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TECHNICAL REPORT

Indoor Thoron and Radon Concentrations in Zhuhai, China

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A field survey of 54 dwellings and 21 points outdoors around Zhuhai area was carried out using a newly developed integrating monitor in the spring of 2001 for a preliminary exposure assessment on ^{222}Rn and ^{220}Rn progeny, focusing especially on ^{220}Rn progeny levels and its contribution to the general public. The flux rates of ^{222}Rn and ^{220}Rn from ground soil and soil nuclide contents were measured simultaneously. The average EEC_{Rn} and EEC_{Tn} were 52.9±39.1 Bq·m^{-3} and 4.0±2.3 Bq·m^{-3} for dwellings and 7.5±3.6 Bq·m^{-3} and 0.6±0.2 Bq·m^{-3} for outdoor air, respectively. Rather high ^{220}Rn flux rates from ground surface were measured, the mean value was 2,645.1±1,667.6 mBq·m^{-2}·s^{-1}. The estimated radiation exposures from the exhalation of ^{222}Rn and ^{220}Rn progeny were 3.3 mSv·a^{-1} and 1.1 mSv·a^{-1}, respectively. The exposure from ^{220}Rn progeny was some 1/3 that of ^{222}Rn progeny, and ought not to be ignored from the viewpoint of radiation protection in Zhuhai area.

KEYWORDS: radon, thoron, progeny, integrating measurement, exposure, Zhuhai

I. Introduction

Over the past few decades, there has been much scientific interest in the study of environmental radon (^{222}Rn). The international database on ^{222}Rn and its progeny has been expanded steadily since 1970, but representative data on thoron (^{220}Rn) and its progeny are still scarce. The main reasons for this situation are that the levels of ^{220}Rn and its progeny are considered to be very low due to the short half-life of ^{220}Rn (55.6 s), and the dose contribution from ^{220}Rn and its progeny to the public can be ignored compared with that from ^{222}Rn and its progeny.

As the half-life of ^{220}Rn progeny (^{212}Pb, 10.64 h) is much longer than that of ^{222}Rn progeny, and the alpha energy emitted from ^{220}Rn progeny is high (^{212}Po, 8.78 MeV), the effective dose per unit equilibrium equivalent concentration of ^{220}Rn (EEC_{Tn}) is near 4.4 times higher than that of equilibrium equivalent concentration of ^{222}Rn (EEC_{Rn}).[1)] The annual effective dose caused by ^{220}Rn and its progeny is 75 μSv, which is only 6% of that of ^{222}Rn and its progeny.[2)] While the annual effective dose from ^{220}Rn and its progeny is up to 9% of that of ^{222}Rn and its progeny.[1)]

However, some high ^{220}Rn and progeny concentrations have been reported in recent years in Asia,[3–5)] and the potential high risk of exposure to indoor ^{220}Rn and progeny was indicated.[6,7)] Scientists worldwide have begun to pay more attention to the exposure to ^{220}Rn and its progeny.

It has been noted in China that the soil ^{232}Th contents in the South-east were higher than that of the national average; for example, the soil ^{232}Th content of Zhuhai area was reported to be 79.5±11.9 (range: 29.8–152.7) Bq·kg^{-1},[8)] which was more than twice that of the world average (30 Bq·kg^{-1}).[1)] Zhuhai is located at 21°48′–22°27′N, 113°03′–114°19′E, very near Macao and Hong Kong, and has an area of 7,650 km^2. The soil in this area was formed mainly by erosion of granite which was formed in the Yanshan period and is rich in uranium and thorium. Zhuhai is a rapidly developing city as well, and its population is about 1.15 million. The purpose of the present study was to make a preliminary exposure assessment on ^{222}Rn and ^{220}Rn progeny, focusing especially on the levels of ^{220}Rn progeny and its contribution to the public.

II. Materials and Methods

1. Integrating Measurements of ^{222}Rn and ^{220}Rn Progeny

Since direct and integrating measurements of ^{220}Rn progeny are desirable for evaluation of its contribution, a new type of portable integrating monitor with etched track detectors (CR-39[a]) was developed by Zhou and Iida,[9)] manufactured in the author's lab, and adopted in the field survey. The monitor sampled ambient air at a flow rate around 1 l·min^{-1} for 24 h continuously, and then the average EEC_{Rn} and EEC_{Tn} of the sampling intervals were obtained after etching and calculating.

2. Measurements of Ground Flux Rates of ^{222}Rn and ^{220}Rn

An apparatus[10)] for measuring ground flux rates of ^{222}Rn and ^{220}Rn was adopted; its structural drawing of the apparatus is shown in **Fig. 1**. The apparatus consisted of 11 cm high steel skirt, ZnS(Ag) scintillation counter (area: 30×40 cm^2), light-guide and photomultiplier. All alpha particles were counted every 15 s, and counting time was 30 min at every measurement points. The flux rates of ^{222}Rn and ^{220}Rn were calculated by adopting the counts of different time which could be got by linear simulation analysis.

Equation (1) is for the calculation of ^{220}Rn flux rate:

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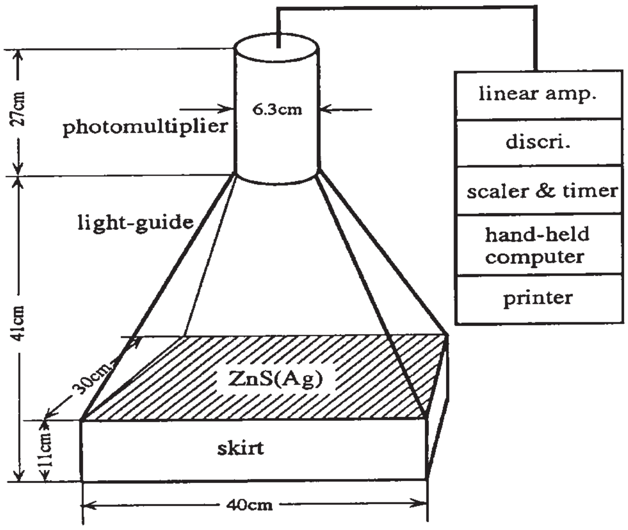

Fig. 1 Illustration of the flux rate measurement apparatus for soil radon and thoron

$$E_T = (N_{10} - N_b) \times CF_T, \tag{1}$$

where N_{10} is the count rate at 10 min after the measurement start (cpm), N_b is the background count rate (cpm) and CF_T is the conversion factor for ^{220}Rn (18.1±3.2 [mBq·m^{-2}·s^{-1}·cpm^{-1}]).

Equation (2) is for the calculation of ^{222}Rn flux rate:

$$E_R = (N_{30} - N_{10} - N_b) \times CF_R, \tag{2}$$

where N_{30} is the count rate at 30 min after the measurement start (cpm) and CF_R is the conversion factor for ^{222}Rn (0.521±0.041 [mBq·m^{-2}·s^{-1}·cpm^{-1}]). **Figure 2** is an example of survey results in Zhuhai area.

3. Field Measurement in Zhuhai Area

A pilot field survey on ^{222}Rn and ^{220}Rn progeny was carried out in Zhuhai area in the spring of 2001, measurements were made at 54 dwellings and 21 outdoor sites distributed throughout the area. Population density, types of buildings and ventilation situation were considered for measurement site selection. The temperatures were 22–30°C during day time, and 18–20°C during night time; the humidity was 75–95%.

III. Results and Discussion

1. ^{222}Rn and ^{220}Rn Progeny Concentrations

Radon-222 and Rn-220 progeny concentrations are shown in **Table 1**. Rather high average concentrations of both EEC_{Rn}, 52.9±39.1 Bq·m^{-3}, and EEC_{Tn}, 4.0±2.3 Bq·m^{-3}, were got in dwellings, and wide ranges of EEC_{Rn}/EEC_{Tn} were gotten as well.

The population-weighted average values of indoor EEC_{Rn} and EEC_{Tn} in China were evaluated to be 12 Bq·m^{-3} and 0.8 Bq·m^{-3}, respectively.[11] Compared with the national averages the values in Zhuhai area were 4–5 times higher. Considering the limitation of both the number of measured dwellings and duration of the survey period, a detailed investigation in the future is necessary and important to clarity the natural radiation levels in this area.

The impact of ventilation situations was analyzed further.

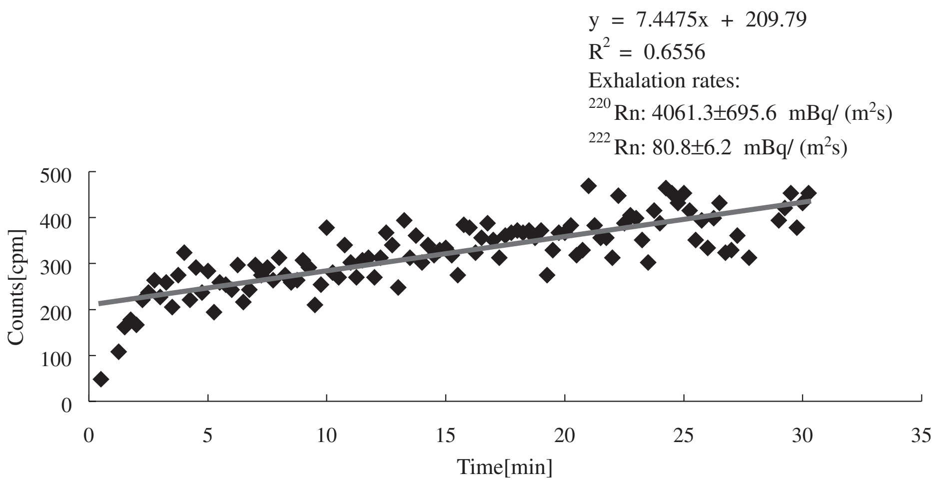

Fig. 2 An example calculation on ground exhalation rates of ^{220}Rn and ^{222}Rn in Zhuhai

Table 1 Indoor and outdoor values of EEC_{Rn} and EEC_{Tn} in Zhuhai area (Bq·m^{-3})

Items	Indoor				Outdoor			
	Number	Range	Mean	S.D.	Number	Range	Mean	S.D.
EEC_{Rn}	54	1.2–152.4	52.9	39.1	21	1.5–12.1	7.5	3.6
EEC_{Tn}	54	0.1–12.6	4.0	2.3	21	0.1–0.8	0.6	0.2

Table 2 Indoor values of EEC_{Rn} and EEC_{Tn} under different ventilation conditions ($Bq{\cdot}m^{-3}$)

Items	Airtight				Ventilated or half-ventilated			
	Number	Range	Mean	S.D.	Number	Range	Mean	S.D.
EEC_{Rn}	31	2.3–152.4	72.7	36.9	23	1.2–31.3	25.0	31.3
EEC_{Tn}	31	0.2–12.6	4.5	1.6	23	0.1–8.8	3.2	3.0

Table 3 Ground flux rates of ^{222}Rn and ^{220}Rn and soil nuclide contents in Zhuhai area

Sites	Flux rate ($mBq{\cdot}m^{-2}{\cdot}s^{-1}$)		Nuclides content ($Bq{\cdot}kg^{-1}$)	
	E_{Rn}	E_{Tn}	^{226}Ra	^{232}Th
Playground	21.3	3,444.5	—	—
Plaza lawn 1	2.7	2,361.3	71.8±2.3	171.2±5.6
Plaza lawn 2	—	1,470.0	18.0±0.6	21.7±0.8
Farmland	—	3,123.0	—	—
Courtyard[a)] of a spa	51.3	16,358.6	236.1±8.0	1,234.1±21.1
Xiang-shan Park 1	0.4	1,514.4	109.1±3.5	181.2±5.9
Xiang-shan Park 2	—	6,176.7	—	—
Lawn of a factory	8.7	1,380.9	—	—
Ground near a dam	80.8	4,061.3	68.1±3.0	131.0±3.5
Lawn of a hotel	10.9	2,470.5	152.6±5.9	191.1±4.3
Courtyard of a school	7.4	468.6	97.5±3.0	263.0±2.5
Mean	22.9±26.6	2645.1±1667.6	107.6±64.9	159.9±73.2

[a)]The data were not used for average calculation considering that the spa water made soil Th-232 content and Rn-220 flux rate unusually higher than other sites.

All the dwellings where measurements were made were classified as airtight and ventilated or half-ventilated, and **Table 2** shows these results. There was a tendency for EEC_{Rn} and EEC_{Tn} in airtight dwellings to be higher than in ventilated or half-ventilated dwellings. Furthermore, EEC_{Rn} appeared to be more sensitive to ventilation conditions; it was three times higher than EEC_{Tn}. This could be attributed to the short half-life of ^{222}Rn progeny which makes its concentration depend on the level of ^{222}Rn. ^{222}Rn has a quite long half-life (3.825 d) compared with that of ^{220}Rn progeny (^{212}Pb, 10.64 h), which might make the concentration of ^{222}Rn progeny in dwellings more sensitive to ventilation condition, however this needs to be confirmed in more detail using a wider range of measurement results.

2. Ground Flux Rate of ^{222}Rn and ^{220}Rn and Soil Nuclides Contents

Soil is the main source of environmental ^{222}Rn and ^{220}Rn, and their diffusion from soil has been identified as one of the important mechanisms influencing their environmental levels. For a better understanding of the natural background levels of radiation in Zhuhai area, ground flux rates of ^{222}Rn and ^{220}Rn and soil nuclide contents were measured during the survey at the same sites. Two samples of soil were collected from the ground surface at each site; these were mixed, and dried for about 24 h at 105°C±2°C in the lab. Then the dry samples were grind and sifted, before being put into a standard plastic container (Φ75×50 mm) and sealed for at least 20 days until the spectrometric measurements were done. Measurements were carried out with a high-purity germanium detector (GEM-10175, EG&G ORTEC), with a relative efficiency of 48.3% (E_γ=1.33 MeV). Measurement time was approximately 6–8 h. The flux rates and soil nuclide contents are listed in **Table 3**.

The ^{222}Rn flux rate could not be calculated, or an unreasonable low result was got in some sites. This was considered to be interference due to the high ^{220}Rn flux rate, which was inherent in the measurement of the flux rate apparatus. Rather high ^{220}Rn flux were got from 11 sites in Zhuhai area, and the mean value was 2,645.1±1,667.6 $mBq{\cdot}m^{-2}{\cdot}s^{-1}$, which was more than twice than that of the world average (1,000 $mBq{\cdot}m^{-2}{\cdot}s^{-1}$).[2)] All the flux results here were proof of the high ^{222}Rn and ^{220}Rn progeny concentrations discussed above, and furthermore, the high flux rates suggested a higher radiation exposure to the general public caused the progeny.

In addition, the results of Table 3 also showed both high soil ^{226}Ra and ^{232}Th contents. The mean values of soil ^{226}Ra and ^{232}Th contents were 107.6±64.9 $Bq{\cdot}kg^{-1}$ and 159.9±73.2 $Bq{\cdot}kg^{-1}$, respectively, 2–3 times higher than their national averages (36.5 $Bq{\cdot}kg^{-1}$ and 49.1 $Bq{\cdot}kg^{-1}$, respectively for ^{226}Ra and ^{232}Th).[12)] The high soil contents of ^{226}Ra and ^{232}Th in this area should be the primary reason for the high flux rates of ^{222}Rn and ^{220}Rn got above, and they would indicate high radiation exposure caused by their progeny.

It is noteworthy that at the spa courtyard site quite high levels of both the flux rates of ^{222}Rn and ^{220}Rn and soil ^{226}Ra and ^{232}Th contents were found, showed in Table 3, this merits further investigation.

3. Exposure Dose Evaluation

Exposure from the inhalation of ^{222}Rn and ^{220}Rn progeny was evaluated based on the survey results in Zhuhai area. A simple of calculation was tried 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}, f_{Tn} were adopted as 9 and 40 [nSv/(Bq·h·m^{-3})] for ^{222}Rn and ^{220}Rn, respectively;[1)] the exposure time T was 7,000 h, and the occupancy factor indoor was assumed to be 0.8. Based on the survey results in 54 dwellings, annual effective doses caused by ^{222}Rn and ^{220}Rn progeny were 3.3 mSv·a^{-1} and 1.1 mSv·a^{-1}, respectively. It was suggested that the exposure from ^{220}Rn progeny was about 1/3 of that from ^{222}Rn progeny in Zhuhai area.

IV. Conclusions

A preliminary survey on ^{222}Rn and ^{220}Rn progeny concentrations was carried out in the radium-thorium rich area of Zhuhai, and rather high EEC_{Rn} and EEC_{Tn} values 52.9 ± 39.1 Bq·m^{-3} and 4.0 ± 2.3 Bq·m^{-3} in dwellings respectively, were got by integrating measurements. These EEC_{Rn} and EEC_{Tn} values were 4–5 times higher than those of the national population-weighted average values. Furthermore, soil ^{226}Ra and ^{232}Th contents and flux rates of ^{222}Rn and ^{220}Rn were also measured, and relatively high values were found. Radiation exposures from the exhalation of ^{222}Rn and ^{220}Rn progeny were estimated to be 3.3 mSv·a^{-1} and 1.1 mSv·a^{-1}, respectively; suggested that the exposure from ^{220}Rn progeny was some 1/3 of that of ^{222}Rn progeny, which was higher than that reported by UNSCEAR 2000.[1)] More detailed studies of larger scale are necessary. The exposure caused by ^{220}Rn progeny should not be ignored from the viewpoint of radiation protection in this area.

Acknowledgment

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