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INVESTIGATION OF CHANGES IN INDOOR RADON CONCENTRATIONS BEFORE AND AFTER SEISMIC ACTIVITIES IN GYEONGJU AND POHANG, KOREA

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ABSTRACT: This paper made a continuous measurement of the indoor radon concentrations at a university building in Gyeongju, Rep. of Korea, to check if there is any notable pattern between the indoor radon concentrations and seismic activities. On September 12, 2016, earthquakes with a magnitude of 5.1 and 5.8 consecutively occurred in Gyeongju. 14 months later, an earthquake with a magnitude of 5.5 occurred in Pohang, about 30 km away from Gyeongju, on November 15, 2017. This study investigated the change in the indoor radon concentrations before and after earthquakes to identify if there is any pattern between them and found an interesting pattern. Prior to earthquakes, radon anomalies, which are radon concentration deviating by more than $\pm2\sigma$ from the seasonal average, was usually identified. When 5.0 or greater magnitude earthquakes occurred, the indoor radon concentrations decreased sharply a few days before them, and then continuously increased until the occurrence of the earthquake.

Keywords: Earthquake, Gyeongju, Pohang, Indoor radon concentration, Radon abnormally

1. INTRODUCTION

Radon is a radioactive gas produced by uranium and radium decaying naturally in soil, rock, and water. About 90% of indoor radon comes from cracks on the floor and wall, and the rest comes from building material such as gypsum board, monazite, and cement [1].

It is known that an elevated concentration of radon in soil or groundwater could be a precursor of the earthquake. Several studies have investigated the relationship between radon concentration and earthquake. Sac et al monitored radon concentration at an active tectonic zone in western Turkey and, found that there was a linear correlation between the radon emission rate and the seismic activities in the area under investigation [2]. Argha et al monitored soil radon concentration and analyzed correlation earthquake precursor in India [3]. Wakita et al observed precursory changes in the radon concentration of groundwater prior to Izu-Oshima-Kinkai earthquake of 7.0 magnitude 14 January 1978 [4]. Also, Kuo et al observed an anomalous decrease in groundwater radon concentration before an earthquake of magnitude 6.4 in Taiwan[5]. Omori et al observed an anomalous radon emanation preceding large earthquakes and considered it to be linked to pre-seismic electromagnetic phenomena such as great changes of an atmospheric electric field and ionospheric disturbance [6]. Kim et al observed considerable variations of radon concentrations before the occurrence of the earthquake [7]. Kumar et al studied the correlation that the between tectonic activities and abnormal measurements of radon concentrations in the North-West Himalayan [8]. Kim et al studied prediction earthquake occurrence by detecting radon radioactivity change [9]. Iovine et al have analyzed the 3 areas where the earthquake occurred and radon concentrations through continuous long-term monitoring [10].

While the previous studies focusing on the outdoor radon concentrations, our study have focused on the indoor radon concentrations measured at a university building in Gyeongju, which is located 10 km away from the epicenter of the 5.1- and 5.8-magnitude earthquakes in Gyeongju on September 12 2016, and 22 km away from the epicenter of the 5.5 magnitude earthquake in Pohang in November 15, 2017. Gyeongju and Pohang are known to be on the same Yangsan Fault and share the geology characteristic [11]. This study checked if there is any notable pattern between the indoor radon concentrations and earthquakes, and the pattern, if any, is repeated during the seismic activities in Gyeongju and Pohang.

2. MATERIALS AND METHODS

2.1 Radon Measurement Device and Procedure

As shown in Fig. 1, a RAD7 detector was used to measure the indoor radon concentration. The RAD7 is able to detect radon concentration in the range of 0.1 pCi/L to 20,000 pCi/L with the relative uncertainty of ±5 % [12].

The RAD7 is able to make the continuous measurement. Our measurements were made on the basis of the U.S Environmental Protection Agency (U.S. EPA) protocols [13]. Before each measurement, the Rad 7 was purged more than 10 minutes to discharge the remaining radon gas including thorium inside the RAD7. After purging, the air inlet nozzle of the RAD7 was positioned 1.5 m above the floor, considering the breathing region of a standard man. The indoor radon concentration was continuously measured for 30 minutes each measurement at the corridor neighboring the main entrance of the first floor in the Energy Engineering Hall of Dongguk University in Gyeongju. At the corridor, there was no forced air-conditioning except natural ventilation through the entrance door opened and closed by visitors. The measurement data were recorded and analyzed by using the program embedded in RAD7.

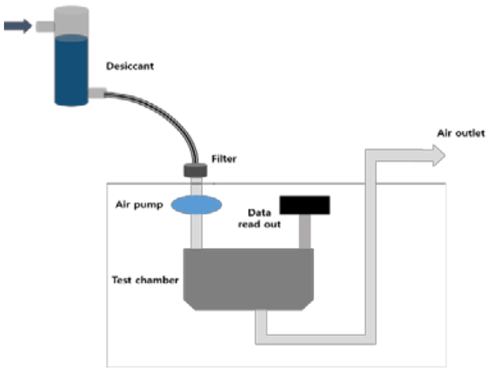

Fig. 1 Structure of RAD7 detector

2.2 Data Analysis Method

Gyeongju is located in the southeastern area of the Korean peninsula, approximately 360 km away from Seoul. Pohang is located 22 km away from Gyeongju. In Pohang on November 15, 2017, the 5.5-magnitude earthquake occurred. Gyeongju and Pohang are on the same Yangsan Fault [14].

The measurement point was 22 km and 10 km away from the epicenter of 5.5-magnitude Pohang earthquake and 5.1, 5.8-magnitude Gyeongju earthquake as the crow flies, respectively, as shown Fig. 2 and Fig. 3.

Radon concentration could be affected by the ambient temperature and humidity. Hence, the inlet air temperature was measured by RAD7 upon each measurement.

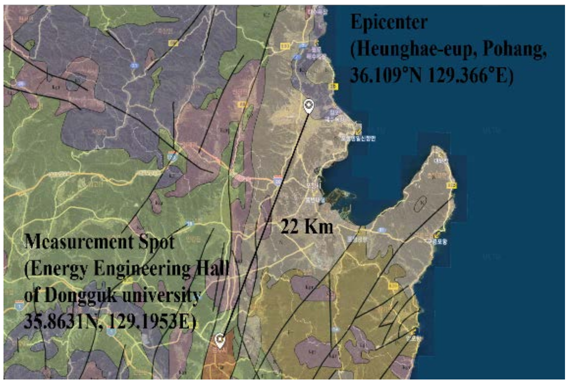

Fig. 2 Pohang earthquake epicenter and measurement spot.

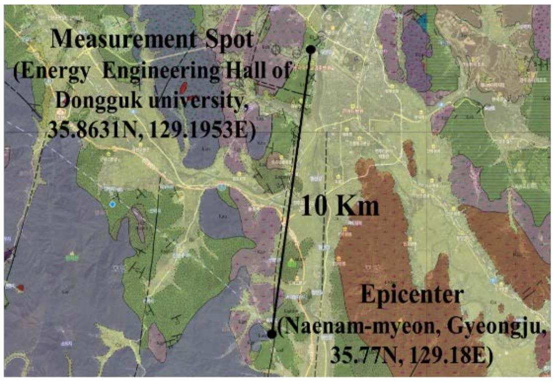

Fig. 3 Gyeongju earthquake epicenter and measurement spot

3. RESULTS AND CONCLUSION

3.1 Measurement Results

3.1.1 Indoor radon concentration variation over time

Fig. 4 and Table 1 show the monthly average indoor radon concentrations from February 2017 to February 2018, except for December 2017 when the measurement was not made because of maintenance of the RAD7.

Table 1 Monthly and seasonal indoor radon concentrations

Season	Month (measurement period)	Monthly average indoor radon concentration $[Bq/m^3]$	Average air inlet temperature [℃]	Seasonal average indoor radon concentration $[Bq/m^3]$
Winter	2017.02	18.4	11.0	18.4 ± 1.2
	2017.03	15.5	13.5	
Spring	2017.04	10.5	18.7	12.4 ± 0.9
	2017.05	10.6	22.3	
	2017.06	10.0	24.4	
Summer	2017.07	10.6	28.4	9.9 ± 0.7
	2017.08	9.0	27.9	

Table 1 continued

Autumn	2017.09	12.2	23.9	15.3 ± 0.9
	2017.10	11.4	20.4	
	2017.11	15.3	14.3	
Winter	2018.01	19.8	10.8	19.4 ± 1.2
	2018.02	18.8	9.9	

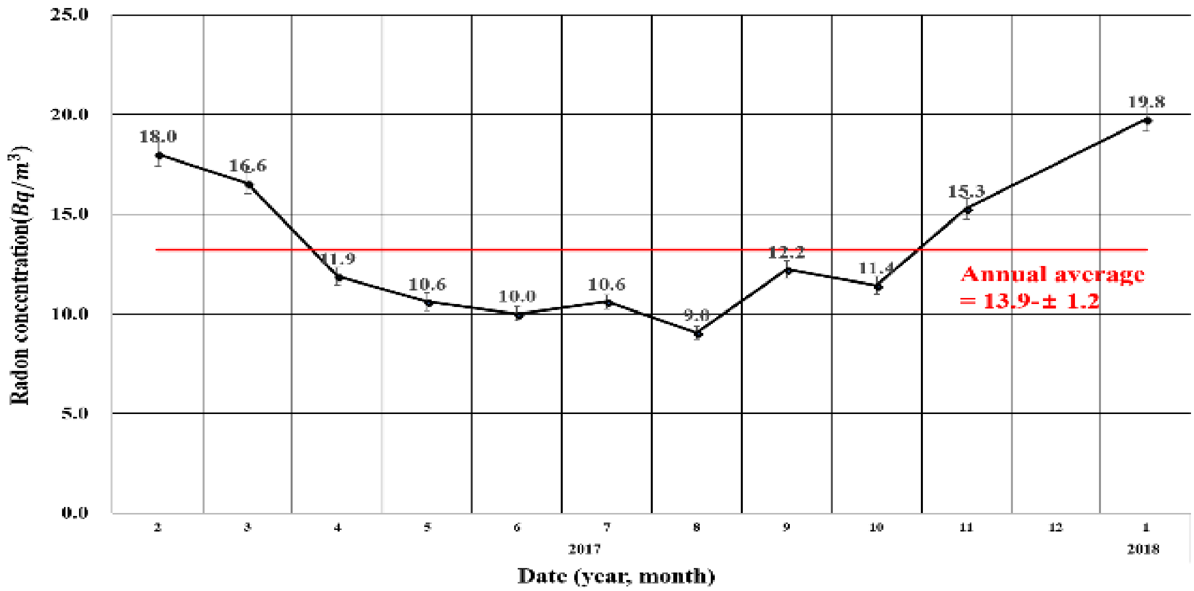

Fig. 4 Monthly average indoor radon concentrations

The curve of the monthly average indoor radon concentrations is shaped like V-letter. While temperatures in spring and summer are higher than those in fall and winter, the indoor radon concentrations are vice versa. As shown in Fig. 4, the annual average indoor radon concentration was 13.9 ± 1.2 Bq/m^3. Table 1 shows the seasonal average indoor radon concentrations in autumn and winter period in 2017, 15.3 ± 0.9 and 19.4 ± 1.2 Bq/m^3, respectively.

Previous studies showed that the radon concentration could be impacted by temperature, pressure, humidity, rainfall, and wind. Using the rainfall data obtained from the Korea Meteorological Administration, we examined the rainfall's effect on the indoor radon concentration but did not find any regular pattern between the two variables in our measurements, as shown in Fig. 5 showing radon concentrations and rainfalls over the duration from July 10 to Nov 20, 2017. Because our measurements were made inside the building, the wind had no impact on it.

The temperature effects were analyzed by comparing the radon concentrations during the periods with similar temperatures. Table 2 summarizes inlet temperature, humidity, and the average radon concentrations.

Examination of Table 2 and Fig. 5 shows the two interesting facts. During the duration from July 10 to November 2, 2017, the average radon concentration was 11.9 ± 0.9 Bq/m^3, as shown in Fig. 5. The indoor radon concentrations for the duration from October 2 to October 16 were mostly less than the average. After October 16, the indoor radon concentration was much higher than the average.

If the radon concentration deviates by more than ±2 σ from the seasonal average, it is possible to say that radon anomalies are possibly caused by earthquake events and not by meteorological parameters [15]. We took a closer look at the period of September 25 to November 21, 2017. During that period, the average radon concentration was 14.80 ± 1.0 Bq/m^3 and 2the σ value was 20.01 Bq/m^3. Over the duration of November 2 to 17, 2017, the indoor radon concentrations exceeded the average + 2 σ , 34.8 Bq/m^3 every day.

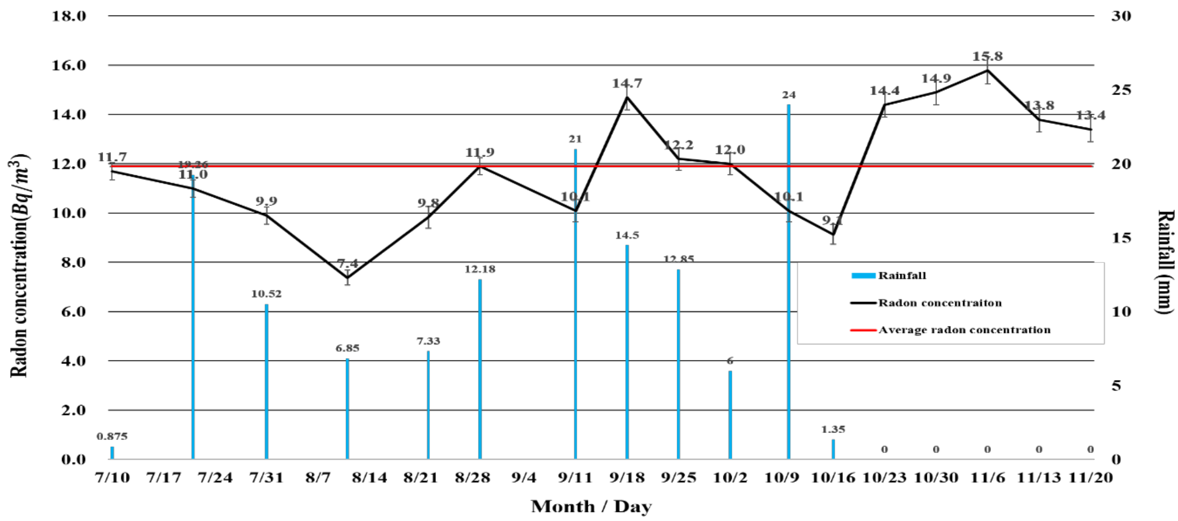

Fig. 5 Radon and rainfall from July 10 to Nov 20

Table 2 Comparison of average radon concentration under similar temperature

Year	Date		Inlet air temperature [℃]		Humidity [%]		Average radon concentration [Bq/m^3]	
2017	08/29 ~ 09/11	05/10 ~ 05/15	25.1	21.4	30.30	3.03	11.9	9.2
	09/11 ~ 09/18	05/15 ~ 05/21	24.1	22.2	5.61	10.00	10.1	9.3
	09/18 ~ 09/25	05/21 ~ 05/31	23.8	23.4	4.10	7.61	14.7	12.9
	09/25 ~ 10/02		22.4		3.86		12.2	
	Average		23.9	22.3	11.0	6.9	12.2	10.5
2017	10/02 ~ 10/10	04/17 ~ 04/25	21.6	18.2	4.25	3.38	12.0	9.8
	10/10 ~ 10/16	04/25 ~ 05/01	21.1	19.9	3.95	15.40	10.1	10.9
	10/16 ~ 10/23	05/01 ~ 05/10	20.1	20.8	3.61	3.02	9.1	11.0
	10/23 ~ 10/30	05/10 ~ 05/15	18.6	21.4	3.08	3.03	14.4	9.2
		05/15 ~ 05/21		22.2		10.00		9.9
	Average		20.4	20.5	3.7	7.00	11.4	10.0
2017	10/30 ~ 11/06	03/14 ~ 03/21	16.3	13.2	2.88	2.00	14.9	16.9
	11/06 ~ 11/13	03/21 ~ 03/27	15.7	13.8	2.72	2.13	15.8	13.8
	11/13 ~ 11/20	03/27 ~ 04/06	13.5	15.2	2.18	2.15	13.8	16.0
	11/20 ~ 11/27	04/06 ~ 04/17	13.2	18.1	17.30	2.92	13.4	10.8
	Average		14.7	15.1	6.3	2.3	14.5	14.4

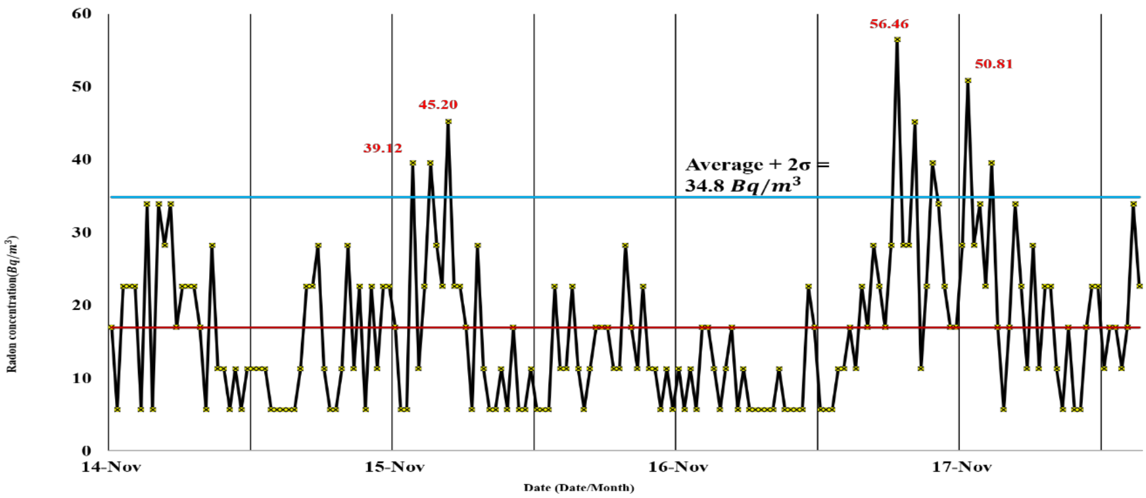

Fig. 6 Radon concentration between Nov 14 to 17

Fig.6 showed the indoor radon concentrations before and after the earthquake. On November 16, the indoor radon concentration did not exceed the average + 2 σ , but on November 17, exceeded average + 2 σ again. Since 3.5- and 3.6-magnitude earthquakes on November 19/20, respectively, the concentration did not decrease but increases again.

3.1.2 Comparison with the Gyeongju Earthquake

Gyeongju earthquake occurred on September 12, 2016. On August 10, 2016, about 1 month earlier than the earthquake, the peak indoor radon concentration was 117.6 Bq/m^3, and the average over August of 2017 was 26.6 ± 24.69 Bq/m^3 [15]. One year later, August 10 to 16, 2017, the average and peak indoor radon concentrations were 10.2 ± 0.9 Bq/m^3 and 45.21 Bq/m^3.

Then, we examined if there were changes in the indoor radon concentrations due to Pohang earthquake. The average and peak radon concentrations over November 2017 were 17.0 ± 1.1 Bq/m^3 and 79.05 Bq/m^3 , respectively. Over November 2016, the average and peak concentrations were 14.4 ± 1.0 Bq/m^3 and 76.8 Bq/m^3, respectively. Table 3 compared the indoor radon concentrations in 2016 and those in 2017.

The peak indoor radon concentration over November 2017 was not much different than over November 2016. It was thought that because the distance between the Pohang epicenter and the measurement spot is two times longer than that between the Gyeongju epicenter and the measurement spot, the seismic activities had relatively less effect on the indoor radon concentrations.

Table 3 Comparison between the indoor radon concentrations in 2016 and those in 2017

Measurement period	Average indoor radon concentration [Bq/m^3]	Maximum radon concentration [Bq/m^3]	Measurement period	Average indoor radon concentration [Bq/m^3]	Maximum radon concentration [Bq/m^3]
Gyeongju earthquake (2016. 09.12)					
2016.06.21 ~ 2016.06.23	8.4	117.6	2017.06.21 ~ 2017.06.23	14.3	62.16
2016.07.11 ~ 2016.07.31	11.0		2017.07.11 ~ 2017.07.31	14.5	
2016.08.10 ~ 2016.08.18	26.6		2017.08.10 ~ 2017.08.18	10.2	
Pohang earthquake (2017. 11. 15)					
2016. 10.19 ~ 2016.10.26	9.8	67.8	2017. 10.19 ~ 2017.10.26	15.0	79.05
2016.11.01 ~ 2016.11.30	14.4		2017.11.01 ~ 2017.11.30	17.0	

3.2 CONCLUSIONS

To check if there is any notable change in the indoor radon concentration before and after the earthquake, we analyzed the indoor radon concentrations measured at one university building near the epicenter of the quake located in southern Gyeongju and Pohang in Rep. of Korea. As shown in Table 3, we compared the indoor radon concentrations at the same periods in the year of 2016 and 2017, to identify if the radon concentration was influenced by any environmental factor except for earthquake. No significant factor, except for earthquake, was found, which had significantly influenced the indoor radon concentration.

For earthquakes with magnitudes of 5.0 or greater, radon anomalies, that is, the indoor radon concentrations exceeding 2σ above the seasonal average, were observed even month earlier than the earthquakes. In some cases, there were noticeable patterns between earthquakes and indoor radon concentrations. In the case of Pohang earthquake, no noticeable changes in the indoor radon concentration were found due to the long distance between the epicenter and the measurement spot. It is expected that this study will provide a guide in identifying a clearer relationship between earthquakes and indoor radon concentrations.

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