Evaluation of indoor radon concentration and dose as a function of wall thickness

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1. Introduction

Radon(^{222}Rn) is an alpha emitting nuclide with a half-life 3.8days and belongs to the ^{238}U decay series that exist in the earth crust. Radon is an inert gas released into the atmosphere through pores in soil or building materials, so that it and its progeny are inhaled into the human body by breathing and contribute to internal exposure. UNSCEAR Report (2000) found that in the case of and indoor space, the radiation source shows a geometric distribution surrounding the space, so the effect is greater than that of an outdoor. According to the Korea Land and Housing Corporation's housing design guidelines, the thickness of the floor and ceiling should be at least 20 *cm* and the thickness of the walls should be within the range of 15-30 *cm*, depending on the structure and load conditions. The most commonly used concrete wall thickness is 20 *cm*, and the density is 2.35 $g\ cm^{-3}$.[1] However, it does not include information on building radon levels and recommended limits for thickness. In this study, the radon exhalation rate was calculated which varies with wall thickness using the previously studied data, and also the radon concentration and exposure dose in the indoor space were evaluated.

2. Methods and Results

2.1 Radon Exhalation Model

While the radon exhalation rate model at the soil surface assumes an infinite depth, the radon exhalation rate from building materials has a finite thickness, so two cases of 1-side or 2-side emission can be considered. For estimating the radon level of indoor space, Model A can be regarded as a case when radon emission to the exterior wall is blocked by other shielding materials, and Model B is a case of general residential space. (Fig. 1.)

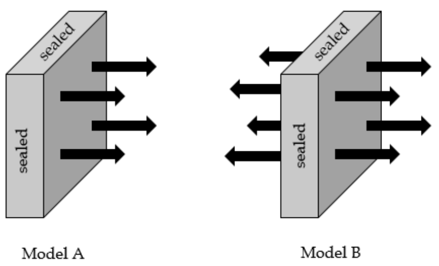

Fig. 1. Exhalation of Radon by 1-side (Model A) and 2-side (Model B)

Model A is a building material with one side exposed and the remaining five sides sealed. Model B denotes a building material with two sides exposed and the remaining four sides sealed. By Fick's law of diffusion, in the case of a 1D finite thickness and infinite extension, the radon concentration distribution N(x) ($\#N_{atom}/m^3$) would satisfy equation (1) in steady state. The radon concentration C(x) (Bq/m^3) satisfies by multiplying equation (1) by λ, which is the decay constant of radon.

$$-\lambda N(x) + \lambda_{Ra} N_{Ra} f \rho + D_E \frac{d^2}{dx^2} N(x) = 0 \qquad (1)$$

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

where λ_{Ra} is the decay constant of radium; N_{Ra} is atom number of ^{226}Ra; C_{Ra} is concentration of radium. By solving equation (2), radon exhalation rate is obtained.

$$\text{Model A: } E_A = D_E \frac{dC(x)}{dx}\bigg|_{x=0} = E_0 \tanh\left(\sqrt{\frac{\lambda}{D_E}}\, d\right) \qquad (3)$$

$$\text{Model B: } E_B = E_0 \tanh\left(\frac{1}{2}\sqrt{\frac{\lambda}{D_E}}\, d\right) \qquad (4)$$

E_A, E_B is radon exhalation rate for model A, B; D_E is effective diffusion coefficient; E_0 is intrinsic radon exhalation rate, i.e. the value of E when $d \to \infty$; d is the thickness of building material.[2]

2.2 Indoor Radon Concentration Model

When the radon exhalation rate on the surface by the thickness of the building material is determined, the indoor radon concentration can be estimated by the following equation.[3]

$$C_{Rn} = \left[\sum_{i=1}^{n} w_{si} E_{si}\right] \frac{S}{V \lambda_v} \qquad (5)$$

where E_{si} is the measured surface exhalation rate of the building material, w_{si} is the surface fractional usage of the building material, *S/V* is the surface to volume ratio of the room and λ_V is the annual average room ventilation rate.

Assuming a homogeneous rectangular parallelepiped interior, equation (5) can be expressed by using the total area of the wall surface.

$$C_{Rn} = \frac{E_A A}{V \lambda_V} \qquad (6)$$

where E_A is the radon exhalation rate, A is the area of the wall surface. The value of λ_V is 0.63 h^{-1} as the geometric mean of commonly existing ventilation rates range.[4]

2.3 Dose Calculation Model

Internal exposure to radon or thoron may be estimated as

$$H_i = C_i \times F_i \times O \times DCF_i, \;\; i = (R_n, T_n) \qquad (7)$$

where *Ci* is the radon (thoron) concentration (*Bq* m^{-3}),Fi is the radon (thoron) equilibrium factor (0.4 for radon, 0.1 for thoron), DCF_i is the dose conversion factor (9 *nSv* Bq^{-1} *EEC h* m^3 for radon, 40 *nSv* Bq^{-1} *EEC h* m^{-3} for thoron), *O* is the occupancy factor expressed as the number of hours which the inhabitant spends in the building in one year, in further calculations taken to be 6570 *h* $year^{-1}$ (75%).[4]

2.4 Literature Data and calculated parameters

For the concrete sample with a wall thickness of 24 *cm*, the diffusion length of 87 *cm* and E_0 of 14.90 *mBq* m^{-2} s^{-1}, the radon exhalation rate was measured as 2.08 *mBq.*$m^{-2}s^{-1}$ based on Model B.[2] Radon decay constant is calculated as $\lambda = 2.094 \times 10^{-6}\ s^{-1}$, effective diffusion coefficient as $D_E = 1.578 \times 10^{-6}\ m^2\ s^{-1}$.

2.5 Results

The indoor residential space was calculated assuming $4 \times 3 \times 2.8\ m^3$, which is the size of a bedroom in an apartment designed as a national housing by Korea National Housing Corporation.[5] (Fig. 2.)

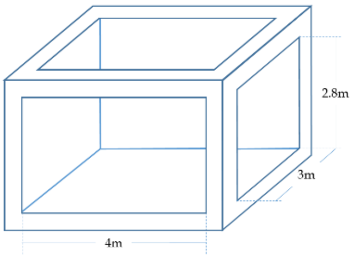

Fig. 2. Diagram of virtual indoor space of bedroom in South Korea

Fig. 3 shows the distribution of radon exhalation rates in the range of wall thickness from 0 *m* to 10 *m*.

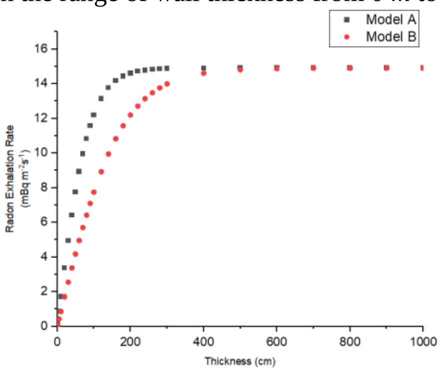

Fig. 3. Radon exhalation rate from 0 *m* to 10 *m*

Radon concentration and effective dose were also confirmed to have similar distributions. Radon exhalation rate, indoor radon concentration, and effective dose *H* were estimated per unit *cm* in the range of 15 *cm* to 30 *cm* for the thickness of the concrete wall according to the architectural design guidelines for the housing sector. (Table I)

Table I: Radon Exhalation Rate, Radon Concentration and Effective Dose from 15cm to 30cm

Thickness (cm)	Radon Exhalation Rate ($mBq\ m^{-2}\ s^{-1}$)		Radon Concentration ($Bq\ m^{-3}$)		H (effective dose) ($mSv\ y^{-1}$)	
	Model A	Model B	Model A	Model B	Model A	Model B
15	2.549	1.284	27.40	13.80	0.648	0.326
16	2.716	1.369	29.19	14.72	0.690	0.348
17	2.881	1.454	30.97	15.63	0.732	0.370
18	3.046	1.539	32.74	16.54	0.774	0.391
19	3.210	1.624	34.50	17.46	0.816	0.413
20	3.373	1.709	36.26	18.37	0.858	0.434
21	3.536	1.793	38.00	19.28	0.899	0.456
22	3.697	1.878	39.74	20.19	0.940	0.477
23	3.858	1.962	41.47	21.09	0.981	0.499
24	4.018	2.047	43.18	22.00	1.021	0.520
25	4.176	2.131	44.89	22.90	1.062	0.542
26	4.334	2.215	46.58	23.81	1.102	0.563
27	4.490	2.299	48.26	24.71	1.142	0.584
28	4.646	2.382	49.94	25.61	1.181	0.606
29	4.800	2.466	51.60	26.50	1.220	0.627
30	4.954	2.549	53.24	27.40	1.259	0.648

3. Conclusions

As a result of the estimation, the radon exhalation rate, indoor radon concentration, and annual effective dose showed a huge increase in the range of 0-200 *cm* as the wall thickness increased. Among the indoor radon concentrations by thickness derived from this study, in the case of a 30 *cm* wall (i.e. highest standard of wall by Korea Land and Housing Corporation), it was 27.401 *Bq* m^{-3} for Model B, which was lower than the domestic average indoor radon level of 50 Bqm^{-3} in South Korea. Radon levels and dose values in actual buildings will vary depending on wall finishing materials, changes in ventilation rate, temperature, humidity, etc, and also expected that there will be a difference in the radon exhalation rate of the inner and outer walls of the building. In future studies, we plan to perform accurate re-verification of this study using concrete samples produced by ourselves.

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