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Natural radioactivity in building materials and activity concentration index I

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1. Introduction

To protect the public from natural radioactive materials, the "Act on safety control of radioactive rays around living environment" (2011.07.25) was established in Korea, focusing on natural resources, byproducts, products, and cosmic rays. Among them, building materials as products can be an important issue, because they are the most significant source of indoor gamma ray exposure for the population. There is an annual effective dose limit of 1mSv for products including building materials, but the activity concentration limit for products is necessary as a screening tool in the production procedure.

2. Methods and Results

As mentioned above, an activity concentration limit such as activity concentration index I [1], was introduced in the EU, is necessary. In this research, we evaluate the specific effective dose rates by building materials with the MCNPX code and suggest the activity concentration index as the following formula.

$$I = \frac{C_U}{A_U} + \frac{C_{Th}}{A_{Th}} + \frac{C_K}{A_K}$$

where, C_U, C_{Th} and C_K are the activity concentration of ^{238}U series, ^{232}Th series and ^{40}K in building materials (Bq/kg), respectively, and A_U, A_{Th} and A_K are activity concentration limit of the ^{238}U series, ^{232}Th series and ^{40}K (Bq/kg).

When indexes I for the building materials are less than 1, the annual dose limit of 1mSv is satisfied.

2.1 Monte Carlo Simulation

Using the Monte Carlo code, we evaluated the specific dose rate for the radionuclides, ^{238}U series, ^{232}Th series, and ^{40}K for concrete as typical building materials. First, as the standard living premises, a room with inner dimensions of 4 m x 5 m x 2.8 m has been assumed [2]. The density and thickness of the concrete were assumed to be 2.35g/cm^3 and 20cm. Photon transport in walls and in air inside a room is simulated by MCNPX code. The modeled radioactive sources are assumed to be uniformly distributed in walls, ceiling and floor, and to emit isotropic photons only. Both ^{238}U and ^{232}Th series are assumed to be in secular equilibrium. The photon energy and emission probability are shown in Table 1.

Table 1: Averaged gamma energies and emission probabilities for radionuclides

Nuclide	Averaged values used in simulation	
	Energy(keV)	Emission probability
^{238}U	810	2.12
^{232}Th	587 2615	2.05 0.356
^{40}K	1461	0.107

The F4 tally was set up to evaluate the absorbed dose in the middle of a room. In the case of the F4 tally, the DE/DF function is employed to convert the flux into the effective dose. Mustonen[3] shows that the dose rate in the middle of the room is a good approximation for the average dose rate in the room. The simulation results are as follows.

Table 2: Specific dose rate for the radionuclides by Monte Carlo simulation

Nuclide	Specific dose rate (nGy/h per Bq/kg)
^{238}U	0.773
^{232}Th	0.928
^{40}K	0.0698

The values of the absorbed dose rate in air per unit of mass concentration of the source radionuclides obtained in this work and parameters adopted in the simulation as those found in other literature are compared. The values for the ^{238}U series, ^{232}Th series and ^{40}K show 0.69 − 1.06, 0.87− 1.21 and 0.067− 0.111 in other literature [4], and the values obtained in present work can be considered as acceptable.

2.2 Derivation of Activity Concentration Index I

The safety requirements for building materials are defined as the excess exposure caused by these materials except exposure caused by the background. The following relation provides the activity concentration index.

$$10^{-3} Sv / year = (SDR_x \times A_x - BKG) \times CF \times AOT$$

where, SDR_x=Specific dose rate for the radionuclide x (nGy/h per Bq/kg)

A_x=activity concentration limit of nuclide x (Bq/kg)

BKG=background dose rate (nGy/h)
CF=conversion factor (Sv/Gy)
AOT=average occupancy time at home (h/year)

The mean terrestrial dose rate outdoors in Korea is 79nGy/h [5]. In the case of the conversion factor, we used 0.74, 0.72 and 0.69Sv/Gy for ^{40}K, ^{232}Th series, and ^{238}U series, given in the UNSCEAR 1993 report [6]. An average occupancy time of 7000h/year is assumed. As a result, the A_x values are as follows.

Table 3: A_x values of index I

Nuclide	A_x (Bq/kg)
^{238}U	370
^{232}Th	299
^{40}K	3898

Finally, the activity concentration index I is shown in the following formula.

$$I = \frac{C_u}{370} + \frac{C_{Th}}{299} + \frac{C_K}{3898}$$

2.3 Analysis of room model

In the same manner, we evaluate the activity concentration index considering the effect of changing the dimension of the room. As smaller and larger rooms than standard, 3m x 4m x 2.8m and 5m x 6m x 2.8m rooms are assumed, and the results are as follows.

$$I = \frac{C_u}{362} + \frac{C_{Th}}{293} + \frac{C_K}{3798} \quad \text{(Smaller room)}$$

$$I = \frac{C_u}{331} + \frac{C_{Th}}{268} + \frac{C_K}{3487} \quad \text{(Lager room)}$$

The result shows that the activity concentration limit variation by the dimension of the room is small.

3. Conclusions

In the present research, we simulate the specific dose rate induced by the ^{238}U series, ^{232}Th series, and ^{40}K contained in concrete to derive the activity concentration index. This index can control the radionuclide concentration of the building materials by informing the activity concentration limit. Because the density, thickness, and chemical composition are different for building materials such as bricks, tile, and gypsum board, the index for each building material considering the differences will be induced in the future.

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