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Radon and thoron concentrations in offices and dwellings of the Gunma prefecture, Japan

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A one year survey of indoor radon and thoron concentrations was carried out in offices and dwellings of the Gunma prefecture, Japan. A passive integrating radon and thoron discriminative monitor was used in the survey. The annual mean radon concentration was 22±14 $Bq \cdot m^{-3}$, and ranged from 12 to 93 $Bq \cdot m^{-3}$ among the 56 surveyed rooms. Radon concentration in offices was generally higher than that in the dwellings, with the arithmetic averages of 29 and 17 $Bq \cdot m^{-3}$, respectively. Radon concentrations were generally lower in the traditional Japanese wooden houses than those houses built with other building materials. Seasonal variation of indoor radon was also observed in this survey. Compared to summer and autumn, radon concentrations were generally higher in spring and winter. The mean value of thoron to radon ratio was estimated to be 1.3, higher values were observed in the dwellings than in the offices. The annual effective dose from the exposure to indoor radon was estimated to be 0.47 mSv after taking the occupancy factors of offices and dwellings into account.

Introduction

According to the UNSCEAR Report 2000, the world mean of annual effective dose due to the inhalation of radon, thoron and their decay products is estimated to be 1.2 mSv. This value corresponds to a half of the total of natural radiation exposure. In general, indoor radon concentration and the occupancy factor are larger than those of outdoor environments, it has been widely recognized from many surveys that the dose due to indoor radon is much larger than that due to outdoor radon. In Japan, indoor and outdoor radon concentrations have been investigated by many researchers, and most of the surveys were carried out in indoor environments.[2,3] On the other hand, the indoor life is mainly divided into office and dwelling lives. Especially, in the advanced countries, the occupancy factor for working people in their offices can equal to or even exceed that in their homes. Therefore, for a more accurately estimation of radon exposure, it is very important to evaluate radon concentrations in both offices and dwellings. In this study, radon concentrations were randomly surveyed in 30 offices and 30 dwellings in Gunma prefecture, Japan in order to estimate the radon exposure more accurately.

Experimental

Figure 1 shows the construction of the passive radon and thoron discriminative monitor (R-T monitor) used in this survey. The allyl diglycol carbonate (CR-39) is used to detect the alpha-particles emitted from radon and thoron as well as their decay products. Details about the monitor was reported by ZHUO et al.[4] Because thoron can be discriminate from radon, it is considered that the monitor can evaluate the radon concentration more accurately. The R-T monitor has also the advantage of cost effectiveness, easy for handling and small size which is suitable for large scales of indoor surveys.

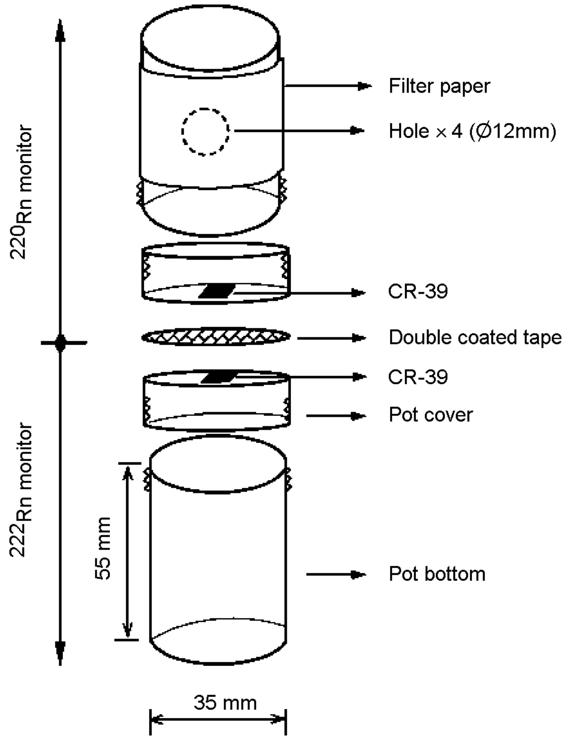

Fig. 1. Exploded view of the passive ^{222}Rn and ^{220}Rn monitors

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The calibration factors of the R-T monitor were decided through the calibration experiments using the radon and thoron chambers in the National Institute of Radiological Sciences, Japan. The result of radon calibration factor agreed well with another calibration experiment performed at Environmental Measurement Laboratory (EML) in New York. The lower detection limits of the R-T monitor were estimated to be 3.5 Bq·m^{-3} and 13 Bq·m^{-3} for the radon and thoron in a period of 90-day exposure, respectively.[4,5]

The survey was mainly performed in Maebashi City, Gunma prefecture, as shown in Fig. 2. Gunma prefecture is almost located in the center of Japan, and has an area of 6,363 km^2 and a population about 2 million. The number of private offices is over 100 thousands.

The radon survey was performed from the end of April, 2002 to the beginning of April, 2003. In order to obtain not only the annual mean radon concentration but also its seasonal variation, measurement were carried out four times in dividing the measuring period into consecutive three months periods. The R-T monitor was randomly set in 30 offices and 30 dwellings in Gunma prefecture.

Results and discussion

The survey was successfully carried out in 27 offices and 29 dwellings. Results are summarized in Table 1. The annual averaged radon concentration in the 56 rooms was in a range of 12 to 93 Bq·m^{-3}, with an arithmetic mean of 22±13 Bq·m^{-3}. The averaged radon concentrations in the offices and dwellings were 29±17 Bq·m^{-3} and 17±4 Bq·m^{-3}, the coefficients of variation are estimated to be 0.61 and 0.24, respectively. Radon concentration in the offices was 1.7 times larger than that of the dwellings. The averaged annual radon concentration in the dwellings of this survey is nearly the same as the national arithmetic mean (15.5±13.5 Bq·m^{-3}, 899 data).[3] On the other hand, the averaged annual radon concentration of all data obtained from this survey is about 7 Bq·m^{-3} higher than the national average. This indicates that the radon concentration in the offices is higher than that of the dwellings.

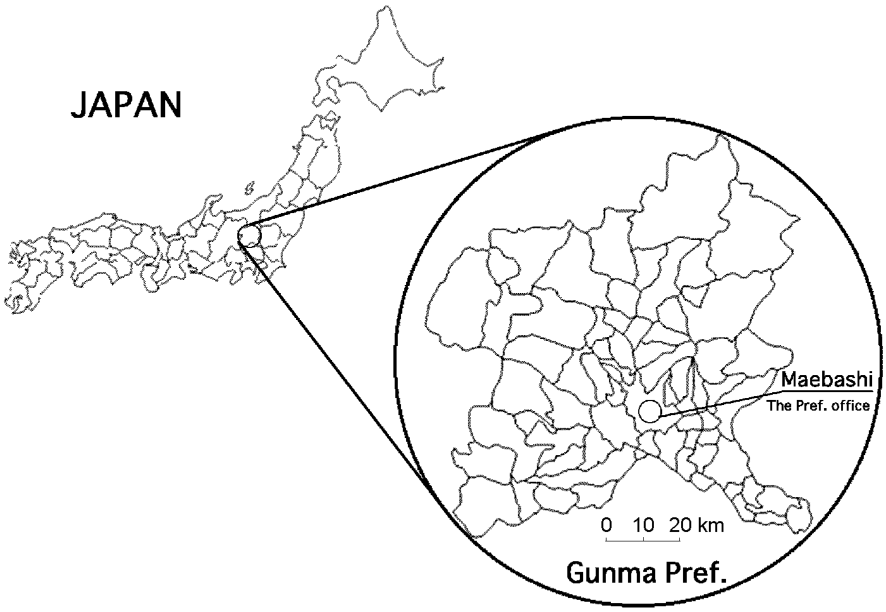

Fig. 2. A map of survey location; large closed circle shows the Gunma prefecture

Table 1. Radon concentrations in Gunma prefecture (in Bq·m^{-3})

Type	Sample No. Total	Wooden	Non-wooden	Spring	Summer	Autumn	Winter	Mean ± S.D.	Range
Offices	27	0	27	33 ± 20	24 ± 17	24 ± 17	33 ± 18	29 ± 17	12–93
Dwellings	29	18	11	17 ± 6	13 ± 3	16 ± 4	22 ± 7	17 ± 4	12–28
Sum:	56	18	38	25 ± 16	19 ± 13	20 ± 13	27 ± 15	22 ± 14	12–93

The seasonal averaged radon concentrations in the offices and dwellings are plotted in Fig. 3. The pattern of seasonal changes of radon concentrations in the offices and dwellings was the same, i.e., indoor radon concentrations were relatively low in summer to autumn and relatively high in winter to spring. This phenomenon can be explained as the different frequencies of using air conditioning equipment and opening the window in both offices and dwellings. In the period of summer to autumn, high frequency of using the air conditioning equipment and opening windows dilutes the indoor radon with low concentrations of outdoor radon. On the other hand, besides of the cold weather, strong winds frequently blow from winter to the beginning of spring in Gunma prefecture, therefore, windows and doors are scarcely opened in the period of winter to spring. The low frequency of using the air conditioning equipment and opening windows makes radon easily to be accumulated indoors. The similar pattern of seasonal variation of indoor radon was also reported by ABE et al.[6] and WILKENIG et al.,[7] and it was also explained as the different seasonal ventilation rate.

Even though significant seasonal variations of indoor ^{222}Rn were observed in most of the surveyed rooms, the variation was negligible at 7 rooms. The coefficient of variation was estimated to be below 0.1. It was found that the ventilation was intently performed by using air conditioner or by frequent openings of the door in the 7 rooms. Therefore, the ventilation rate in those rooms was relatively constant even in different seasons. This also indicates that the ventilation rate is a determinative factor for the variation of indoor radon.

All offices (27) are reinforced concrete houses in this survey. While, there are 18 traditional Japanese wooden houses, 6 reinforced concrete houses and 5 light steel structures among the 29 dwellings. Figure 4 shows the seasonal averaged radon concentrations in the traditional Japanese wooden houses and other types of houses (non-wooden). The annual averaged radon concentration in the non-wooden houses was about 7 $Bq\cdot m^{-3}$ higher than that of wooden houses in this survey. This tendency continued throughout the whole year ($p<0.001$). The same phenomenon was also reported by others.[2,3] It can be explained as the air tightness of the concrete houses is much better than those of others.

In general indoor environments, contribution of thoron to radon measurements is negligible because of its small quantity and short half-life. However, in case that indoor thoron is much higher than radon, the estimation of the influence of thoron to radon measurements is indispensable for more accurate evaluation of radon.[8] In this survey, a total number of 113 data of thoron was observed among the 216 measurements. The histogram of thoron to radon (Tn/Rn) ratio is plotted in Fig. 5. The arithmetic mean of Tn/Rn ratio is 1.28, with a maximum of 6.75 in a dwelling and a minimum of 0.08 in an office. About 50% of the Tn/Rn ratio exceeded 0.7 and 25% exceeded 1.6. If the influence of thoron was not evaluated in the place where the Tn/Rn exceeded 1.0, radon concentration might be overestimated to over 4% by using the single radon monitor. On the other hand, TOKONAMI et al.[9] reported that other kinds of passive radon monitors might provide up to 1.8 times higher value than the actual radon concentration in the case if the influence of thoron was not evaluated. This difference of the influence of thoron on radon measurements in this radon monitor is derived from the type of the detector and the opening size of the monitor. Therefore, attention must be paid to thoron, when the radon concentration is accurately to be measured by the radon monitor only, without a thoron monitor. Alternatively, it is more appropriate to use a thoron monitor together with an ordinary one as the R-T monitor.

According to the dose evaluation method recommended by UNSCEAR 2000[1] and taking the working time into account, the annual mean exposure (H) to indoor radon for the working personnel in Gunma prefecture is estimated by:

$$H = F\cdot D\,(Q_1\cdot T_1+Q_2\cdot T_2)$$

where Q_1 and Q_2 are the mean value of radon concentrations in offices and dwellings, respectively; F is the equilibrium factor (0.4); T_1 is the occupancy factor (0.8)×annual mean working hours (1,826 hrs); T_2 is the occupancy factor (0.8)×[a year (8,760 hrs) – annual mean working hours (1,826 hrs)]; and D is the conversion coefficient ($9\cdot 10^{-6}$ $mSv/Bq\cdot h\cdot m^{-3}$).

The annual mean effective dose due to the exposure to indoor radon for the working personnel in Gunma prefecture is estimated to be 0.47 mSv. It corresponds to about 40% of the world average (1.2 mSv per year).

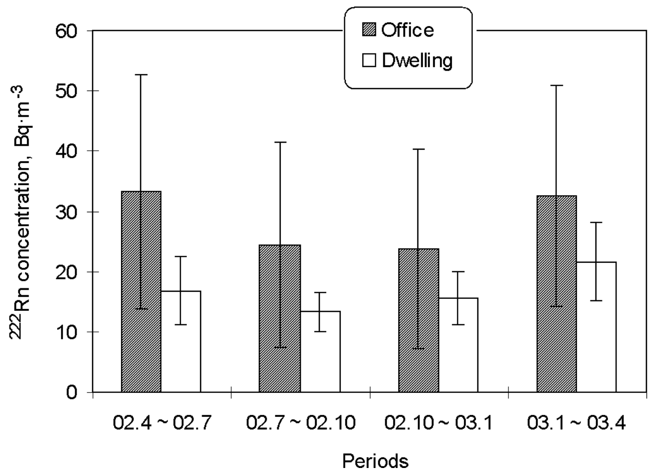

Fig. 3. Seasonal variation of radon concentrations in offices and dwellings in the Gunma prefecture

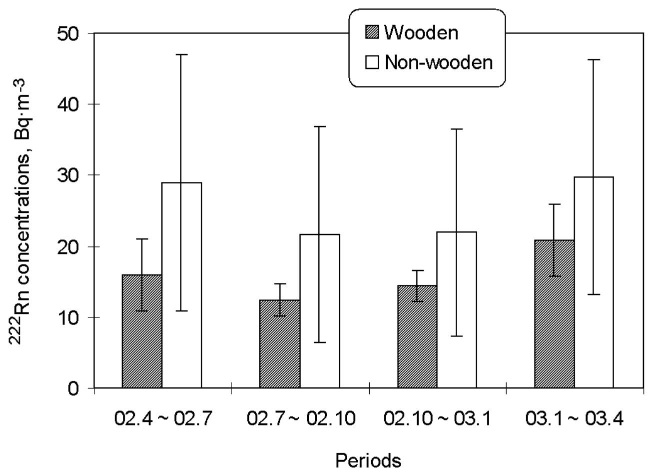

Fig. 4. The difference of the radon concentrations between wooden and non-wooden construction

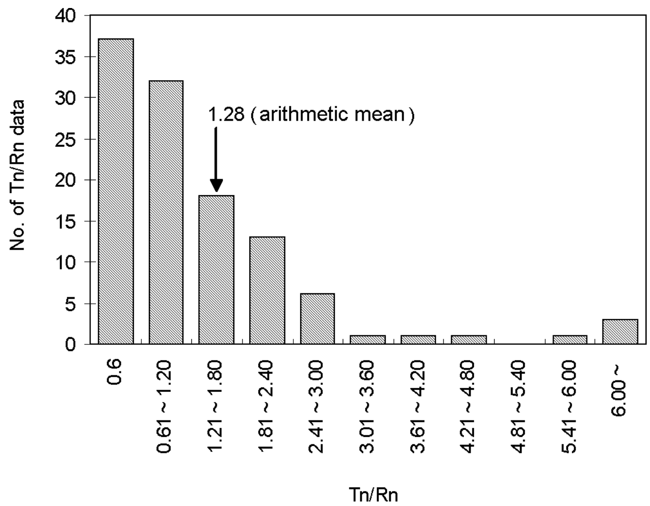

Fig. 5. Histogram of Tn/Rn (113 data)

Conclusions

A survey of the radon concentrations in the offices and dwellings was carried out in the Gunma prefecture, Japan. From the results, the following points can be summarized:

The averaged radon concentration in the offices of the Gunma prefecture was 29 $Bq \cdot m^{-3}$, and it was about 1.7 times of that in the dwellings (17 $Bq \cdot m^{-3}$).

Both of radon concentrations in the offices and dwellings showed a seasonal variation, which was low from summer to autumn and high from winter to spring. This can be explained as the different frequencies of using the air conditioning equipment and opening windows.

Radon concentration in the traditional Japanese wooden houses was about 7 $Bq \cdot m^{-3}$ lower than that of other houses in Gunma prefecture.

For more accurate measurements of radon concentrations, simultaneous measurements of thoron are necessary and valuable.

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References

1. UNSCEAR, Sources and Effects of Ionizing Radiation, United Nations, 2000.
2. K. FUJIMOTO, S. KOBAYASHI, M. UCHIYAMA, M. DOI, Y. NAKAMURA, J. Hoken Butsuri, 32 (1997) 41 (in Japanese).
3. T. SANADA, K. FUJIMOTO, K. MIYANO, M. DOI, S. TOKONAMI, M. UESUGI, Y. TAKATA, J. Environ. Radioact., 45 (1999) 129.
4. W. ZHUO, S. TOKONAMI, H. YONEHARA, Y. YAMADA, Rev. Sci. Instr., 73 (2002) 2877.
5. S. TOKONAMI, W. ZHUO, H. YONEHARA, Y. YAMADA, M. SHIMO, Radiat. Prot. Dosim., 103 (2003) 69.
6. M. ABE, S. ABE, A nationwide survey of radon indoors and outdoors in Japan, Proc. 15th NIRS Seminar, held at Chiba, December 3–4, (1987) 79.
7. M. WILKENING, A. WICKE, Health Phys., 51 (1986) 427.
8. M. DOI, K. FUJIMOTO, S. KOBAYASHI, H. YONEHARA, Health Phys., 66 (1944) No. 1.
9. S. TOKONAMI, M. YANG, T. SANADA, Health Phys., 80 (2001) No. 6.