# Measurement and Analysis of Radon Exhalation Rates from Soil and Concrete Samples With Two-Layer Structure

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## 1. Introduction

Rn-222 is an inert gas with a half-life of 3.8 days, belonging to the decay series of U-238 found in the Eerth's crust. It is generated from natural sources or building materials and infiltrates the atmosphere or indoor environments through the pores of the medium. The exhalation rate varies depending on the content of U-238 or Ra-226, the characteristics of the medium, and external conditions.

Especially, with the high usage of concrete in modern construction and the increased time spent indoors, there is a growing need for attention to radon concentration reduction in indoor environments. Accurate measurement and evaluation of radon concentration and exhalation rate are essential.

In this study, the exhalation rates from soil, concrete, and a two-layer structure will be compared and analyzed using natural soil samples and concrete samples self-made.

## 2. Methods and Results

### *2.1 Diffusion Model*

The diffusion equation for radon generation in porous materials follows Fick's Law. Under the assumption of steady-state conditions, the exhalation rate at the surface(x=0) is given by the following equation.[1]

(1) $D_e \frac{d^2C(x)}{dx^2} - \lambda C(x) + \lambda C_{Ra}\rho f = 0$

(2) $C(x) = C_{max}(1 - e^{-\frac{1}{L}x})$

(3) $E = \tanh\left(\frac{d}{L}\right)\sqrt{D_e\lambda}C_{Ra}\rho f$

Where $D_e$ is the effective diffusion coefficient $(m^2/s)$, $C(x)$ is the radon concentration $(Bq/m^3)$, $\lambda$ is the radon decay constant $(s^{-1})$, $C_{Ra}$ is the radium concentration $(Bq/kg)$, $\rho$ is the density of the sample $(kg/m^3)$, $f$ is the emanation coefficient, $C_{max}$ is the saturation radon concentration $(Bq/m^3)$, $L$ is the diffusion length $(m)$.

In the exhalation rate from Eq. (3), when the sample thickness is much smaller than the diffusion length, it can be expressed as follow[2]:

(4) $\tanh\left(\frac{d}{L}\right) = \frac{d}{L}$

(5) $E = \lambda C_{Ra}\rho f d$

### *2.2 Sample*

The samples used in the experiment were soil samples and concrete samples that were self-made. The soil samples were collected from a construction site within Kyungpook National University. To avoid external environmental influences, the soil was extracted from a depth of 30 cm below the ground surface. The collected soil was sieved through a 2 mm mesh to ensure uniform particle size distribution and then dried in an electric oven at 110℃ for 24 hours. After that, the soil was placed in polycarbonate cases with a width of 18 cm and a length of 20 cm, and heights of 5, 10, 15 and 20 cm respectively.

According to the Ministry of Land, Infrastructure, and Transport (MOLIT)[3], The mixing ratios of aggregates, cement, and the water-to-cement ratio must be adjusted to meet the design strength of concrete. Additionally, the required quantities may vary depending on the scale of the structure and the materials other than concrete, making it difficult to satisfy the conditions of concrete typically used in laboratory settings. Therefore, the criteria for "small amounts of concrete or structurally non-critical concrete" as specified in the 2010 Construction Work Standard Unit Price[4] published by the Korea Institute of Civil Engineering and Building Technology were referenced. As a result, the concrete mix was prepared with a cement : sand : aggregate ratio of 1 : 2.39 : 2.08 and a water-to-cement(w/c) ratio of 60%. After mixing, the concrete was placed in polycarbonate cases with a width of 18 cm and a length of 20 cm, and heights of 5, 10, 15 and 20 cm respectively. The samples were cured for two months.

### *2.3 Measurement System*

First, the Dust filter, Drying Unit and Inlet filter are connected to the chamber, followed by the connection of the RAD7. Each connection point is sealed with Parafilm to prevent radon gas leakage and air purging is performed to remove any residual radon in the closed circuit. The sample to be measured is placed inside the chamber and the radon concentration is measured over time using the RAD7.

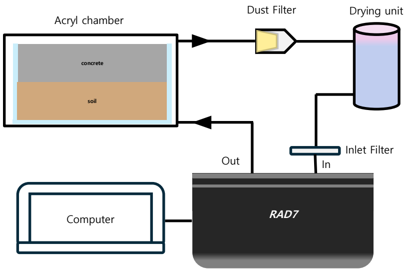


Fig 1. Schematic of the Radon measurement system, illustrating the measurement of the two-layer system of soil and concrete.

### *2.4 Results*

The radon exhalation rate measurement was conducted based on the initial 12 hours of measurement, as the leakage in the closed circuit and the back diffusion effects tend to increase over time. Figure 2. below shows the graph of the measured data with a linear fit and the radon exhalation rates for each sample are detailed in table 1.

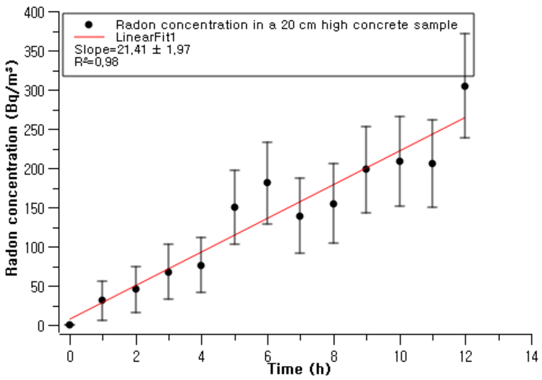


Fig 2. Radon concentration in a 20 cm high concrete sample, with a linear fitting graph of the 12-hour measurement data.

Table. 1: Radon exhalation rate measurement results

| Sample | Thickness (cm) | Exhalation rate $(Bq/m^2h)$ |
|---|---|---|
| Soil | 5 | $2.99 \pm 0.41$ |
| | 10 | $5.84 \pm 0.84$ |
| | 15 | $7.02 \pm 1.32$ |
| | 20 | $10.5 \pm 1.26$ |
| Concrete | 5 | $7.22 \pm 1.04$ |
| | 10 | $9.85 \pm 1.25$ |
| | 15 | $17.19 \pm 1.33$ |
| | 20 | $21.41 \pm 1.97$ |
| Concrete over Soil (Soil+Concrete) | 5 + 5 | $7.37 \pm 1.53$ |
| | 5 + 10 | $16.24 \pm 1.1$ |
| | 5 + 15 | $18.14 \pm 1.11$ |
| | 10 + 5 | $13.63 \pm 1.91$ |
| | 10 + 10 | $16.98 \pm 1.24$ |

The comparison and evaluation of the exhalation rates were performed at the same thickness. According to the results in Table. 1, the exhalation rates for each sample were highest for concrete, followed by concrete over soil, and lowest for soil, across all thicknesses of 10 cm, 15 cm, and 20 cm. this indicates that the radium content in concrete is higher than in soil, leading to a higher radon exhalation rate. Additionally, for the two-layer structure, the exhalation rate was higher when the proportion of concrete was greater, regardless of whether the soil thickness was 5 cm or 10 cm.

## 3. Conclusions

Radon diffusion at the interface between two different media, soil and concrete, was evaluated by measuring radon levels in soil samples, concrete samples, and a two-layer structure. For comparison of the exhalation rate, samples of identical thickness were used. The results showed that the exhalation rate was highest for concrete and lowest for soil, suggesting that the radium content in concrete is higher than in soil. Therefore, In the two-layer structure, whether the soil thickness was 5 cm or 10 cm, the exhalation rate was higher when the proportion of concrete was greater.

Future research will involve measuring the radon concentration until it reaches saturation for each sample. The exhalation rate will then be calculated more accurately using the Slope Correction Factor(SCF) from a 24-hour linear fitting graph, and the correlation between radon potential and saturation concentration will be evaluated.

## REFERENCES

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