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Note

High Indoor Radon Concentration Observed in Yomitan-son, Okinawa Prefecture, Southwestern Part of Japan

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In Yomitan-son, a village of Okinawa prefecture located in the subtropical region of Japan, the highest annual average of indoor radon (^{222}Rn) concentration, 220 Bq m^{-3}, has been observed in a private residence by a nationwide survey. In this study, to estimate the distribution and origin of the high concentration, measurements for atmospheric radon were conducted on eight dwellings intermittently from 2005 to 2013. And *in situ* measurements of gamma radiation energy spectrum on the outdoor ground were performed at 26 points in 2018 to estimate the origin of the high indoor radon concentration. As the result, the highest indoor radon concentration, 289 Bq m^{-3}, was observed in a dwelling. For the seasonal variation, indoor radon concentration in winter is obviously higher than that in summer was observed in several dwellings. From the results for the analyses of gamma radiation data, useful information about the origin of the high indoor radon concentration was not provided in this study.

Key words: indoor radon, gamma radiation, ^{238}U series, Yomitan village, Okinawa prefecture, Japan

1. Introduction

Assessment of the radiation and radioactive levels due to natural sources is very important to estimate the collective and personnel doses to the public. For example, based on the results for several nationwide surveys, the Japanese population dose from natural radiation was given as 2.2 mSv y^{-1} [1)]. In this case, the arithmetic mean of annual effective doses from cosmic rays, terrestrial radiation, radon (^{222}Rn, ^{220}Rn and these progenies), and foodstuffs were estimated as 0.29, 0.33, 0.59, and 0.99 mSv y^{-1}, respectively, and the total of these values was used as the population dose. On the other hand, it is also important to understand the regional variation of the doses. Particularly for the high background radiation area, detailed study is needed to estimate the exact effective dose including the causes.

In this study, we introduce the preliminary results for a case of Yomitan-son, a village of Okinawa prefecture located in the subtropical region of Japan (Fig.1). By a nationwide survey with passive radon monitors at the end of 20th century, the highest annual mean of indoor radon (^{222}Rn) concentration, 220 Bq m^{-3}, has

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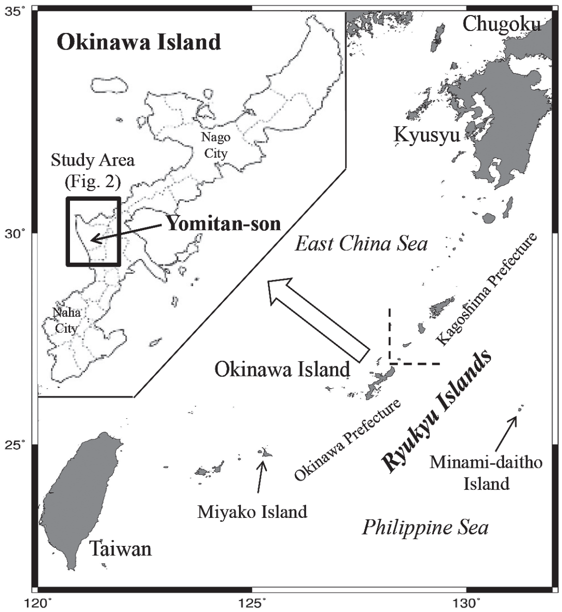

Fig. 1. Location of study area.

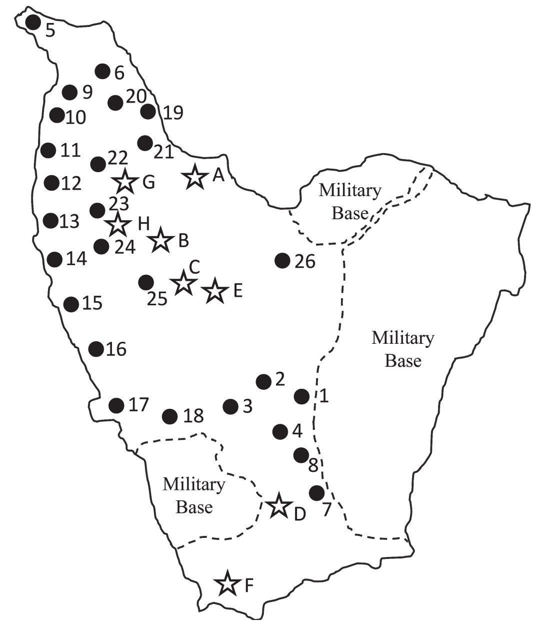

Fig. 2. Location of measurement site and points.
☆ A-H: Measurement site of indoor/outdoor radon concentration.
● 1-26: Measurement point of gamma radiation.

been observed in a private residence in this village[2]. After that, in a residence that is different from one for the nationwide survey, anomalously high indoor radon concentrations for a short time in a day, 400-1000 Bq m^{-3}, were measured with an active radon monitor[3]. Indoor radon is considered to be an important source of environmental radiation exposure among the public throughout the world[4], and World Health Organization (WHO) issued a reference level of 100 Bq m^{-3} for indoor radon concentration[5]. Therefore, to get an overview for the distribution of high indoor radon concentration in Yomitan-son, annual or short-term measurements of the atmospheric radon were conducted in this study. In addition, to study the origin of high indoor radon concentration, activity of the source nuclides (^{238}U series) of the soils distributed in the village were estimated by *in situ* measurement of terrestrial gamma radiation energy spectra.

2. Locality and measurements

Yomitan-son is located in the central part of Okinawa Island, the main island of Okinawa prefecture, and it faces East China Sea (Fig.1). The area, population and number of dwelling units of the village are 35.28 km^2, 41,774 and 15,340, respectively[6, 7]. By the way, Yomitan-son is the largest village in Japan in terms of population. In addition, the areas of residential, farmland and the U.S. military base (Fig. 2) are 14%, 16% and 36% of the whole, respectively[6, 7]. In other words, the area occupancy of the military base to the whole is very large. The basement geology is mainly Pleistocene coral reef-origin limestone[8], and the limestone is widely covered with red soil that is called "Shimajiri- mahji" in Okinawan language[9].

Measurements of atmospheric radon concentrations were performed with passive monitors (RADUET, Radosys Co. Ltd.)[10] in a total of eight stand-alone concrete houses, about 0.05% of the total number of dwelling units in the village (Fig. 2, Sites A-H). Two monitors were installed indoors in Sites A-G. For Site H, six monitors were installed indoors. One to three monitors were also installed outdoors in Sites B, D, E, F, G and H. The all monitors were hung on the inner or outer wall of the houses. The measurements were taken in five periods from December 2005 to March 2013, except for February 2007 to November 2012. The radon and thoron concentrations were calculated using the track densities for each of the two pieces of CR-39 and the conversion factors. The conversion factors from track densities to radon and thoron concentrations were evaluated by the calibration experiments using radon and thoron exposure systems at National Institute of Radiological Sciences, Japan[11].

In addition to the measurement of atmospheric radon concentration, to consider the radon potential in the study area, *in situ* measurements of gamma radiation energy spectrum were performed at 1m in height from the outdoor soil ground with a 3"φ×3" NaI(Tl) scintillation spectrometer (EMF211, EMF Japan Co. Ltd.) at total of 26 points in the village (Fig. 2) during January 2018. Based

Table 1. Indoor radon concentration at the A to H sites

Site ID	Place of Monitor Installation	Period 1 Dec. 2005 - Mar. 2006 4 months	Period 2 Apr. 2006 - Jun. 2006 4 months	Period 3 Jul. 2006 - Sep. 2006 3 months	Period 4 Oct. 2006 - Jan. 2007 4 months	Period 5 Dec. 2012 - Mar. 2013 4 months
A	bedloom	23 ± 3	8 ± 2	–	–	–
	living room	30 ± 3	5 ± 2	–	–	–
B	dining kitchen	21 ± 3	8 ± 2	14 ± 4	13 ± 3	–
	bedloom	16 ± 3	8 ± 2	4 ± 3	16 ± 3	–
C	living room 1	104 ± 6	25 ± 3	35 ± 6	131 ± 8	–
	living room 2	122 ± 6	35 ± 4	25 ± 5	128 ± 8	–
D	living room 1	21 ± 3	14 ± 3	14 ± 4	28 ± 4	–
	living room 2	18 ± 3	11 ± 2	14 ± 4	20 ± 4	–
E	living room 1	30 ± 3	8 ± 2	4 ± 2	22 ± 4	–
	closet	31 ± 3	16 ± 3	14 ± 2	46 ± 5	–
	living room 2	44 ± 4	42 ± 5	32 ± 4	76 ± 7	–
F	living room 1	67 ± 6	32 ± 4	25 ± 3	101 ± 8	–
	living room 2	73 ± 6	25 ± 3	26 ± 3	94 ± 7	–
G	closet	–	7 ± 2	3 ± 1	12 ± 3	–
	living room	–	5 ± 2	2 ± 1	5 ± 2	–
H*	① bedroom	–	–	–	289 ± 17	211 ± 15
	② bedroom	–	–	–	–	200 ± 9
	③ entrance	–	–	–	143 ± 12	138 ± 18
	④ dining kitchen	–	–	–	–	122 ± 6
	⑤ dining kitchen	–	–	–	–	128 ± 6
	⑥ living room	–	–	–	144 ± 12	160 ± 17

*Location is shown in Fig. 3.

Table 2. Outdoor radon concentration at the sites

Site ID	Place of Monitor Installation	Period 4 Oct. 2006 - Jan. 2007 4 months	Period 5 Dec. 2012 - Mar. 2013 4 months
B	under the eaves	10 ± 3	–
D	under the eaves	10 ± 3	–
E	under the eaves	1 ± 2	–
	under the eaves	6 ± 2	–
F	under the eaves	14 ± 3	–
G	under the eaves	9 ± 3	–
H*	⑨	30 ± 6	–
	⑦	–	1 ± 3
	⑧	–	5 ± 2

* Location is shown in Fig. 3.

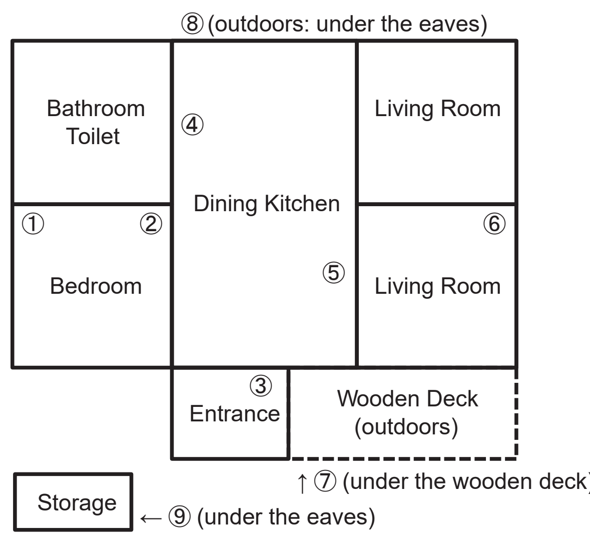

Fig. 3. Simplified floor plan of a dwelling, radon measuring Site H (Fig. 2). ① – ⑨ show measuring points where radon monitors were placed.

on the energy spectrum data, the concentration of ^{238}U series, parent nuclides of radon, contained in the soils and the gamma radiation dose rate in air were calculated by a response matrixes method[12].

3. Results and discussion

The results for measurements of indoor and outdoor radon concentrations are summarized in Tables 1 and 2, respectively. The estimated gamma radiation dose rate in air and concentrations of natural radionuclides at/around the *in situ* measuring points are shown in Table 3.

The range of indoor radon concentration was estimated to be 2-289 Bq m^{-3}. In Sites C, F and H, indoor radon concentration exceeded 100 Bq m^{-3} regularly from late autumn to early spring. Though the fluctuation range is small, similar seasonal trend of indoor radon concentration, rise in winter and fall in summer, was also observed in other sites. The concentrations of 200 Bq m^{-3} or more observed in a bedroom of Site H (Fig. 3), 200-289 Bq m^{-3}, are roughly comparable to the maximum value of the nationwide survey, 220 Bq m^{-3} [2]. The arithmetic mean ± standard deviation of all data for indoor radon

Table 3. Gamma radiation dose rate in air and concentrations of natural radionuclides at/around measuring points (Fig. 2)

Measuring Point No.	Dose Rate (nGy/h)	Concentration (Bq/kg)		
		U-238 series	Th-232 series	K-40
1	56.2	47.8	36.6	214.5
2	60.8	41.7	48.0	246.8
3	64.2	63.2	38.7	244.3
4	60.1	49.6	39.4	286.8
5	39.4	34.7	25.8	200.8
6	48.5	43.3	29.9	226.3
8	67.2	56.2	47.2	261.5
9	60.8	52.0	35.8	269.0
10	50.9	42.6	29.6	283.3
11	50.4	36.2	31.5	317.1
12	58.1	53.2	34.9	257.0
13	57.0	51.4	34.2	256.0
14	57.3	53.5	35.1	231.8
15	60.0	52.0	35.5	243.5
16	57.9	50.7	39.4	252.0
17	57.2	49.4	38.0	242.3
18	27.9	22.4	18.4	171.6
20	47.1	34.9	26.7	287.0
21	44.9	40.9	28.5	193.6
22	38.4	16.1	20.2	376.3
23	62.4	54.6	40.0	271.5
24	42.8	41.8	22.9	173.0
25	46.0	34.6	26.9	267.3
26	44.9	28.7	28.3	251.9

concentration was calculated to be 52.2 ± 60.1 Bq m^{-3}. The annual means of indoor radon concentrations in Japan were estimated to be 15.5 Bq m^{-3} from 1994 to 1996[2] and 15.2 Bq m^{-3} from 2007 to 2010[13]. Based on these results for indoor radon concentration, about 25% of concrete houses in the village may have concentrations above 100 Bq m^{-3} especially in winter, and the village could be a relatively high concentration area for the indoor radon in Japan.

The number of data is limited, but the range and arithmetic mean ± standard deviation of outdoor radon concentration were estimated to be 1-30 Bq m^{-3} and 9.5 ± 8.8 Bq m^{-3}, respectively. The nationwide annual mean of outdoor radon concentration in Japan was estimated to be 6.1 Bq m^{-3}[14]. The minimum and maximum mean values ranged from 3.3 Bq m^{-3} in Okinawa prefecture to 9.8 Bq m^{-3} of Chugoku region (Fig. 1) because of geological and pedological characteristics in the nationwide survey[14]. In other words, the outdoor radon concentration observed in this study may be relatively high in Okinawa prefecture, but it is not much different from the nationwide perspective in Japan.

Incidentally, the very low indoor and outdoor radon concentrations, >5 Bq m^{-3} that is lower than the limit of detection for the passive monitor using in this study, were observed in Sites B, E, G, and H (Tables 1 and 2).

Based on the results for *in situ* measurements of gamma radiation energy spectrum, the arithmetic mean ± standard deviation and range of the dose rate in air at/around the measuring points were estimated to be 52.5 ± 10.2 nGy h^{-1} and 27.9-67.2 nGy h^{-1}, respectively. These results roughly correspond to the reported values for Yomitan-son, 51.4 ± 19.2 nGy h^{-1} and 23.0-112.0 nGy h^{-1}[15]. These means are almost same as the nationwide one, about 50 nGy h^{-1}[16-18], and as the preliminary means of Okinawa Island and Ryukyu Islands (Fig. 1) that are about 47 nGy h^{-1} and 50 nGy h^{-1}, respectively[19].

Also based on the analysis of the gamma radiation data, the arithmetic mean ± standard deviation and range of the ^{238}U series concentration were estimated to be 44.2 ± 11.6 Bq kg^{-1} and 16.1-63.1 Bq kg^{-1}, respectively. These values are relatively lower than that of reported ones for Yomitan-son, 67.1 ± 43.8 Bq kg^{-3} and 21.0-168.8 Bq kg^{-3}[15]. On the other hand, these are estimated to be higher than the values for the main land of Japan. That are, the mean is about 16 Bq kg^{-1} and the range is 3-26 Bq kg^{-1}[20].

In brief, it is considered that these results for the gamma radiation dose rate and the ^{238}U series concentration are insufficient to explain the relatively high indoor radon concentrations observed in Yomitan-son. For further understanding of this matter for the indoor radon concentration, it is necessary not only to expand the measurement but also to try other research method, such as the analysis of radionuclides for building materials and the measurement of radon emanation/exhalation process for the soils.

By the way, the result for a preliminary study on the radon emanation process suggests that Shimajiri-mahji with 95 Bq kg^{-1} of ^{226}Ra from Yomitan-son has significant high emanation coefficient, 0.25-0.39[21]. Furthermore, recent studies for Shinajiri-mahji suggest that the base material originated from eolian dust blown across the East China Sea mainly from the southeastern part of China, a high background radiation area[22, 23], during the last glacial period or after the previous one[24-27]. In Miyako and Minami-daitho islands of Okinawa prefecture (Fig.1) where the shimajiri-mahji soils with high ^{238}U series concentration (Max. 220 Bq kg^{-1}) are widely distributed, comparatively high atmospheric radon concentrations were observed[25, 26, 28, 29]. However, there is no clear evidence to define the relationship between relatively high indoor radon concentration and the shimajiri-mahji soils at this time.

4. Summary

In Yomitan-son, a village of Okinawa prefecture, higher indoor radon concentrations, >100 Bq m^{-3}, were observed in some ordinary concrete dwellings compared to the Japanese annual average, 15.5 Bq m^{-3}[2]. The indoor radon concentration showed that the increasing tendency in winter season, and the maximum value reached to 289 Bq m^{-3}. The origin of the relatively high concentration is unknown at present, but solving this issue is one of important challenge in the fields of environmental radiation and radiation protection. Therefore, continuous study for the environmental behavior of radon is required.

Conflict of Interest Disclosure

The authors declare that they have no conflict of interest.

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