ORIGINAL PAPER

An Outline Survey of Indoor and Outdoor ^{222}Rn Concentrations in South Korea

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An outline survey of indoor and outdoor ^{222}Rn concentrations in South Korea was carried out with electrostatic integrating ^{222}Rn monitors (EIRM) from Sept. 1995 to Feb. 1997. The annual mean indoor and outdoor ^{222}Rn concentrations at the six central cities across Korea were $26.1 \text{ Bq}\cdot\text{m}^{-3}$ and $9.0 \text{ Bq}\cdot\text{m}^{-3}$, respectively. The outdoor ^{222}Rn concentrations in seashore areas were lower than those of inland areas. Relatively high outdoor ^{222}Rn concentrations were found at the inland cities in Korea, which may be explained as the geological structure. The ratios of indoor to outdoor ^{222}Rn concentrations ranged from 1.6 to 3.8 with an average of 2.9. The seasonal pattern seems to be relatively high during spring to summer and relatively low during autumn to winter for both indoor and outdoor ^{222}Rn concentrations. Passive integrating ^{222}Rn cup monitors were also used to measure the indoor ^{222}Rn concentrations at Seoul. The results showed that the concentrations in basements were clearly higher than those in usual living/working places, and the averages were $43.8 \text{ Bq}\cdot\text{m}^{-3}$ and $24.2 \text{ Bq}\cdot\text{m}^{-3}$, respectively.

KEY WORDS: survey, South Korea, natural radiation, environmental ^{222}Rn , collective equivalent dose, annual mean, seasonal pattern.

I INTRODUCTION

Radon is the biggest single contributor to natural radiation exposure of the public, and accounts about half of the total natural sources of radiation, according to the UNSCEAR reports.^{1,2)} Although ^{222}Rn has become a great concern in recent decades, little information about environmental ^{222}Rn concentrations has been reported in Korea.^{3,4)}

Furthermore, ^{222}Rn is also a useful tracer for studying the behavior of atmospheric pollutants and gas exchange at the air-sea interface. To precisely evaluate the annual collective equivalent dose, and to study the environmental ^{222}Rn , it is necessary to measure both indoor and outdoor ^{222}Rn concentrations with adequate monitors. In this aspect, our laboratory has developed a series of monitors, such as an electrostatic ^{222}Rn monitor (ERM),⁵⁾ an

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electrostatic integrating ^{222}Rn monitor (EIRM)⁶⁾ and a cup monitor.⁷⁾ And successful surveys have been carried out in both Japan⁸⁾ and China.⁹⁾ To study the overall situation of environmental ^{222}Rn in East Asia, it is also necessary to obtain the indoor and outdoor ^{222}Rn levels in Korean Peninsula. Cooperated with Hanyang University in Korea, surveys of indoor and outdoor ^{222}Rn concentrations in South Korea were carried out, and the outline results are reported in this study.

II INSTRUMENTS AND METHODS

1. Monitoring instruments

1.1 Electrostatic integrating ^{222}Rn monitor (EIRM)

Electrostatic integrating ^{222}Rn monitor, shown as Fig. 1, was used for both indoor and outdoor ^{222}Rn measurements. Its prototype was developed by IIDA *et al.*⁶⁾ The practical one (Aloka GS-201) is now commercially available. Radon-222 decays by emission of an α particle to ^{218}Po , and most of the ^{218}Po atoms are positively charged.¹⁰⁾ The positive ^{218}Po ions are collected electrostatically on the electrode of the monitor. Alpha particles from ^{218}Po atoms are detected with allyl diglycol carbonate (CR-39)

plastic. The track density on the CR-39 is related to the ^{222}Rn concentration through calibration. The calibration method had been reported by IIDA.¹¹⁾ The monitor has a volume of about 2.26 l, and one air inlet of 30 mm diameter at the bottom. The measured radon exchange rate is 0.67 h^{-1} . Since the electrostatic collection of $^{218}\text{Po}^+$ atoms depends on the humidity in air, the inside of the EIRM is dehumidified with a P_2O_5 drying agent which is powerful and does not absorb ^{222}Rn gas. According to the CURRIE's definition,¹²⁾ the detection limit was found to be $0.4\text{ Bq}\cdot\text{m}^{-3}$ for an exposure time of two months. Therefore, even the outdoor ^{222}Rn level can also be measured with an adequate sensitivity.

1.2 Passive integrating ^{222}Rn cup monitor

The features of the cup monitor, shown as Fig. 2, had also been reported by IIDA *et al.*⁷⁾ It is constructed by mounting a stainless steel hemisphere with radius 50 mm on an aluminum plate bottom, which has a 5 mm diameter air inlet and a 16 mm inner diameter circular window with a CR-39 detector in the center. The effect of ^{220}Rn can be neglected.⁷⁾ To avoid the influence of electrical charges on the CR-39, a $6\text{ }\mu\text{m}$ thick Al Mylar foil

Fig. 1 Constructive diagram of the electrostatic integrating ^{222}Rn monitor.

Fig. 2 Cross-section of passive integrating ^{222}Rn cup monitor.

is fixed on the top of the CR-39. The calibration method had also been reported by IIDA.¹¹⁾ According to the CURRIE's definition,¹²⁾ the detection limit was found to be $2.3 \text{ Bq}\cdot\text{m}^{-3}$ for an exposure time of 90 d. Therefore, it is also sensitive enough for long-term integrating measurement indoors.

2. Monitoring methods

2.1 Site selection

In order to represent the regional feature from the north to the south, six central cities—Seoul, Taejeon, Taegoo, Kwangjoo, Pusan and Jeju were selected as survey locations, shown as Fig. 3. And the EIRMs which have high sensitivity were used in these locations. For indoor measurements, the EIRMs were set in the concrete buildings which are typical dwellings in South Korea. Furthermore, in order to compare the indoor ^{222}Rn concentrations among differently functional compartments, typical hospital, apartment, office and shopping center at Seoul were selected, and measured with cup monitors which are less sensitive, but more economical.

2.2 Monitor setting

In principle, the indoor and outdoor surveys at the six selected cities were simultaneously carried out by setting the EIRMs indoors and outdoors. Each indoor sample was collected in a professor's office (4th~6th floor) in the same building which outdoor monitor was set on the roof. The normal surveys were carried out about 2-month integrating intervals from Feb. 1996, except Jeju from Oct. 1996.

Fig. 3 Average outdoor and indoor (in the brackets) ^{222}Rn concentrations at 6 cities in Korea.

The surveys of indoor ^{222}Rn concentrations in differently functional compartments at Seoul were carried out by setting the cup monitors in the different floors of the five selected buildings. Having known the relatively high indoor ^{222}Rn concentrations in Korea from the previous surveys with EIRMs, the normal surveys were also started about 2-month integrating intervals from Sept. 1996. Two cup monitors were set at the same floor of each site in order to overcome the defect of lower sensitivity of the cup monitors.

III RESULTS AND DISCUSSION

1. Distribution of outdoor ^{222}Rn concentrations in Korea

The variation and annual mean of outdoor ^{222}Rn concentrations at 6 cities in Korea from Feb. 1996 to Feb. 1997 are shown in Table 1 and Fig. 3. The mean outdoor ^{222}Rn concentrations at the six cities ranged from $6.3 \text{ Bq}\cdot\text{m}^{-3}$ to $10.7 \text{ Bq}\cdot\text{m}^{-3}$ with an average of $9.0 \text{ Bq}\cdot\text{m}^{-3}$. The average value was nearly the same as the results of China ($9.3 \text{ Bq}\cdot\text{m}^{-3}$),⁹⁾ but even the smallest value ($5.7 \text{ Bq}\cdot\text{m}^{-3}$) was higher than the average of Japan (about $5.0 \text{ Bq}\cdot\text{m}^{-3}$),⁸⁾ measured by the same type of monitors. Furthermore, all of the outdoor ^{222}Rn concentrations at the three inland cities—Taejeon, Taegoo

Table 1 Indoor and outdoor ^{222}Rn concentrations* in Korea measured with EIRMs.

Location	Indoor ($\text{Bq}\cdot\text{m}^{-3}$)			Outdoor ($\text{Bq}\cdot\text{m}^{-3}$)		
	Range	Mean	SD	Range	Mean	SD
Seoul	24.2–44.7	33.4	9.0	6.4–10.4	8.8	1.9
Taejon	28.7–45.6	37.6	6.0	6.2–15.2	10.4	3.2
Taegoo	15.1–32.9	26.1	9.6	6.3–13.0	10.6	3.7
Kwangjoo	16.6–26.5	23.3	4.5	8.2–12.2	10.7	1.8
Pusan	8.3–14.9	10.3	2.7	5.7–7.3	6.3	0.6
Jeju	25.3–27.0	26.2	1.2	6.7–7.6	7.2	0.6
Total	8.3–45.6	26.1	7.4	5.7–15.2	9.0	1.9

* Data from one year survey, except Jeju from Oct. 1996 to Mar. 1997.

Table 2 Mean indoor ^{222}Rn concentrations* at Seoul measured with cup monitors.

Location	Hospital	Apartment 1	Apartment 2	Office	Shop	Average
Basement	30.5 ± 3.3	59.6 ± 6.6	25.2 ± 4.2	66.9 ± 9.5	36.8 ± 3.5	43.8 ± 15.6
Other floors	24.6 ± 3.6	14.3 ± 2.3	23.9 ± 5.3	34.8 ± 5.3	23.6 ± 3.0	24.2 ± 4.4

* Note: Unit in $\text{Bq}\cdot\text{m}^{-3}$, data averaged from Sept. 1996 to Mar. 1997.

and Kwangjoo were slightly higher than the average concentration of $10 \text{ Bq}\cdot\text{m}^{-3}$ in continental areas indicated in the UNSCEAR report (1993).²⁾ The higher outdoor ^{222}Rn concentration in Korea may be explained as that the radioactivity in the soil may be relatively high, because most of the Korean Peninsula was originated from the granite of Cambrian era.¹³⁾ And the higher soil gas ^{222}Rn concentration was also observed with the range of $3.9\sim 23.1 \text{ kBq}\cdot\text{m}^{-3}$ in another study.³⁾ Among the six cities, the highest and lowest annual mean outdoor ^{222}Rn concentrations were $10.7 \text{ Bq}\cdot\text{m}^{-3}$ ($8.2\sim 12.2 \text{ Bq}\cdot\text{m}^{-3}$) at Kwangjoo and $6.3 \text{ Bq}\cdot\text{m}^{-3}$ ($5.7\sim 7.3 \text{ Bq}\cdot\text{m}^{-3}$) at Pusan, respectively. From the geographical point of view, they were lower in seashore areas than that of inland areas, and the same situations were also found in both China⁹⁾ and Japan.¹⁴⁾

2. Distribution of indoor ^{222}Rn concentrations in Korea

The variation and annual mean of indoor ^{222}Rn concentrations measured with EIRMs at the six cities in Korea are also shown in **Table 1** and **Fig. 3**. The highest and lowest annual mean indoor ^{222}Rn concentrations were $37.4 \text{ Bq}\cdot\text{m}^{-3}$ at Taejon

and $10.3 \text{ Bq}\cdot\text{m}^{-3}$ at Pusan, with an average of $26.1 \text{ Bq}\cdot\text{m}^{-3}$. It was slightly higher than the average of China ($21.8 \text{ Bq}\cdot\text{m}^{-3}$),⁹⁾ but much higher than that of Japan ($15.5 \text{ Bq}\cdot\text{m}^{-3}$).¹⁵⁾

Annual mean indoor ^{222}Rn concentrations in the differently functional compartments of the five selected buildings at Seoul are shown in **Table 2**. The concentrations found in the basement were clearly higher than those measured in usual living/working places, and the averages were $43.8 \text{ Bq}\cdot\text{m}^{-3}$ and $24.2 \text{ Bq}\cdot\text{m}^{-3}$, respectively. The mean indoor ^{222}Rn concentration in usual living/working places at Seoul measured with cup monitors was nearly the same as that of the six cities measured with EIRM.

3. The seasonal pattern of the indoor and outdoor ^{222}Rn concentrations in Korea

Because the data are still insufficient and measuring periods were not strictly the same, it is still difficult to make a precise conclusion about the seasonal pattern of ^{222}Rn concentration. Although the variations of ^{222}Rn concentrations among different seasons were not so obvious, the seasonal pattern seems to be relatively high during spring to summer and relatively low during autumn to

Fig. 4 Seasonal variation of mean indoor and outdoor ^{222}Rn concentrations in Korea.

winter for both indoor and outdoor ^{222}Rn concentrations, shown as Fig. 4. It is slightly different from the most major patterns of China and Japan, which is a summer minimum and a winter maximum pattern.^{8,9)}

4. The relationship between indoor and outdoor ^{222}Rn concentrations in Korea

As shown in Fig. 4, whenever the indoor ^{222}Rn concentration is higher, the outdoor ^{222}Rn concentration is basically higher. The ratios of indoor to outdoor ^{222}Rn concentrations in Korea ranged from 1.6 to 3.8 with an average of 2.9, which is slightly higher than both of China (2.5)⁹⁾ and Japan (2.1).¹⁴⁾

In addition, the ratios of maximum outdoor ^{222}Rn concentrations to the minimum in different seasons are usually supposed as an index to estimate the airflow transport of outdoor ^{222}Rn .^{9,16,17)} Based on this survey, the ratios in Korea ranged from 1.3 to 2.5, with an average of 1.8, which was equal to that of China,⁹⁾ but it was less than that of Nagoya of Japan (2.6).¹⁴⁾ Because the seasonal pattern of outdoor ^{222}Rn concentrations were not strictly same among the three countries, and the ^{226}Ra concentration in the soil of Korea is still unknown, it is still unable to estimate the transported ingredient of outdoor ^{222}Rn among China, Korea and Japan, based on the present surveys.

IV CONCLUSIONS

Surveys of the indoor and outdoor ^{222}Rn concen-

trations at six cities in Korea were carried out from Sept. 1995. The annual mean indoor and outdoor ^{222}Rn concentrations at six cities in Korea were $26.1 \text{ Bq}\cdot\text{m}^{-3}$ and $9.0 \text{ Bq}\cdot\text{m}^{-3}$, respectively. Relatively high outdoor ^{222}Rn concentrations were found at the inland cities, which may be explained as the potential high radioactivity in the soil due to the geological structure. The ratios of the indoor to outdoor ^{222}Rn concentrations ranged from 1.6 to 3.8 with an average of 2.9. Lacking of quantity and uniformity of data, it is still difficult to make a precise conclusion of the seasonal pattern of ^{222}Rn concentrations, but it seemed to be relatively high during spring to summer and relatively low during autumn to winter for both indoor and outdoor ^{222}Rn concentrations. The outdoor ^{222}Rn concentrations in seashore areas were lower than that of inland areas.

The indoor ^{222}Rn concentrations at Seoul found in the basement were clearly higher than those measured in usual living/working places, their averages were $43.8 \text{ Bq}\cdot\text{m}^{-3}$ and $24.2 \text{ Bq}\cdot\text{m}^{-3}$, respectively for the five selected typical buildings.

As we know, the indoor and outdoor ^{222}Rn concentrations depend on the factors of building materials, geological conditions, geographical features, and meteorological conditions, etc. To precisely evaluate the annual collective equivalent dose, and to study the environmental ^{222}Rn in Korea more detail, long-term nation-wide and typical measurements are still needed.

REFERENCES

- 1) UNSCEAR; Sources and effects of ionizing radiation, p. 62, UN, New York (1988).
- 2) UNSCEAR; Sources and effects of ionizing radiation, p. 33-89, UN, New York (1993).
- 3) W.H. CHUNG; Radon and thoron concentrations in Korea, Proc. 32th Annual Meeting of Japan Health Physics Society, p. 35, Nara, Japan (1997).
- 4) Y.S. KIM and T. IIDA; Airborne radon concentrations in different environments in Korea, Proc. 7th Tohwa University International Symposium, Fukuoka, Japan, CI-3 (1997).
- 5) T. IIDA, Y. IKEBE and K. TOJO; An electrostatic radon monitor for measurements of environmental radon, *Res. Lett. Atmos. Electr.*, **11**, 55-59 (1991).

- 6) T. IIDA, Y. IKEBE, T. HATTORI, H. YAMANISHI, S. ABE, K. OCHIFUJI and S. YOKOYAMA; An electrostatic integrating ^{222}Rn monitor with cellulose nitrate film for environmental monitoring, *Health Phys.*, **54**, 139–148 (1988).
- 7) T. IIDA, R. NURISHI and K. OKAMOTO; Passive integrating ^{222}Rn and ^{220}Rn cup monitors with CR-39 detectors, *Environ Inter.*, **22** (Suppl. 1), 641–647 (1996).
- 8) M. ABE and S. ABE; A nation-wide survey of radon indoors and outdoors in Japan, Proc. 15th NIRS Seminar on Environmental Research, pp. 79–87, Chiba, Japan (1987) (in Japanese).
- 9) Y. JIN, Z. WANG, T. IIDA, Y. IKEBE, S. ABE, H. CHEN, L. WU, Q. ZENG, K. DU and S. LI; A new sub-nationwide survey of outdoor and indoor ^{222}Rn concentrations in China, *Environ. Inter.*, **22** (Suppl. 1), 657–663 (1996).
- 10) A. BUSIGIN, A.W. VAN DER VOOREN, J.C. BABCOCK and C.R. PHILLIPS; The nature of unattached RaA (^{218}Po) particles, *Health Phys.*, **40**, 333–343 (1981).
- 11) T. IIDA; Calibration methodology of radon monitors, *Bull. Japan Chemical Analysis Center*, **28**, 47–53 (1996) (in Japanese).
- 12) L.A. CURRIE; Limits for qualitative detection and quantitative determination, *Anal. Chem.*, **40**, 586–593 (1968).
- 13) A. TOJO; “Earth Science 16—Geology of the World,” pp. 355–384, IWANAMI, Tokyo (1979) (in Japanese).
- 14) H. YAMANISHI, T. IIDA and Y. IKEBE; Measurements of regional distribution of ^{222}Rn concentration, *J. Nucl. Sci. Technol.*, **28**(4), 331–338 (1991).
- 15) National Institute of Radiological Science; The final report of nationwide ^{222}Rn concentrations, NIRS-R-32, p. 6, Chiba, Japan (1997) (in Japanese).
- 16) Y. IKEBE, S. KOJIMA and M. SHIMO; On the origin and transport of ^{222}Rn in the atmosphere, *Res. Lett. Atmos. Electr.*, **3**, 51 (1983).
- 17) H.E. MOORE, S.E. POET, E.A. MARTELL and M.H. WILKENING; Origin of ^{222}Rn and its long-lived daughters in air over Hawaii, *J. Geophys. Res.*, **79**, 5019 (1974).