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Measurements of Rn-222, Rn-220 and Their Decay Products in the Environmental Air of the High Background Radiation Areas in Yangjiang, China

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For the renewal of dose estimation from internal irradiation in the high background radiation areas (HBRA) of Yangjiang, the measurements of radon, thoron and their decay products in the environmental air were conducted, including: (1) integrating measurements of Rn-222 and Rn-220 concentrations; (2) equilibrium factor F for Rn-222 and alpha-potential energy value of Rn-220; (3) external gamma radiation in places where radon measurements were undertaken; (4) cumulative exposure to indoor radon for each family in a case-control study on lung cancer. The Rn-Tn cup monitor method was used for the integrating measurement of Rn-222 and Rn-220 concentration. An alpha track detector was used for the integration measurement of Rn-222 concentration in the case-control study on lung cancer.

The results of measurements show that although the investigated areas are located between the Equator and the Tropic of Cancer, and that people live in well-ventilated dwellings, the concentrations of radon, especially of Rn-220 are significantly higher in the indoor air of HBRA than those in the control area. The value of equilibrium factors for Rn-222, the alpha potential energy of decay products from Rn-222 and Rn-220 are determined.

INTRODUCTION

Rn-222 and Rn-220 are decay products of Ra-226 and Ra-224, respectively. Since they are natural radionuclides that appear in the environment, exposure to the radiation from these two elements and their decay products is inevitable. Many researchers have confirmed that excess

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exposure to Rn-222 is harmful to the human body; and exposure to excessive Rn-222 increases the incidence of lung cancer. The worldwide average annual effective dose from natural radiation sources is estimated to be 2.4 mSv, of which 1.3 mSv is from exposure to radon and its decay products[1]. Some researchers reported that the average effective dose from inhalation of radon and its decay products is even higher[2].

In the high background radiation area (HBRA) in Yangjiang, China, preliminary work showed that the levels of Rn-222, Rn-220 and their decay products as well as that of gamma radiation are higher than that of a nearby control area[3]. Some fifteen to twenty years ago, measurements were made on Rn-220 and Rn-222 in HBRA. The methodology of measurements, especially measurement of cumulative exposure to radon, thoron and their decay products, has been much improved since then. We used updated methodology and conducted an extensive survey on Rn-222, Rn-220 and their decay products in the environmental air of a high background radiation area in Yangjiang, including 1) integrating measurements of Rn-222 and Rn-220 concentrations; 2) equilibrium factor F for Rn-222 and alpha-potential energy value of Rn-220; 3) external gamma radiation in places where radon measurements were undertaken; and 4) cumulative exposure to indoor radon for each family in a case-control study on lung cancer. We describe in this report the results of Rn-222 and Rn-220 measurements, potential alpha energy of decay products from Rn-222, Rn-220, and of the determination of the equilibrium factor for Rn-222.

MATERIALS AND METHODS

To measure the equilibrium factor F for Rn-222, we used a two-filter method to assess the concentrations of Rn-222 by discrete sampling[4]. Meanwhile, we used the three-period method to measure the concentration of radon progeny, and the five-period method for the concentration of potential alpha energy of decay products from Rn-222 and Rn-220[5]. The following equations were used in the present analysis.

$$C_p(\mathrm{Rn}) = 5.79C\,(\mathrm{RaA}) + 28.6C\,(\mathrm{RaB}) + 21.0C\,(\mathrm{RaC}) \quad (1)$$

$$C_p(\mathrm{Tn}) = 69.06C\,(\mathrm{ThB}) + 6.55C\,(\mathrm{ThC}) \quad (2)$$

Where Cp(Rn) is the concentration of potential alpha energy of radon progeny in $10^{-4}\ \mu\mathrm{J}\cdot\mathrm{m}^{-3}$,Cp(Tn) is the concentration of potential alpha energy of thoron progeny in $10^{-4}\ \mu\mathrm{J}\cdot\mathrm{m}^{-3}$, C (RaA), C (RaB), C (RaC), C (ThB), and C (ThC) are concentration of Po-218, Pb-214, Bi-214, Pb-212, and Bi-212 in the air in Bq m^{-3}, respectively.

The equilibrium factor F for Rn-222 can be calculated using the following formula:

$$F = 181C_p/C \quad (3)$$

Where Cp is the concentration of potential alpha energy of radon progeny in $10^{-4}\ \mu\mathrm{J}\cdot\mathrm{m}^{-3}$, C is the radon concentration in Bq m^{-3}.

The Rn-Tn cup monitor method was used for the integrating measurement of Rn-222 and Rn-220 concentration[6]. The alpha track detector was used for the integrating measurement of Rn-222 concentration in the case-control study on lung cancer (all cases). Considering the very high concentration of Rn-220 and its decay products in the air in HBRA, we paid attention to diminishing the interference of Rn-220 with the result of Rn-222. One filter was installed in the alpha track detector to separate the decay products of Rn-222 and Rn-220. The permeation rate of Rn-222 in the filter should be as large as possible, while the rate of Rn-220 is as small as possible. This filter can be used to separate these two radionuclides.

Sampling

Several factors were considered in order to select the location of the measurements of Rn-222 and Rn-220. These factors included 1) gamma radiation level[7], 2) building material; and 3) population size. Selection of points for the integrating measurements of Rn-222 and Rn-220 is summarized in Table 1. There are mainly three types of house in the investigated areas, i.e., houses of bricks, adobe bricks, and a combination of bricks and adobe bricks, according to the

Table 1. Locations of measurements of Rn-222 and Rn-220

Items	Number of points	Note
Hamlet	8	Two hamlets in each dose-rate group (control, low, medial, and high)
Family	8x6 = 48	Six families (houses) per hamlet
Points of measurement	8x6x2 = 96	Two points per family
Outdoor environment	8x5 = 40	Five points per hamlet, i.e., lane, yard, road, farmland or rice paddy.
Total	136	

building materials. We chose every type of house to measure the radon level. The distance between the radon detector and the wall is an important factor when determining radon concentration measured by the detector: the closer the detector to the wall, the higher the concentration of Rn-222. It was reported that in a traditional Japanese wooden house the ratio of Rn-220 concentration at 8 and 80 centimeters from the wall is 8.4 from June to August, and 7.7 from January to March; the ratio of Rn-222 concentrations at 20 and 80 centimeters from the wall is 5.8[8]. The radon detectors were either placed on furniture that was close to the wall or hung directly on the wall. The distance between the detector and wall were within 5 to 30 centimeters.

Ten hamlets in HBRA and two hamlets in the nearby control area were selected for the measurement of equilibrium factor of Rn-222 and alpha potential energy of Rn-220. Measurements were done in an alley in each hamlet. The sampling was started around 8 a.m. in November 1997. The windows and doors were open during the sampling. We took the samples at 1.2 meters above the ground, which is the position of the lung or respiratory tract in the human body. Temperature, pressure, and other weather parameters were also recorded.

RESULTS AND DISCUSSIONS

The results of Rn-222 measurements made on discrete samplings are shown in Table 2. Concentrations of the potential alpha energy of decay products from Rn-222 and Rn-220 are shown in Table 3. Concentrations in indoor air of radon in HBRA and CA are shown in Table 4. Thoron concentrations are shown in Table 5. The equilibrium factor of Rn-222 is shown in Table 6.

Table 2 shows that the average indoor and outdoor concentrations of Rn-222 are 42.6 and 17.3 Bq m^{-3}, respectively in the HBRA, and 13.2 and 11.7 Bq m^{-3}, respectively in the control area. The ratio of concentration of Rn-222 between HBRA and the control area is 3.2:1.0 for indoor air, and 1.5:1.0 for outdoor air. The results of integrating measurements (one year) summarized in Table 4 show that the air concentrations of radon correlated with the dose of external gamma radiation. According to the UNSCEAR report[1)], the population-weighted average of indoor radon concentration is 40 Bq m^{-3}. Outdoor average level is 10 Bq m^{-3} in the continental area, and somewhat lower in coastal regions. It is interesting to note that the indoor concentrations of radon in HBRA were not as high as expected. This is likely due to the geographical location of the investigated area, between the Equator and the Tropic of Cancer. The weather of the area is warm for the whole year , so that windows are always open and therefore the houses are well ventilated. It has been stated in the UNSCEAR Report that " Concentrations of ^{222}Rn and its progeny are usually higher in indoor air than in outdoor air; exceptions are in tropical areas, where ^{222}Rn concentrations in well-ventilated dwellings are essentially the same as in outdoor air." In our investigated areas, air concentrations of radon in the control area were similar between indoors and outdoors. This is consistent with the notion of the UNSCEAR report. However, the indoor concentrations were still significantly higher than that of the outdoors in HBRA.

Table 2. Concentration of Rn-222 based on discrete sampling[a]

Sampling location	No. of sampling	Concentration in Bq・m^{-3} Average ± S.D	Range
HBRA			
Indoor	31	42.6 ± 27.7(31.8)	98.7–15.2
Outdoor	21	17.3 ± 12.4(16.4)	56.5– 6.5
CA			
Indoor	5	13.2 ± 1.58(1.11)	15.5–11.7
Outdoor	4	11.7 ± 0.63(11.2)	12.4–11.0

[a] Numerals in parentheses are measurements done before the joint research project.

Table 3 shows the averages of indoor and outdoor alpha potential energy concentrations of the daughters of Rn-222 are 0.109 and 0.051 μJ m^{-3} in the HBRA, and 0.045 and 0.041 μJ m^{-3} in the control area. The averages of indoor and outdoor alpha potential energy concentrations of the daughters of Rn-220 are 0.249 and 0.053 μJ m^{-3}, respectively in the HBRA, and 0.051 and 0.025 μJ m^{-3}, respectively in the control area. It is clear that the concentration of thoron in environmental air in HBRA is significantly higher than in the control area; i.e., the decay products of Rn-220 is five times higher in the HBRA compared to that in the control area. We noted that Rn-220 and its decay products are very important components of effective dose for inhabitants living in the HBRA

Table 3. Concentrations of the potential alpha energy of decay products from Rn-222, Rn-220[a]

Sampling location	No. of sampling	Concentration in μJ・m^{-3} Rn-222	Rn-220
HBRA			
Indoor	31	0.109 ± 0.097 (0.100)	0.249 ± 0.264 (0.255)
Outdoor	21	0.051 ± 0.041 (0.097)	0.053 ± 0.031 (0.058)
CA			
Indoor	5	0.045 ± 0.007 (0.038)	0.051 ± 0.033 (0.069)
Outdoor	4	0.041 ± 0.004 (0.044)	0.025 ± 0.001 (0.020)

[a] Numerals in parentheses are measurements done before the joint research project.

Table 4. Radon concentration of indoor air in HBRA and CA[a]

Dose group	External dose (10^{-5}Sv・a^{-1})	Number of hamlets	Number of points	Concentration (Bq・m^{-3})
HBRA	125.29–308.04	111	137	47.57 ± 24.85
High	224.10–308.04	38	45	56.09 ± 30.29
Medial	198.07–224.09	40	51	47.42 ± 26.12
Low	125.29–198.06	33	41	38.41 ± 14.31
Control	50.43– 95.67	41	52	18.14 ± 7.57

[a] Based on the data of integrating measurement for case-control study

Table 5 summarizes the concentrations of thoron (Rn-220, indoor) in HBRA and the control area. The results indicate that Rn-220 concentration is significantly higher in HBRA compared to the control area (7.18 times).

The indoor and outdoor equilibrium factors of Rn-222 are shown in Table 6. We judged that the indoor and outdoor equilibrium factors are normally distributed. UNSCEAR recommended in its 1993 report that the worldwide averages of the equilibrium factor of Rn-222 are 0.4 and 0.8 for indoors and outdoors, respectively. Based on our measurements of fifty-two points in ten hamlets in the HBRA and nine points in two hamlets in the control area, averages of equilibrium factor of Rn-222 in the HBRA is 0.43 for indoors and 0.53 for outdoors. The values in the control

Table 5. Thoron concentration of indoor fixed points[a]

Dose group	External dose (10^{-5}Sv・a^{-1})	Number of hamlets	Number of points	Concentration (Bq・m^{-3})
HBRA	125.29–308.04	6	60	89.0 ± 19.4
High	224.10–308.04	2	20	80.4 ± 35.9
Medial	198.07–224.09	2	20	126.5 ± 34.3
Low	125.29–198.06	2	20	60.6 ± 44.4
Control	50.43– 95.67	2	20	12.4 ± 3.3

[a] Based on the Rn-Tn cup monitor method

Table 6. Equilibrium factor F for Rn-222

Sampling location	No. of sampling	Average ± S.D	Range
HBRA			
Indoor	31	0.429 ± 0.159	0.187-0.806
Outdoor	21	0.525 ± 0.176	0.268-0.782
CA			
Indoor	5	0.584 ± 0.048	0.548-0.598
Outdoor	4	0.678 ± 0.146	0.497-0.845

area are 0.58 for indoors and 0.68 for outdoors. Our indoor equilibrium factor is slightly higher than the worldwide average, and outdoor factor lower. However, all values are within the range of the worldwide average.

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