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Radon Gas Estimation from Building Materials

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Abstract

Radon gas originating from building materials is generally thought to cause low concentration. Investigation and estimation of radon levels originating from building materials are important in terms of public health due to the use of dense concrete in tunnel form type houses, which is a building type widely used in Turkey, even though a significant part of Turkey is an earthquake zone. In this article, the effects of different parameters such as ^{238}U concentration in building materials, diffusion constant of building elements, emanation rate, and ventilation rate on radon gas concentration are investigated. As a result, it is concluded that in some cases (such as high diffusion coefficient and insufficient ventilation rate) in houses built with tunnel form concrete structures, the radon level arising from building materials can reach a level that cannot be neglected.

Keywords: Radon, emanation rate, diffusion coefficient, exhalation rate, concrete

1. INTRODUCTION

Approximately 85% of the radiation that people are exposed to is of natural origin and 15% is artificial. Approximately 50% to 60% of this natural radiation exposure is due to radon gas [1-2]. Radon gas is the radioactive gas resulting from the decay of the ^{238}U isotope. The half-life of radon gas (^{222}Rn) is 3.8235 days [3]. It is a colorless, odorless, tasteless gas that we cannot detect with our senses [4].

Radon gas causes very serious problems for human health. There is strong evidence that lung cancer can occur as a result of exposure to radon and radon decay products in indoor environments, and that it is the second most important cause of cancer after smoking, according to a report published by the International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO) [5-6]. The International Commission on Radiological Protection (ICRP) specified the maximum amount of radon gas that should be present in the indoor environment as 200-300 (Bq m^{-3}) in 2007, while the Turkish Atomic Energy Authority (TAEK) accepted 400 (Bq m^{-3}) as the limit value. In Sweden, the limit value is 200 (Bq m^{-3}) [7]. The United States Environmental Protection Agency (EPA) specified that the amount of radon generated should be below 148 (Bq m^{-3}). It also states that radon levels below this value still pose a risk [8]. The World Health Organization (WHO) recommends a limit level of 100 (Bq m^{-3}) to

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minimize the health hazards caused by radon gas indoors [6].

In 1984, TAEK (Turkish Atomic Energy Authority) started a study to determine radon levels in homes, and as a result of this study (completed in 2004), the average radon level was found to be around 35±12 (Bq m^{-3}) [4]. When the radon activity concentration is compared with the results of the literature reviews, it has been shown that the average radon level of Turkey is 81 (Bq m^{-3}) [9].

When the literature reviews on radon measurements in homes are examined [9-12], it is stated that the ground floors are at risk in general. The reason for this is the high amount of radon gas leaking from the soil to the houses.
However, radon gas is found not only in soil but also in building materials. Studies have shown that there are uranium and thorium isotopes in different building materials such as sand, cement, or brick [13]. However, in the literature reviews, it is stated that the radon concentration originating from the building materials is low in the apartments on the upper floors of the buildings. In this article, in order to test this general opinion, radon gas originating from building materials will be estimated in buildings made with building materials with different radiation levels and properties.

1.1. Radon in Soil and Rocks

Uranium and thorium elements, which are a part of the earth's make-up, are abundant in soil and rocks. Thorium and radium appear during the radioactive decay series of ^{238}U, which is in the soil. Radium diffuses into the upper layers of the soil. ^{226}Ra isotope, which has a half-life of 1600 years, decays continuously in the soil. As a result of this decay, radon atoms are formed, allowing radon to be found freely in the soil [14]. The radon concentration in the soil depends on the radioactivity mass concentration of the radium in the soil, its diffusivity, and the type of soil [15].

1.2. Effect of Radon on Human Health

Radon forms radioactive aerosols by clinging to dust and water droplets in the air. These dust and water droplets are retained by the lungs through respiration. The energy released during the decay of these radioactive particles trapped by the lungs damages the lung tissue. As a result of this damage, it causes cancer [14].

According to the National Radiological Protection Board (NRPB), at least 2500 of the 41,000 lung cancers in the UK annually are attributable to radon. The International Commission on Radiological Protection (ICRP) attributes 10% of total lung cancers to radon [16].

2. MATERIALS AND METHODS

2.1. Sample Room Model

There are many different types of buildings around the world. The tunnel form method is a steel formwork system that allows the load-bearing wall and slabs to be poured at once. When the formwork is removed, the upper concrete slab forms, while the side concretes form reinforced concrete shear walls.

The sample room model shown in Figure 1 was used to investigate the radon concentration from construction materials. It is assumed that all the walls of the room are laid with concrete 10 cm thick. Our sample room is 3x3x2.8 m in size and has a floor area of 9 m^2 and a volume of 25.2 m^3. Calculations were made when the room had a window and a door and no objects in it. In an average house, about 10% of the volume of the room is occupied by furniture. It should be taken into account that this situation will increase the radon concentration at the same rate.

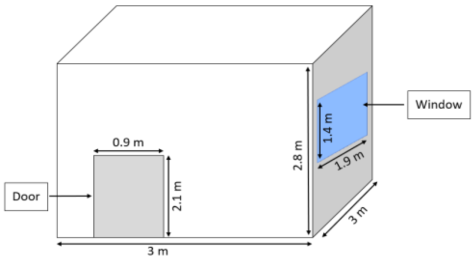

Figure 1 Sample room model made with tunnel form

2.2. Theoretical Framework

2.2.1. Emanation rate

Not all of the radium atoms in porous materials can escape into the space around the pores. Emanation Rate is the rate at which the radium atoms in the material escape into the space of the pores of the material.

The fraction of emanation, f, is equal to the ratio of the rate of emanation and the production rate of Radon. The fraction of emanation is shown in equation (1).

$$f = \frac{E}{A_{Ra}} \quad (1)$$

Where E is the rate of radon production inside the sample and A_{Ra} (Bq kg^{-1}) is the radium activity. The highest fraction of emanation from the soil is 20% [17].

As a result of the studies for concrete, the fraction of emanation produces different results between 0.07 and 0.14. These studies show that the fraction of emanation average value is 0.11 ± 0.02 [18].

2.2.2. Exhalation rate

Exhalation Rate is defined as the number of radon atoms escaping from the sample towards the medium per unit of time.

Radon is transported from the wall into the room by diffusion. Diffusion is the most basic mechanism described by Fick's law. Simplifying the definition in the first theory of Fick's law, it can be considered a one-dimensional equation. The one-dimensional form of the first theory of Fick's law is given in equation (2).

$$J = -D\frac{\partial C}{\partial Z} \quad (2)$$

Where J is the radon flux (Bq m^{-2} s^{-1}), D is the radon diffusion coefficient (m^{2} s^{-1}), $\partial C/\partial Z$ is the concentration gradient (Bq m^{-3}) [19].

The radon diffusion in the material varies depending on factors such as the porosity of the material found and the particle size. It is stated that the diffusion constant of concrete is between 10^{-10} (m^{2} s^{-1}) and 10^{-6} (m^{2} s^{-1}) [17].

If equation (2) is solved, the exhalation rate can be calculated by equation (3) below.

$$E = \frac{2 \cdot C_{SC} \cdot l \cdot \lambda}{e^{d/l} - e^{(-d/l)}} \quad (3)$$

Where E is the exhalation rate (Bq m^{-2} h^{-1}), C_{SC} is the average concentration in the wall (Bq m^{-3}), l is the radon diffusion length (m), and d (m) is the thickness of the wall.

The radon diffusion length is given in equation (4).

$$l = (D/\lambda_{Rn})^{1/2} \quad (4)$$

Where l is the radon diffusion length (m), D is the radon diffusion coefficient (m^{2} s^{-1}), λ_{Rn} is the radon decay constant ($2.11 \cdot 10^{-6}$ s^{-1}) [20].

2.2.3. Radon concentration

When t→∞, the radon concentration in the room is shown in equation (5) [21].

$$C_{\infty} = \frac{\sum_{i=1}^{6} E_i \cdot A_i}{(\lambda_{Rn} + \lambda_v) V_{room}} \quad (5)$$

Where C_{∞} is the radon concentration in the room (Bq m^{-3}), i = 1, 2, 3, 4, 5, 6 are surfaces in the room, E_i is the exhalation rate, A_i is the surface area (m^{2}), λ_{Rn} is the radon decay constant (h^{-1}), λ_v is the ventilation rate (h^{-1}).

In the absence of t→∞, the radon concentration at different time intervals is shown by equation (6) [17].

$$C(t) = C_{\infty}(1 - e^{-(\lambda_{Rn}+\lambda_v)t}) \quad (6)$$

3. RESULT AND CONCLUSIONS

The given equations show that the radon gas that will accumulate in the room varies depending on factors such as the diffusion coefficient, the radium concentration in the wall concrete, the emanation rate, the wall thickness, the ventilation rate, the volume, and the surface area. According to the different values of these variables, the radon concentration accumulated in the sample room model was calculated. In all calculations, it has been assumed that the radon concentration in the room is zero and the only contribution to the radon concentration that will accumulate in the room comes from the building materials.

As a result of the calculations, it was seen that the changes in the ACH (air changes per hour) value greatly affect the radon concentration that will occur in the environment. Table 1 shows how the radon concentration that will occur in the environment changes under different concentration values of ACH by keeping the diffusion coefficient 10^{-8} (m^2 s^{-1}) and the fraction of emanation 0.11.

Table 1 Radon concentration resulting from the change of ACH values

C_{Ra} (Bq/kg)	ACH (h^{-1})				
	0.1	0.2	0.3	0.4	0.5
10	14	9	7	6	5
50	61	33	23	18	15
100	120	63	44	33	27
150	179	94	64	49	40

For figure 2, the diffusion constant 10^{-8} (m^2 s^{-1}), and the fraction of emanation 0.11 are kept constant. With this constant value, it is shown how the ACH value changes with time by taking 0, 0.1, 0.2, 0.3, 0.4 and 0.5 respectively.

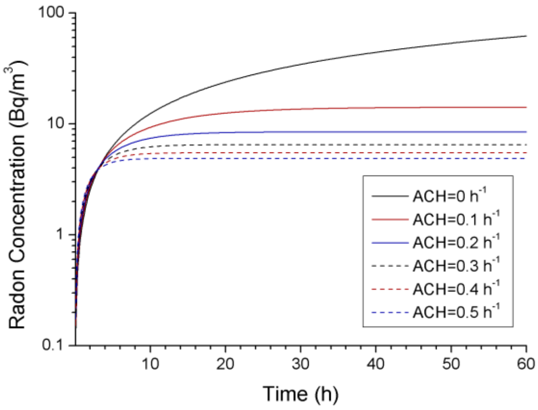

Figure 2 Variation of the effect of different ACH values on radon concentration with time

As seen in Figure 2, the radon concentration reaches its maximum level in a very short time (approximately 10 h).

While keeping diffusion coefficient at 10^{-8} (m^2 s^{-1}) and ACH = 0.1 (h^{-1}) rates constant, according to different radium concentration values (10, 20, 30, 40, 50, 75, 100, 125, 150 (Bq kg^{-1}), radon concentrations to accumulate in the room were calculated. As a result of these calculations, radon concentrations were found as, in order, 14.18, 25.18, 37.75, 49.53, 61.31, 90.77, 120.23, 149.68 and 179.14 (Bq m^{-3}).

As mentioned in the fraction of emanation section, the fraction of emanation rate in concrete varies between 0.07 and 0.14 [18]. While keeping the diffusion coefficient constant at 10^{-8} (m^2 s^{-1}), radium concentration 50 (Bq kg^{-1}), and ACH = 0.1 (h^{-1}), according to different fractions of emanation 0.07, 0.08, 0.09, 0.10, 0.11, 0.12, 0.13, 0.14 radon concentrations to accumulate in the room were calculated. As a result of these calculations, radon concentrations were found as 39.89, 45.25, 50.60, 55.96, 61.31, 66.67, 72.03, and 77.38 (Bq m^{-3}).

In order to calculate the minimum radon concentration to accumulate in our room model, when we take the diffusion coefficient as 10^{-9} (m^2 s^{-1}), ACH 0.5 (h^{-1}), fraction of emanation 0.07, and radium concentration 10 (Bq kg^{-1}), the radon concentration was found to be 2.55 (Bq m^{-3}). Similarly, in order to calculate the maximum radon concentration to accumulate in our room model, when we take the diffusion coefficient as 10^{-8} (m^2 s^{-1}), ACH 0.1 (h^{-1}), fraction of emanation 0.14, and radium concentration 150 (Bq kg^{-1}), the radon concentration was found to be 227.34 (Bq m^{-3}).

The radon concentration accumulated in the room varies depending on the diffusion coefficient, ventilation rate, fraction of emanation, and the radium (^{238}U) concentration in the concrete. It has been observed that in some cases, it can contribute to the accumulation of radon gas in houses built with the tunnel form, where the use of concrete is high. It has been observed that radon concentrations above 100 Bq, which is specified as the upper limit by WHO, may occur in the total radon concentration in the room, especially in cases where the ventilation rate is low. In order to minimize this situation, it is important to investigate building materials such as sand, cement, and concrete to be used during the construction of the building, to determine their concentration values and to predict the amount of radon that will contribute to the environment.

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Authors' Contribution
The authors contributed equally to the study.

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The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics
The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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