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Derivation of the Flexible Radioactivity Index for Building Materials Considering Density and Thickness

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1. Introduction

In Korea, to protect the public from natural radioactive material, it has established the "Act on protective action guidelines against radiation in the natural environment", focusing on raw materials, residues, products and cosmic rays.[1] In the regulations, there is an annual effective dose limit of 1mSv for building materials containing naturally occurring radioactive materials (NORM), but the activity concentration limit is not established yet. The activity concentration limit for building materials studied in the last 5 years [2] and the related notifications will be made in the form of radioactivity index. These radioactivity indexes can be used to screen the products of building materials. In this study, we derived the radioactivity index for field to apply to the existing building.

2. Methods and Results

To apply to the existing building, it is necessary to derive the flexible activity concentration limits considering the characteristics of field measurements such as density and thickness of building materials.[3]

2.1 MCNP Simulation

Using the Monte Carlo code MCNPX, we evaluated the specific effective dose rate for ICRP reference phantom in a room model by the radionuclides ^{226}Ra series, ^{232}Th series and ^{40}K. A room with dimensions of 4m × 5m × 2.8m has been assumed and the photon energy and emission probability are shown in Table I.

Table I: Averaged gamma energies and emission probabilities used in simulation

Radionuclide	Energy(keV)	Emission Probability
Ra^{226}	845	1.98
Th^{232}	894	2.61
K^{40}	1461	0.106

2.2 Density Variation

To find the combinations of density (ρ) and thickness (d), we calculated the specific effective dose rate according to the density variation when the thickness of building materials is 20 cm. The density of the building materials are varied from 100 to 3000 kg m^{-3}. As shown in Fig. 1, the specific effective dose rate for Ra^{226} is varied from 5.3×10^{-11} to 6.0×10^{-10} (Sv h^{-1} per Bq kg^{-1}) when the ρd (kg m^{-2}) is varied from 20 to 600.

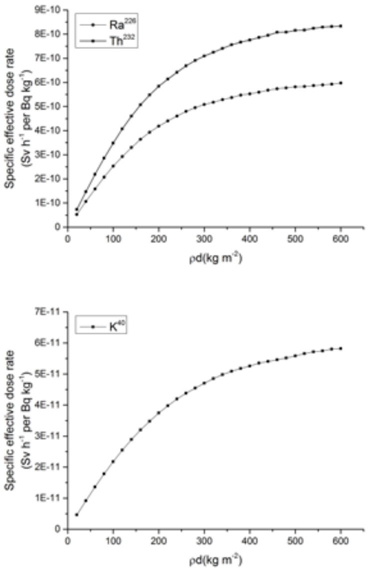

Fig. 1. Specific effective dose rate for Ra^{226}, Th^{232} and K^{40} (ρ : 20~600 kg m^{-3}, d : 20cm)

2.3 Thickness Variation

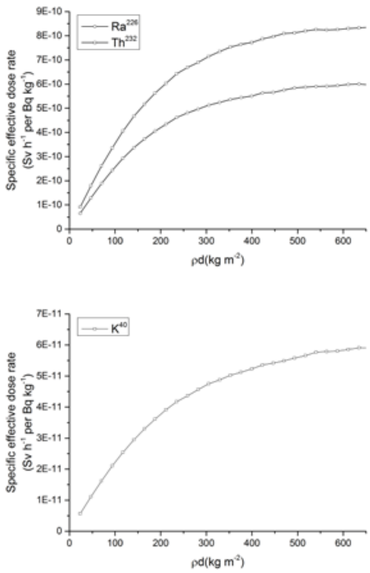

Fig. 2. Specific effective dose rate for Ra^{226}, Th^{232} and K^{40} (ρ : 2350 kg m^{-3}, d : 1~30cm)

In addition to the density variation, we evaluated the specific effective dose rate according to the thickness variation when the density of building materials is 2350 kg m^{-3}. As shown in Fig.2, the specific effective dose rate for Ra^{226} is varied from 6.5×10^{-11} to 6.0×10^{-10} (Sv h^{-1} per Bq kg^{-1}) when the ρd(kg m^{-2}) is varied from 23.5 to 705. The results of the specific effective dose rate by thickness variation are very similar to that by density variation. Therefore, we evaluated the specific effective dose rate according to the ρd variation by thickness variation.

2.4 Derivation of the activity concentration limits

In order to derive the flexible radioactivity index, we calculated the activity concentration limits using the specific effective dose rate by ρd variation. Using the equation (1), the activity concentration limits are derived and shown in Fig.3.

$$0.001\ (\mathrm{Sv\ y^{-1}}) = SDR_x \times A_x \times AOT - BKG \quad (1)$$

where, SDR_x=Specific effective dose rate for the radionuclide x (Sv h^{-1} per Bq kg^{-1})

A_x=activity concentration limit of nuclide x (Bq kg^{-1})

BKG=annual outdoor background dose (Sv)

AOT=average occupancy time at home (h $year^{-1}$)

The annual outdoor background of 79 nGy h^{-1}[4] multiplied by average occupancy time at home (7000 h) and conversion factor (0.7 Sv Gy^{-1}) [5], and the result BKG is 0.387 mSv. The activity concentration limit A_x is derived with the equation form (2) by fitting the curve.

$$A_x = a(1+b(\rho d)^{-1}+c(\rho d)^{-2}) \quad (2)$$

For example, as the fitting result for Ra^{226} shown in Fig. 3, activity concentration limit can be expressed in equation (3).

$$A_{Ra} = 220(1+224(\rho d)^{-1}+2532(\rho d)^{-2}) \quad (3)$$

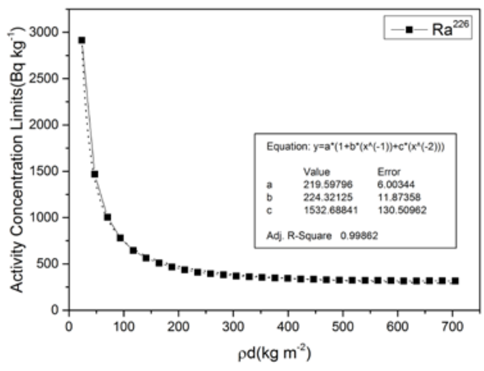

Fig. 3. Activity Concentration limits for Ra^{226}

For same manner, the activity concentration limits for Th^{232} and K^{40} are can be expressed as follows;

$$A_{Th} = 163(1+230(\rho d)^{-1}+1480(\rho d)^{-2}) \quad (4)$$

$$A_K = 2134(1+309(\rho d)^{-1}+1278(\rho d)^{-2}) \quad (5)$$

3. Conclusions

To derive the flexible radioactivity index, we calculated the activity concentration limits for many combinations of density and thickness. As a result, the radioactivity index I(ρd) can be expressed as following equation and used to apply for existing building with a variety of building materials.

$$I = \frac{C_{Ra}(\rho d)^2}{220[(\rho d)^2 + 224(\rho d) + 2532)} + \frac{C_{Th}(\rho d)^2}{163[(\rho d)^2 + 230(\rho d) + 1480)} + \frac{C_K(\rho d)^2}{2134[(\rho d)^2 + 309(\rho d) + 1278)}$$

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