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Technical Note

Investigation of the relationship between earthquakes and indoor radon concentrations at a building in Gyeongju, Korea

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A B S T R A C T

This article measured and analyzed the indoor radon concentrations at one university building in Gyeongju, Republic of Korea, to investigate if there is any relationship between earthquakes and indoor radon concentration. Since 12 September 2016, when two 5.1 and 5.8 magnitude earthquakes occurred, hundreds of aftershocks affected Gyeongju until January 2017. The measurements were made at the ground floor of the Energy Engineering Hall of Dongguk University in Gyeongju over a period between February 2016 and January 2017. The measurements were made with an RAD7 detector on the basis of the US Environmental Protection Agency measurement protocol. Each measurement was continuously made every 30 minutes over the measurement period every month. Among earthquakes with 2.0 or greater magnitude, the earthquakes whose occurrence timings fell into the measurement periods were screened for further analysis. We observed similar spike-like patterns between the indoor radon concentration distributions and earthquakes: a sudden increase in the peak indoor radon concentration 1–4 days before an earthquake, gradual decrease before the earthquake, and sudden drop on the day of the earthquake if the interval between successive earthquakes was moderately longer, for example, 3 days in this article.

1. Introduction

Radon is a natural radioactive gas produced by radioactive decays of radium-226, which is found in uranium ores, phosphate rock, shale, igneous and metamorphic rocks such as granite, gneiss and schist, and, to a lesser degree, in common rocks such as limestone [1]. In the last decade, several studies have concluded that elevated concentrations of radon gas in soil or groundwater could be signs of an imminent earthquake. It is believed that the radon is released from cavities and cracks as the Earth's crust is strained prior to the sudden slip of an earthquake [2].

Sac et al. monitored the radon concentration of an active tectonic zone in western Turkey and found that there was a linear correlation between the radon emission rate and the seismic activity in the area under investigation [3]. Wakita et al. observed precursory changes in the radon concentration of groundwater prior to the Izu-Oshima-Kinkai earthquake, of 7.0 magnitude, on 14 January 1978 [4]. Omori et al. observed anomalous emanation of radon preceding large earthquakes and considered it to be linked to preseismic electromagnetic phenomena such as great changes of atmospheric electric field and ionospheric disturbance [5]. Kim et al. observed considerable variations of radon concentrations before the occurrence of earthquakes [6].

Previous studies have focused on anomalies in radon concentrations in outside environments such as soil and groundwater before earthquakes, but few studies have investigated the relationship between the indoor radon concentration and earthquakes. In this article, hence, we measured and analyzed the indoor radon concentrations at one university building in Gyeongju, where there have been hundreds of aftershocks since 12 September 2016; the study was performed to check if there were indicative changes in the indoor radon concentrations prior to earthquakes.

2. Materials and methods

2.1. Radon measurement device and procedure

We used a RAD7 detector to measure the indoor radon concentrations because this detector allows continuous measurements. As shown in Fig. 1, the RAD7 has a 0.7 L hemisphere coated on the inside with an electrical conductor; a silicon alpha detector is at the center. Samples of air drawn through a fine inlet filter enter

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the silicon alpha detector, and alpha radiation is directly converted to an electrical signal. The RAD7 can detect radon concentrations between 0.1 pCi/L and 20,000 pCi/L, with an uncertainty range of ±5 % [7].

The measurements of the indoor radon concentrations were on the basis of the US Environmental Protection Agency protocols [8]. Before the measurement, the RAD7 was purged for more than 10 minutes outside of a building to remove the remaining radon gas inside the chamber. Then, the air inlet of the RAD7 was placed 1.5 m above the floor, considering the breathing zone of a Korean adult. The indoor radon concentrations were continuously measured every 30 minutes over the measurement periods each month. The measurements were made in the corridor near the main entrance on the first floor of the Energy Engineering Hall of Dongguk University in Gyeongju. In the corridor, there was no forced air-conditioning, just natural ventilation through the entrance door as it was opened and closed by visitors. The measurement data were recorded and analyzed by using the program embedded in RAD7.

2.2. Data analysis method

Gyeongju is located in the southeastern area of the Korean peninsula, approximately 360 km away from Seoul. In Gyeongju on 12 September 2016, 5.1 and 5.8 magnitude earthquakes occurred one after another at a 48-minute interval. Since then and until 23 January 2017, 572 aftershocks have followed [9].

The indoor radon concentrations were measured on the ground floor of the Energy Engineering Hall of Dongguk University in Gyeongju, which is 10 km away as the crow flies from the epicenter of the 5.8 magnitude earthquake, as shown in Fig. 2, over a period between February 2016 and January 2017. The building is 5-story building and was built in 2008.

We applied an empirical relationship proposed by Hauksson and Goddard [10] to screen earthquakes, including aftershocks, to find the relationship between earthquakes and the indoor radon measurements. The empirical magnitude–distance relationship is

$$M = 2.4log_{10}D - 0.43 \quad (1)$$

where M is the earthquake magnitude on the Richter scale and D is a distance (km) from the epicenter. Eq. (1) indicates that an earthquake of magnitude M could be preceded by a radon anomaly at a distance of less than or equal to D (km).

Replacing D in Eq. (1) with 10 km gives $M = 1.97$. With the magnitude value rounded off, therefore, we used $M = 2.0$ as the screening criterion of earthquakes for further analyses. Applying the screening criterion, we reduced the number of earthquakes to 172 from 572. Among those, we finally chose 15 earthquakes for scrutiny, those whose occurrence times fell into the span of the indoor radon measurements. Table 1 shows statistics for the 2.0 magnitude or greater earthquakes that occurred in Gyeongju over the period of 12 September 2016 to 23 January 2017.

A radon anomaly is defined as a significant deviation from the mean value. A very common practice in determining radon anomalies is the use of standard deviation (σ). The periods when radon concentration deviates by more than ±2σ from the related seasonal value are considered radon anomalies that are possibly caused by earthquake events and not by meteorological parameters [11]. Consequently, to check if radon anomalies in the indoor radon concentration occur prior to earthquakes, we examined if and how many indoor radon concentrations exceeded 2σ above the seasonal average before earthquakes occurred.

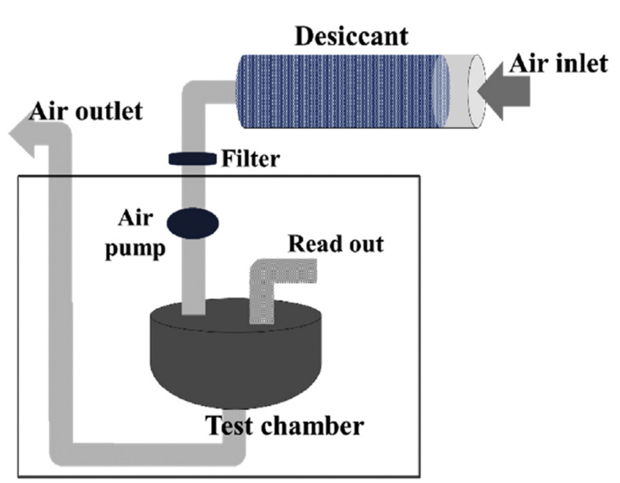

Fig. 1. Structure of RAD7 detector.

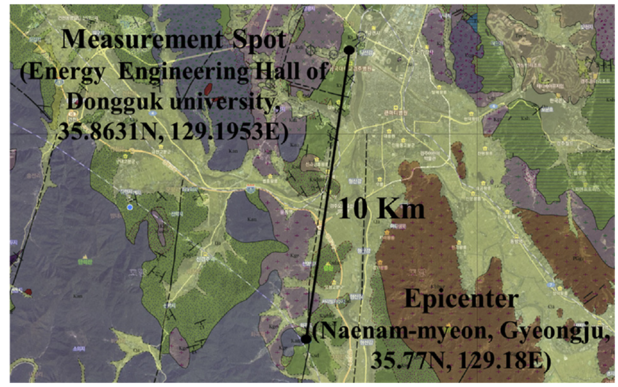

Fig. 2. Locations of epicenter and measurement spot.

3. Results

3.1. Measurement results

Fig. 3 and Table 2 show monthly averages of the indoor radon concentration measurements from February 2016 to January 2017, except for September 2016, during which month the measurements were not made because of maintenance of the RAD7.

As shown in Fig. 3, the annual average was 13.4 ± 15.5 Bq/m^3. The indoor radon concentration in August 2016 was much higher than other months' concentrations and the seasonal average for summer, 12.6 ± 22.3 Bq/m^3. The measurement dates for August were about one month earlier than those for September, when the 5.1 and 5.8 magnitude earthquakes occurred. Unfortunately, we could not measure the indoor radon concentrations during September 2016

Table 1
Statistics for 2.0 magnitude or greater earthquakes that occurred in Gyeongju over the period of 12 September 2016 to 23 January 2017.

Month	Seismic magnitude			
	2.0–3.0	3.0–4.0	4.0–5.0	≥5.0
2016.09	120	15	1	2
2016.10	13	2	0	0
2016.11	7	0	0	0
2016.12	7	2	0	0
2017.01	2	1	0	0
Sum	149	20	1	2

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