preferred.

A brief calculation of exposure from the inhalation of thoron, radon progeny in dwellings was tried as follows:

$$E_{Tn} = EEC_{Tn} \times f_{Tn} \times T, \tag{3}$$

$$E_{Rn} = EEC_{Rn} \times f_{Rn} \times T, \tag{4}$$

where the conversion factors f_{Tn} and f_{Rn} were adopted as 40 and 9 [nSv/(Bq·h·m^{-3})] for thoron and radon, respectively;[4] The exposure time T is 6,720 h for the occupancy factor indoor is assumed to be 0.8. The results was shown in **Table 5**.

It is indicated that in Guangzhou and Zhuhai, the dose contribution from thoron progeny is over half of that from radon progeny, and in the cave dwellings in Pingliang area, the dose contribution from radon and thoron are nearly the same. Even though the survey is small and the data is limited, the results suggested it is necessary to pay attention to the presence of high thoron progeny in some areas for accurate dose assessment in radiation protection field.

IV. Conclusions

Indoor and outdoor concentrations of thoron, radon and their progeny were surveyed in four areas in China. The presence of both high thoron concentrations near to walls and its progeny were found during the preliminary survey. From the limited data, the levels of both thoron and its progeny appeared to be somewhat higher than the typical value in the UNSCEAR Report 1993 and 2000. It suggested that attention should be paid to the exposure from the inhalation of thoron and its progeny in some areas.

Much works have to be done on thoron and its progeny study in China, where integrating measurements of thoron and its progeny is desired for a precise assessment of the radiation exposure.

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