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Dosimetric evaluation of thoron exposure in the three typical rural indoor environments of China

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Abstract In order to evaluate thoron exposure in indoor environments, field measurements of both concentration and its size distribution were carried out in three typical rural residential houses in China, and exposure dose was evaluated using dosimetric method. Results show that the thoron progeny size distributions of rural indoor environments (AMAD: 76.5 nm; GSD: 2.7) are much smaller than those of urban (AMAD: 115 nm; GSD: 2.0), which makes the dose conversion factors of thoron in rural environments [307.4 nSv/(Bq m^{-3} h^{-1})] are much higher than those in urban [113.4 nSv/(Bq m^{-3} h^{-1})]. The highest thoron exposure (10.12 mSv a^{-1}) was found in mud house of Yangjiang, the high radiation background area.

Keywords Thoron progeny · Size distribution · Dose conversion factor · Dose evaluation

Introduction

Radon (^{222}Rn) has been widely paid attention in the last century because it contributes the most to the human body among the dose from natural radiation [1]. Thoron (^{220}Rn) is one of the radioactive isotopes of radon, but due to its short half-life (55.6 s) and the lack of measurement methods as well as measuring results. It has been ignored for a long time. With the improvement of thoron measuring methods and the rich of thoron related data, thoron exposure in some indoor environments has begun to attract people's attention [2, 3].

The brick houses, the mud houses and the caves are the three typical rural residential houses in China, usually with naked surface from where the thoron gas can easily come out, especially in some high background regions such as Yangjiang, Guangdong Provence. It's necessary to evaluate the thoron exposure in those rural residential houses. In different indoor environments, the equilibrium between the thoron gas and the thoron progeny are quite different and also change frequently. So the direct measurement of thoron progeny seems more reasonable for the purpose of dose evaluation [4].

The dose conversion factor (DCF), which characterizes the dose to the respiratory tract per unit exposure of thoron progeny, changes with the unattached fraction of thoron daughters and their size distribution [5]. While the unattached fractions of ^{212}Bi and ^{212}Pb which contribute nearly total dose of thoron progeny usually could be ignored in usual indoor environments, so the measurement of size distribution of attached thoron progeny and thoron progeny concentration will determine thoron exposure dose.

For the purpose of evaluating thoron exposure dose, field measurements were carried out in three typical rural indoor environments and one kind of urban indoor environment for comparison, including the thoron progeny concentrations and the size distributions of thoron progeny. The dose conversion factors and annual effective doses of thoron exposure in those environments were calculated using dosimetric methods.

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Fig. 1 The drawings of thoron progeny concentration and size distribution measuring devices

Materials and methods

Measuring devices

Two portable integrated devices were used in these field measurements for dose evaluation. One is a portable ^{222}Rn/^{220}Rn daughter equilibrium equivalent concentration (EEC) measuring device Progeny Integrating Sampling Unit (PISU) [6], and another is a newly developed ^{212}Pb particle size distribution measuring device [7]. The drawings of those two devices are shown in Fig. 1.

The ^{222}Rn/^{220}Rn daughter equilibrium equivalent concentration measuring device is a cylinder made of stainless steel with 4 air inlets (ϕ3 mm) on its wall and one outlet at the top. Four disks of CR-39[1] are set at the sites and ^{222}Rn and ^{220}Rn progeny are collected on the surface of a 0.8 μm pore membrane filter.[2] Through discriminating the ^{222}Rn and ^{220}Rn progeny emitted alpha particles using Al Mylar absorbers (mainly 8.78 MeV alpha particle from ^{212}Po) and ignoring ^{216}Po in the air, the thoron progeny are separated from the radon progeny. The flow rate is 0.8 L min^{-1}, sampling for 24 h, the low level detection of equilibrium equivalent concentration of ^{222}Rn and ^{220}Rn is 0.57 and 0.07 Bq m^{-3}.Because it is still impossible to calibrate ^{222}Rn/^{220}Rn progeny concentrations in different environments at present, this device is compared with two sets of working level monitors, BWLM[3] and WLx,[4] which can determine the individual concentrations of ^{222}Rn or ^{220}Rn progeny.

The ^{212}Pb particle size distribution measuring device consists of three holders with a diameter of 2.0 cm, containing, respectively, a 400-mesh screen, a 635-mesh screen and a back-up filter. With a flow rate of 3.0 L min^{-1}, aerosols with different size are separately collected on different screens by Brownian diffusion with different penetration rates. Wait for 6 h after sampling (the ^{212}Bi and radon daughters are nearly decayed completely), the alpha particles emitted from the decay products of ^{212}Pb on different screens and the filter are recorded by three CR-39 s separately. In order to reconstruct the aerosol particle size distributions, the Monte Carlo method which has been termed ThBSDC (ThB Size Distribution Calculation) was used to calculate particle size collection efficiencies. The uncertain of AMADs (Activity Median Aerodynamic Diameter) and GSDs(Geometric Standard Deviation) are designed to be 5 and 0.1 nm, respectively. Ignoring the different ^{212}Pb and ^{212}Bi size distributions and the influence of unattached ^{216}Po, this measuring value can be taken as the size distribution of thoron progeny. This device was compared with the results of screen diffusion battery (SDB) with the relationship between the CMD (count median diameter) and AMAD.

Dose evaluation

LUDEP 2.07 was used for thoron dose evaluation in this paper. LUng Dose Evaluation Program (LUDEP) is a computer program for personal computers developed by the International Commission on Radiation Protection (ICRP) No. 2 Task Group, which implement the model of human respiratory tract issued by ICRP in Publication 66. LUDEP enables the user to calculate doses and dose rates from intakes of radionuclides to regions of the respiratory tract and to other body organs for a wide range of user-defined conditions. LUDEP 2.07 includes databases containing the ICRP Publication 30 biokinetic models and special treatment of radioactive decay chains, which is also able to calculate bioassay functions [8]. The deposition fractions and dose conversion factors of user-defined radionuclide size distributions are able to be calculated in LUDEP 2.07. The use of LUDEP 2.07 for thoron dose evaluation has been reported by Ishikawa [9].

In our calculation progress, the unattached fraction of thoron progeny were ignored as there were nearly no unattached ^{212}Pb and ^{212}Bi in normal indoor environments.

[1] Fukuvi Chemical Industry Co., ltd, Sanjuhassha-cho, Fukuicity, 910-37, Japan.

[2] Advantec MFS, Inc, 6691 Owen Drive, Pleasanton, CA94588.

[3] Tracerlab Instruments, Horst Kelm, Kolner Str. 64-66, Postfach, P.O. Box 1922, Germany.

[4] Pylon Electronics, Inc., 147 Colonnade Road, Ottawa, Ontario, Canada.

Table 1 Measuring results of thoron progeny in three typical rural indoor environments comparing with the urban indoor environment

Site	House style	Sampling number	Measurement result of thoron progeny[a]		
			AMD (nm)	GSD	EEC_{Tn} (Bq m^{-3})
Pinggu	Brick	7	110.0 (90–130)	2.5 (2.3–2.7)	0.95 (0.27–1.35)
Yangjiang	Mud	8	63.8 (30–130)	2.7 (1.9–3.3)	25.25 (14.03–53.32)
Datong	Cave	5	50.0 (40–60)	3.1 (3.1–3.6)	2.33 (1.63–4.41)
Urban environment[b]	Brick	2	155.0 (150–160)	2.0 (1.7–2.2)	0.14 (0.06–0.22)

AMD activity medium diameter, *GSD* geometrical standard deviation, EEC_{Tn} equilibrium equivalent concentration of thoron

[a] The average value is out of bracket and the variety range is in bracket

[b] The sampling time is 48 h in urban environment for lowing the MDLs

Therefore, we assume that all thoron daughters which contribute to the DCF of thoron are attached. While the half-life of ^{212}Bi (1.01 h) is much smaller than that of ^{212}Pb (10.6 h), the assumption that ^{212}Bi has the same particle size distribution with that of ^{212}Pb is reasonable. ^{212}Pb: ^{212}Bi = 1:0.25 was used in this calculation [10]. The half-time of ^{212}Pb and ^{212}Bi absorbed into bloodstream is taken as 10 h [11].

Results and discussion

Measurement results of three typical rural indoor environments

For the three typical rural residential houses (brick houses, mud houses and caves), field measurements were carried during the last year, respectively, in Pinggu District of Beijing (latitude and longitude: 40.35 and 117.17), Yangjiang City of Guangdong Province (latitude and longitude: 21.83 and 111.54) and Datong City of Shanxi Province (latitude and longitude: 39.81 and 113.56). Among them, Yangjiang City of Guangdong Province is one of the high level background districts. The bedrooms were chosen for measurement and the windows were kept half closed and the doors closed as usually, additional aerosol sources were averted to keep the environment stable. For comparison, two brick houses in urban indoor environment were chosen. The measuring results of thoron progeny in three typical rural indoor environments comparing with the urban indoor environment are shown in Table 1.

The difference between three rural environments and the urban environment is quite large including the thoron progeny size distribution and the thoron progeny concentration. The thoron progeny size distributions of rural environments are significantly smaller than that of urban environment, while the thoron progeny concentrations are significantly larger than that of urban environment. The results of size distribution are in consistent with our former surveys, which could be interpreted by the good ventilation [7]. The thoron concentrations are higher mainly because of high background level as well as the naked wall which make thoron exhaling much easier.

A significant difference of thoron progeny size distribution and thoron concentration appears in different typical houses, no matter in rural areas or in urban areas. The brick house has a much larger thoron progeny size and a much lower thoron concentration might be due to different ventilation and different thoron exhalation rate. Especially, the average equilibrium equivalent concentration of thoron in mud house is 25.25 Bq m^{-3}, which is much higher than that of the global average value 0.5 Bq m^{-3} [12].

Dose evaluation of three typical rural indoor environments

For dose evaluation, the input parameters of LUDEP 2.07 is shape factor 1.1, the particle density 1.4 g cm^{-3}, respiratory rate is 0.78 m^3 h^{-1}, ^{212}Pb biological dynamics model PB (D). MOD and ^{212}Bi biological dynamics model BI (D).MOD. Assumes the weight factor of ET region is 0.025. The dose conversion factors and annual average effective doses are listed in Table 2.

Comparing the different dose conversion factors of different environments, we can easily find that the DCF of cave house is largest due to its smallest aerosol size distribution. The typical rural environments have larger DCF than the urban environment, especially the mud houses and the caves. However the largest thoron exposure dose exists in the mud house of Yangjiang due to its highest thoron concentration. The urban environment has an annual average effective dose only 0.03 mSv a^{-1}, which is quite smaller than that of rural environment due to its small dose conversion and low thoron concentration. The DCF of brick houses in urban environment is quite close to the result published by Tschiersch [13], which prove that the traditional DCF could only be used for some urban indoor environment by side. The BB and bb regions contribute the most to the total dose conversion factors, while ET and AI's contributions could be ignored comparatively.

Table 2 The dose conversion factors and annual average effective doses of three typical rural environments comparing with the urban environment

Site	Dose conversion factors (nSv/(Bq m^{-3} h^{-1})$^{-1}$)					Annual average effective dose (mSv a^{-1})[a]
	ET	BB	bb	AI	Total	
Pinggu	3.24	57.53	95.11	3.52	159.40	0.26
Yangjiang	4.51	86.05	140.50	4.67	235.73	10.12
Datong	23.12	315.83	286.95	3.25	629.14	2.49
Urban environment	2.39	41.36	67.10	2.58	113.44	0.03

ET extra thoracic region, *BB* bronchial region, *bb* bronchiolar region, *AI* alveolar interstitial

[a] The occupancy factor is 0.8

Conclusion

Many researches have been done on the relationship between the thoron progeny and the environment parameters, and between the DCF and the thoron progeny particle size, but few field measurements have been carried before, especially in the rural area where most people live.

The thoron exposure dose evaluation, with thoron progeny size distribution and thoron progeny equilibrium equivalent concentration, was examined in three typical rural residential houses in China: the brick house, the mud house and the cave. For comparison, field measurements were also carried out in urban environment. The Results showed that the rural indoor environments have much larger dose conversion factors than that of urban indoor environment due to its smaller thoron progeny size distributions, the smallest of thoron progeny size distribution is in the cave which give the largest DCF. The annual average effective dose due to thoron exposure is influenced by the DCF as well as thoron equilibrium equivalent concentration, and the value in mud house of Yangjiang was estimated to be 10.12 mSv a^{-1},suggesting that some attention is needed.

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