Evaluation of activity concentration limits for building materials using voxel phantom

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1. Introduction

To protect the public from natural radioactive materials, it is necessary to consider the building materials because of natural radioactivity and quantity. There is an annual effective dose limit of 1mSv for products, but an activity concentration limit is necessary for the product screening.

2. Methods and Results

In this research, we derived the activity concentration limit using a room model and ICRP reference adult phantom. In addition, we compared the results with the value using the reference Korean phantom.

2.1 Room Model

As the standard living premises, a room with dimensions of 4m x 5m x 2.8m has been assumed. The density and thickness of the concrete as typical building materials were assumed to be 2.35g/cm^3 and 20cm. Photon transport in walls and in air inside a room is simulated using a MCNPX code. The modeled radioactive sources are assumed to be secular equilibrium. The photon energy and emission probability are shown in Table 1. The gamma energy represents the average gamma energy calculated by using the emission probability as a weighting factor. The emission probability for gamma energy is the sum of the emission probabilities.

Table1. Averaged gamma energies and emission probabilities used in simulation

Radionuclide	Energy(keV)	Emission Probability
^{226}Ra[1]	845	1.98
^{232}Th[2]	894	2.61
^{40}K	1461	0.106

[1]Calculated from ^{214}Pb and ^{214}Bi gamma energy [1]
[2]Calculated from ^{228}Ac, ^{224}Ra, ^{212}Bi, ^{212}Pb and ^{208}Tl gamma energy [1]

2.2 Activity Concentration Limits

Using the Monte Carlo code MCNPX, we evaluated the absorbed dose rate for the ICRP reference male and female phantoms [2] in a room model as shown in figure1. The ICRP reference phantom based on computed tomography images of human bodies is more similar to human anatomy than mathematical phantom.

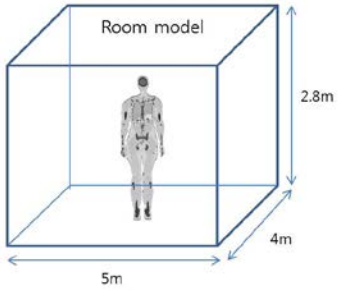

Fig. 1. ICRP reference phantom in a room model

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 limit.

$$1(mSv/year) = (SDR_x \times A_x - BKG) \times AOT$$

where, SDR_x=specific effective dose rate for the radionuclide x (Sv/h per Bq/kg)
A_x=activity concentration limit of nuclide x (Bq/kg)
BKG=background dose rate (Sv/h)
AOT=average occupancy time at home (h/year)

Considering the average occupancy time of 7000h/year and tissue weighting factor, the activity concentration limits for ICRP phantoms are as follows.

Table2. Activity concentration limits for ICRP phantoms

Radionuclide	A_x(Bq/kg) Male	A_x(Bq/kg) Female
^{226}Ra	445	426
^{232}Th	313	306
^{40}K	4541	4490

2.3 Comparison with reference Korean phantom

We evaluated the absorbed dose rate for a reference Korean phantom [3, 4] as well as ICRP reference phantom. In the same manner, the activity concentration limits for the reference Korean phantom are as follows. As the results show, the variations are very small.

Table3. Activity concentration limits for Korean phantoms

Radionuclide	A_x(Bq/kg) Male	A_x(Bq/kg) Female
^{226}Ra	425	418
^{232}Th	303	299
^{40}K	4343	4322

3. Conclusions

We derived the specific effective dose rates by building materials with the MCNPX code and evaluated the activity concentration limits. Using these values, we can suggest the activity concentration index as the following formula. [5]

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

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 the 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. When we suggest the activity concentration index from the derived results in this research, we must consider international harmony as well as social economic cost.

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