EFFECTS OF BEDROCK TYPE ON THE INDOOR RADON CONCENTRATIONS AT THE OFFICE BUILDINGS IN GYEONGJU, KOREA

by

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This study measured the indoor radon concentrations at 23 administrative office buildings in Gyeongju, Korea, which consists of 23 administrative districts. Using the Korean geological information system, the type of bedrock under the administrative office buildings was identified and classified in 3 major types: granite, sedimentary rock, and sedimentary rock-based fault. The changes in the indoor concentrations at the 23 administrative office buildings were analyzed according to the type of bedrock. As a result, the radon concentration in the areas with the granite bedrock was generally higher than that in the region of two other types of bedrock. In addition, the radon concentration was evaluated according to surface area and construction timing of the building. The indoor radon concentration generally increased with decreasing surface area of the building, particularly in granite distributed areas. For a building aged more than 15 years, the radon concentration in the building in the granite area was much higher. For the building aged 1 or 2 years, the radon concentration was high regardless of the type of the bedrock due to radon emanation from the building material, such as concrete.

Key words: radon, administrative office building, Gyeongju, bedrock distribution

INTRODUCTION

Radon is a naturally occurring radioactive gas, which decays into radioactive particles that can be trapped in human lungs when inhaled. As they break down further, these particles release small bursts of energy. This can damage the lung tissue and lead to lung cancer over the course of one's lifetime [1]. Radon is responsible for the majority of the public exposure to naturally occurring radiation. The United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that radon and its progenies cause on average a radiation dose of 1.3 mSv per year and 79% of the radiation dose is due to the indoor radon inhalation [2]. Therefore, each country makes national surveys of the actual radon concentration and implements radon management measures to protect its citizens [3-6].

Gyeongju is located in southeast of the Korean peninsula and is approximately 360 km away from Seoul. Gyeongju was a capital of the Silla dynasty which was a kingdom maintained over 1,000 years and had great historical heritage. In Gyeongju, the percentage of old buildings is relatively high because the development and construction of new buildings is restricted due to heritage listing. Old buildings are more likely to have high indoor radon concentration because those buildings have many pathways for radon to permeate the indoor space from the external environment. In addition, various types of bedrock, such as granite, sedimentary rocks, and sedimentary rock-based faults, are distributed in the underground areas of Gyeongju. There have been no measurements and analysis of the indoor radon concentrations, particularly in the administrative office buildings, considering these historic and geological characteristics in Gyeongju.

Therefore, this paper presents the results of measuring the indoor radon concentrations at 23 administrative office buildings in order to determine the relationship between the indoor radon concentrations and the type of bedrock under each building. In addition, this study examined how did the surface area and the construction timing of the administrative district office building affect the indoor radon concentration.

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Table 1. Overview of the administrative office buildings in Gyeongju

Administrative district		Point	Establishment	Surface area [m^2]	No. of staffs	No. of residents
Eup	Gampo	Eup office	1991	472.91	23	7,240
	Oedong		2009	110.34	34	18,959
	Angang		1956	795	49	34,211
	Geoncheon		1986.03.27	1.209	25	11,152
Myeon	Naenam	Myeon office	1988.04	833	18	6,142
	Sannae		1988.09.06	634.67	17	3,561
	Yangnam		1995.09.19	1,259.42	18	7,131
	Yangbuk		1989.12.21	120.06	27	4,558
	Gangdong		1990	1,477.53	19	8,705
	Seo		1974	690	20	4,166
	Cheonbuk		1993	3.047	25	6,140
	Hyeongok		1998.05.07	452	20	13,658
Dong	Dongcheon	Dong office	1987.08.26	806.65	15	26,957
	Seonggeon		1995.09.05	484.11	26	18,605
	Seondo		2010.03.08	1,485.72	22	13,891
	Yonggang		1996.10	1,326.4	15	16,424
	Jungbu		1994.08.05	1,507.71	20	7,232
	Hwango		1996.12.26	890.55	18	5,007
	Bodeok		1988	199.32	15	2,278
	Hwangseong		1988.02.03	421	18	30,364
	Bulguk		2009	1.913	14	8,996
	Wolseong		1970	1.045	15	6,646
	Hwangnam		1993	504.54	14	3,572

MATERIALS AND METHODS

As shown in tab. 1, Gyeongju consists of 23 administrative districts. In this study the indoor radon concentrations in 23 administrative district office buildings were measured, the example ones of which are shown in fig. 1. The reason that the administrative district office buildings were selected as a measurement point is that many people move in and out of the buildings and dozens of workers remain in the buildings for 8 hours more per day. In addition, it is relatively easy to identify the characteristics of the buildings, such as construction timing or building material. The age structure of the buildings was more than 10 years on average.

(a) Bodeok-dong office building

(b) Hwangseong-dong office building

Figure 1. Example of the administrative community office buildings in Gyeongju

From June to December 2010, the measurements were made at points where the indoor radon concentration was expected to be the highest in each building, such as a basement storage area or machinery room that has been unused for a long time or is poorly ventilated. The type of bedrock under the 23 administrative district office buildings was examined to determine the relationship between the type of bedrock and the indoor radon concentration in the buildings. Figure 2 shows the geographical location of Gyeongju in the Korean peninsula and the measurement points in each administrative district in Gyeongju. Table 1 includes the number of the floating population, surface area, and the construction timing of the administrative district office buildings.

A geological map under each measurement point was examined using the Korean geological information system developed by the Korea Institute of Geoscience and Mineral Resources. Table 2 lists the bedrock distribution under the measurement points in the administrative district office buildings. Table 2 reveals decades of sedimentary rock-based faults. The granite exists under the 4 administrative district office buildings: Sannae-myon, Hwangseong-dong, Cheonbuk-myon, and Seondo-dong.

Figure 2. The measurement points in each administrative area in Gyeongju

Table 2. The distribution of bedrocks under each administrative area in Gyeongju

Administrative district	A Granite	B Sedimentrary rock	C Fault	Note
Eup		Gampo	Geoncheon	Fault (base of sedimentary rock)
		Oedong	Angang	
Myeon	Sannae	Seo	Naenam	
	Cheonbuk	Hyeongok	Gangdong	
		Yangnam		
		Yangbuk		
Dong	Hwangseong		Yonggang	
	Seondo		Dongcheon	
			Hwango	
			Jungbu	
			Seonggeon	
			Bodeok	
			Bulguk	
			Wolseong	
			Hwangnam	

These granites are known to have formed mainly during the Jurassic or Cretaceous periods. The radon concentration in granite rock masses is higher due to their high uranium content [3]. This paper shows the examined indoor radon concentrations according to the types of bedrock under the administrative district office buildings, which are categorized in 3 main types; granite, sedimentary rock, and sedimentary rock-based fault.

A RAD7 detector (Durrridge Co.) was used to measure the indoor radon concentration because it allows continuous measurement. Figure 3 shows the structure of the RAD7.

The experimental procedure for the indoor radon concentration was shown in fig. 4 and as follows:

– before the measurement, the detector was purged for 15 minutes,
– the radon concentration in the air outside the building was measured for 5 minutes,
– for the measurement inside the building, the detector should be installed at the center and 1.5 m high from the floor of the building,

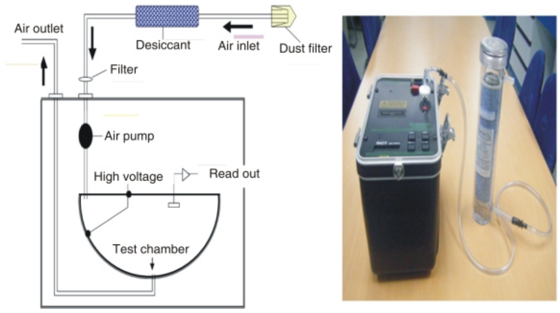


Figure 3. The structure of a radon detector

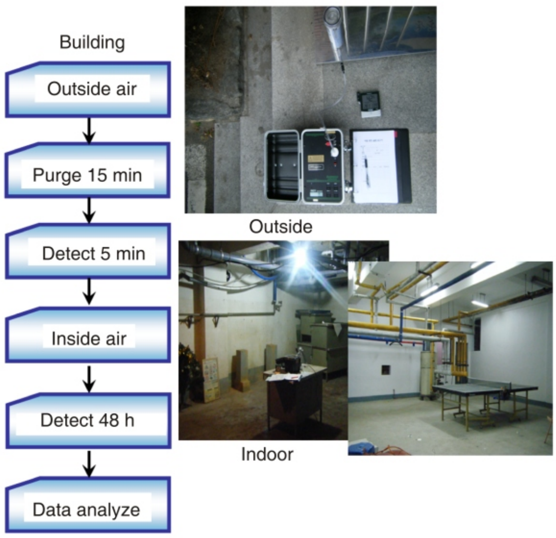


Figure 4. The measurement procedure

– at the measurement point, the measurement was made continuously for 48 hours, and
– if the indoor radon concentration exceeded 148 Bq/m^3 or was found to be an abnormal value, measurement was repeated and analyzed.

RESULTS

Figure 5 shows the indoor radon concentrations at each interval for each administrative district office building according to the type of bedrock under the building. As shown in fig. 5, the indoor radon concentrations in the granite region were generally higher than those in the region of the other bedrock types. That is, the frequencies exceeding 148 Bq/m^3, which is an action level recommended by the U.S. Environmental Protection Agency (EPA), in the region of granite were larger than those in the other regions. For the region of granite, the range most frequently measured was 125~225 Bq/m^3 and the maximum concentration was 387.1 Bq/m^3. In comparison, for the regions of sedimentary rock and sedimentary rock-based fault, the range of radon concentrations most frequently measured was 2.8~70 Bq/m^3 and the frequency exceeding the EPA action level was low.

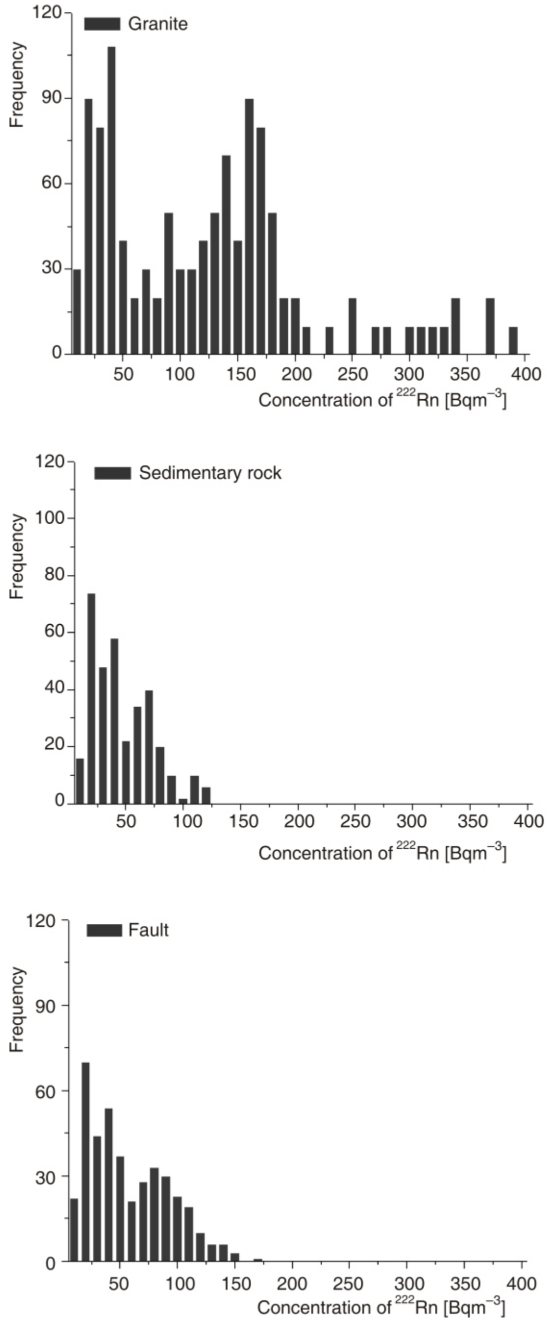
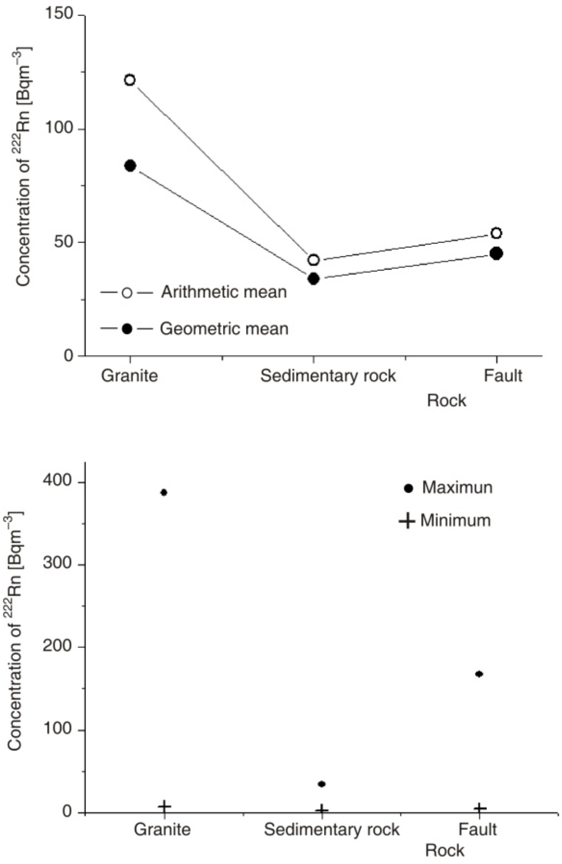


Figure 5. The indoor radon concentration in the administrative office building in Gyeongju according to the type of bedrock

Figure 6 shows the representative statistics of the indoor radon concentrations, such as the arithmetic mean, geometric mean, maximum value and minimum values, according to the type of bedrock. The indoor radon concentrations in the buildings in the area whose bedrock is granite were 125~188% higher than those in the buildings in the areas whose bedrock was sedimentary rock or fault. For the two regions except granite, the difference between the radon concentrations was approximately 28%. As demonstrated in a previous study [3], the radon concentration in the area where the granite was distributed is higher than that in



Rock	Arithmetic mean	Geometric mean	Maximum	Minimum
Granite	121.3	83.6	387.1	7.5
Sedimentary rock	42.1	33.9	33.9	2.8
Fault	23.9	45.1	167.5	4.1

Figure 6. The representative statistics of the indoor radon concentration measurements according to the type of bedrock

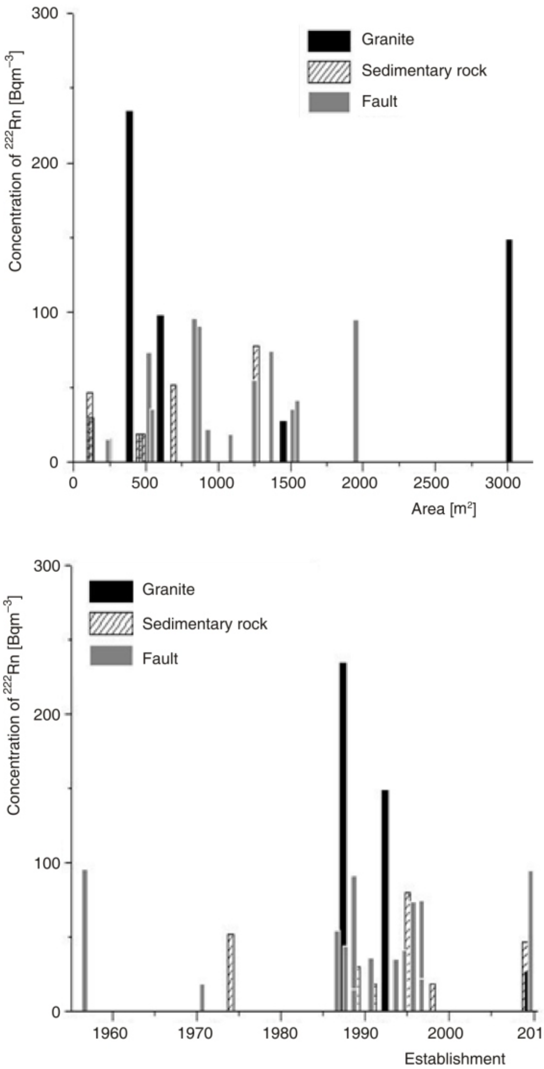
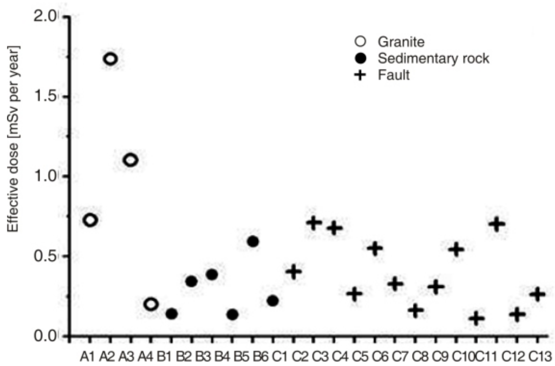


Figure 7. The indoor radon concentration according to the area and concentration time of each office building

the area where the other types of bedrock were distributed because the emanation rate of radon from granite is higher than that from sedimentary or volcanic rock. [7] The indoor radon concentration may be influenced by the inflow of radon gas from the soil to the building.

Figure 7 shows the indoor radon concentrations according to the surface area and construction timing of the administrative district office building. The indoor radon concentration generally increased with decreasing surface area of the building, particularly in the granite distributed areas. Regarding construction timing, for a building aged more than 15 years, the radon concentration in the building in the granite area was much higher. As the building ages, crevasses will form on the floor or wall of the building, which can allow the passage of the radon from the soil. The concentration of radon gas inside the building will increase with time. On the other hand, for a building aged one or two years, the radon concentration was high regardless of the type of the bedrock. This appears to be due to the radon emanating from the construction material of new buildings, such as concrete, because most of the buildings newly built in Korea have been constructed using concrete. It was also found that the radon concentration in the concrete building was higher than that in the building made of other materials [8].

Figure 8 shows the projected annual effective dose to staff working in the administrative district office building due to indoor radon inhalation according to the type of bedrock. To estimate the radiation dose due to radon and its progenies, it was assumed that the annual working time for a worker was 2,000 hours (40 hours per week, 50 working weeks). The radiation dose can be estimated using the working level (WL), which is a measure of the atmospheric concentration of radon and



Administrative district

Rock	Point	mSv per year
Granite	Sannae	0.711
	Hwangseong	1.702
	Cheonbuk	1.079
	Seondo	0.194
Sedimentary rock	Seo	0.375
	Yangbuk	0.217
	Gampo	0.137
	Yangnam	0.582
	Hyeongok	0.133
	Oedong	0.335
Fault	Angang	0.696
	Wolseong	0.135
	Geoncheon	0.397
	Dongcheon	0.321
	Naenam	0.663
	Bodeok	0.11
	Gangdong	0.259
	Hwangnam	0.258
	Jungbu	0.303
	Seonggeon	0.533
	Yonggang	0.54
	Hwango	0.157
	Bulguk	0.39

Figure 8. The projected annual effective dose of the staff in each office building

its progenies. 1 WL is defined as any combination of short-lived radon daughters in 1 L of air that will result in the ultimate emission of 1.3 10^5 MeV of alpha particles energy. This corresponds to an atmospheric concentration of 3,700 Bq/m^3 of ^{222}Rn (100 pCi per liter) in equilibrium with its daughters [9]. Using the indoor equilibrium factor (0.4 recommended by UNSCEAR), the annual effective dose can be calculated as follows [10, 11]

$$\mathrm{WL} = F_t \quad C_{\mathrm{Rn}}/100 \tag{1}$$

where C_{Rn} is the average radon concentration in each building.

If the exposure resulting from inhalation of air with a 1-WL concentration for a period of one working month (170 hours) is 1 WML (working level month), the actual exposure can be calculated as

$$\mathrm{WLM} = \mathrm{WL} \quad \text{exposure time (hours)}/170 \tag{2}$$

Using the effective dose conversion factor of 5.4 mSv per year/WLM, then the annual effective dose (AED) can be estimated as

$$\mathrm{AED} = \mathrm{WLM} \quad 5.4 \text{ mSv per year/WLM} \tag{3}$$

The annual effective doses for the region of granite were projected to be 2.4~3.1 times higher than those for the regions of other types of bedrock. In particular, the annual dose for the Hwangseong-dong office building was estimated to be 1.702 mSv per year. This was attributed to the office building being old because it was constructed in 1988 and the measurement point was in a sealed area with water but no ventilation. From some references [12, 13], the reason why the annual effective doses for the office buildings of the Angan-eup and Naenam-myon were higher than the other office buildings regardless of the type of bedrock could be inferred such that the two buildings were older than the other office buildings in Gyeongju and the humidity in the two office buildings was 30~40% higher.

CONCLUSION

The indoor radon concentrations were examined in 23 administrative office buildings in Gyeongju. The measurement values were processed into the frequency and mean radon concentration in each building according to the type of bedrock: granite, sedimentary rock, and sedimentary rock-based fault. For the area whose bedrock was granite, the number of measurement points whose radon concentration exceeded the action level recommended by the U.S. EPA was much higher than those of the other two areas. In addition, the indoor radon concentration increased with decreasing area and increasing age of the office building.

The importance of surveying and managing the radioactivity due to natural occurring radon is well known. Therefore, it is necessary to examine the distribution of bedrock under the building as well as the emanation rate of radon from the building material before its construction, and prepare measures to reduce the indoor radon concentration. This data is expected to be used as basic data for establishing a national radon management system.

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УТИЦАЈ СТЕНОВИТОГ ТЛА НА КОНЦЕНТРАЦИЈУ РАДОНА У АДМИНИСТРАТИВНИМ УСТАНОВАМА ГЈЕОНГЏУ ОБЛАСТИ У КОРЕЈИ

У овом раду приказано је мерење концентрације радона унутар 23 административне установе у области Гјеонгџу у Кореји, која је подељена на 23 округа. Користећи се геолошким информационим системом Кореје, одређена је врста стеновитог тла испод ових зграда и извршена је подела на три основна типа: гранит, седиментну стену и седиментну стену са пукотинама. Према врсти тла анализирана је промена концентрације радона у зградама. Концентрација радона у областима са гранитним тлом била је виша него у областима са другим врстама тла. Поред тога, концентрација радона је процењивана према површини и времену градње зграде. Концентрација радона је расла са смањењем површине зграде – нарочито у областима са гранитним тлом, а код зграда старијих од 15 година, била је знатно виша. У зградама старим једну до две године, услед емисије радона из грађевинског материјала као што је бетон, концентрација радона била је висока без обзира на врсту тла.

Кључне речи: радон, администраīивна зīрада, Гјеонīџу, расūодела īла