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Preliminary Evaluation of the Activity Concentration Limits for Consumer Goods Containing NORM

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ABSTRACT
Background: To protect the public from natural radioactive materials, the 'Act on safety control of radioactive rays around living environment" was established in Korea. There is an annual effective dose limit of 1 mSv for products, but the activity concentration limit for products is not established yet.
Materials and Methods: To suggest the activity concentration limits for consumer goods containing NORM, in this research, we assumed the "small room model" surrounding the ICRP reference phantom to simulate the consumer goods in contact with the human bodies. Using the Monte Carlo code MCNPX, we evaluate the effective dose rate for the ICRP reference phantom in a small room with dimension of phantom size and derived the activity concentration limit for consumer goods.
Results and Discussion: The consumer goods have about 1600, 1200 and 19000 Bq·kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, and the activity concentration limits are about six times comparing with the values of building materials. We applied the index to real samples, though we did not consider radioactivity of ^{40}K, indexes of the some samples are more than 6. However, this index concept using small room model is very conservative, for the consumer goods over than index 6, it is necessary to reevaluate the absorbed dose considering real usage scenario and material characteristics.
Conclusion: In this research, we derived activity concentration limits for consumer goods in contact with bodies and the results can be used as preliminary screening tool for consumer goods as index concept.

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Keywords: Activity concentration limit, Consumer goods, NORM

1. INTRODUCTION

To protect the public from natural radioactive materials, the ‘Act on safety control of radioactive rays around living environment’ (July 25th, 2011) was established in Korea, focusing on natural resources, by-products, products and cosmic rays. Actually, some consumer goods contain naturally occurring radioactive material (NORM). Particularly, in the case of consumer goods to promote health such as anion bracelets, anion necklace and anion mats, etc., some of them can cause problems because of high radioactivity to generate anions. In the regulations, there is an annual effective dose limit of 1 mSv for products, but the activity concentration limit for products is not established yet. Therefore, it is necessary to derive the activity concentration limit for consumer goods. To derive the activity concentration limit, modeling for products considering usage scenario is necessary. For example, in the case of building materials, in order to derive the activity concentration limit as index concept [1], room models to predict the external exposure by gamma radiation from building materials have been developed and used in the last 20 years [2-7]. However, for the consumer goods in contact with or close to human bodies, because they have a variety of shape, size and usage position, it is very difficult to evaluate the exposure dose by each consumer goods and to derive the index as building materials. In this study, we assumed the “small room model” surrounding the International Commission on Radiological Protection (ICRP) reference phantom to simulate the consumer goods in contact with the human bodies and to derive the activity concentration limits.

2. MATERIALS AND METHODS

2.1 Modeling

In order to predict the external exposure by gamma radiation from consumer goods, small room model was assumed based on the ideas of room model to evaluate the building materials. In other words, we reduced from the size of the room model (4 m×5 m×2.8 m) to phantom size considering the mat of queen size (150 cm×200 cm) as shown in Figure 1. Considering the conservativeness, because the mat or bed is the most huge and heavy among the consumer goods in contact with bodies, we assumed the mat of queen size with 1 cm thickness. Finally, the small room was composed of by the mat to surround the phantom properly. The density of mat was assumed 2.35 g·cm^{-3}, therefore, the weight of the small room is about 70 kg. This assumption makes it possible to secure the consistency in regulation comparing with building materials.

2.2 External dose evaluation

Using the Monte Carlo code MCNPX, we evaluated the effective dose rate for the ICRP reference male and female phantoms in a small room model. MCNPX is a general-purpose Monte Carlo code that can be used for gamma transport. The modeled radioactive sources are assumed to be secular equilibrium. The gamma energy showed in Table 1 represents the average gamma energy calculated by using the emission probability as weighting factor. The emission probability for gamma energy is the sum of the emission probabilities. In the uranium series, because the decay chain segment from ^{226}Ra is important in terms of dose evaluation by gamma radiation, it is often

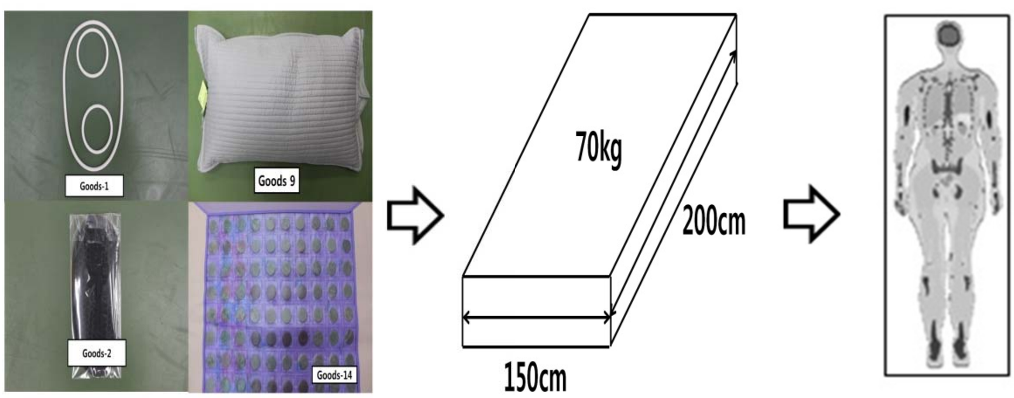

Figure 1. Small room modeling for consumer goods in contact with body.

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Table 1. Averaged Gamma Energies and Emission Probabilities Used in Simulations

Radionuclide	Energy [keV]	Emission Probability
^{238}U(or ^{226}Ra)*	845	1.98
^{232}Th†	894	2.61
^{40}K	1461	0.106

*Calculated from ^{214}Pb and ^{214}Bi gamma energy [8].
†Calculated from ^{228}Ac, ^{224}Ra, ^{212}Bi, ^{212}Pb and ^{208}Tl gamma energy [8].

Table 2. Effective Dose Rate for ICRP Phantom by Small Room Model

Radionuclide	Male [Sv · h^{-1} per Bq · kg^{-1}]	Female [Sv · h^{-1} per Bq · kg^{-1}]
^{238}U(or ^{226}Ra)	6.82×10^{-11}	7.75×10^{-11}
^{232}Th	9.46×10^{-11}	1.07×10^{-10}
^{40}K	6.00×10^{-12}	6.84×10^{-12}

Table 3. Activity Concentration Limits for Consumer Goods in Contact with Body

Radionuclide	Male [Bq·kg^{-1}]	Female [Bq·kg^{-1}]
^{238}U(or ^{226}Ra)	1673	1472
^{232}Th	1207	1063
^{40}K	19034	16700

marked as ^{226}Ra instead of ^{238}U. Considering the tissue weighting factor, the effective dose rates for the each radionuclide are shown in Table 2.

2.3 Activity concentration limits

The safety requirements for consumer goods are defined as the excess exposure cause by these materials. The following relation provides the activity concentration limit.

$$1\,(\mathrm{mSv\cdot year^{-1}}) = (SDR_x \times A_x) \times AUT$$

where, SDR_x is specific effective dose rate for the radionuclide x (Sv·h^{-1} per Bq·kg^{-1}). A_x is activity concentration limit of nuclide x (Bq·kg^{-1}) and *AUT* is average usage time (h·year^{-1}). Considering the average usage time of 8760 h·year^{-1} and tissue weighting factor, the activity concentration limits for ICRP phantoms are represents in Table 3. Using these values, we can 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 consumer goods (Bq·kg^{-1}), 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^{-1}). For the building materials, the A_U, A_{Th}, and A_K are 300, 200 and 3000 Bq·kg^{-1} and when indexes I for the building materials are less than 1, the annual dose limit of 1 mSv is satisfied. Comparing with the values by building materials, the consumer goods have about six times of activity concentration limits for each radionuclide. Therefore, we can suggest the index for consumer goods in contact with bodies such as bracelet, necklace and mats etc.

$$6 \geq \frac{C_U}{300(Bq\cdot kg^{-1})} + \frac{C_{Th}}{200(Bq\cdot kg^{-1})} + \frac{C_K}{3000(Bq\cdot kg^{-1})}$$

In other words, when the index I for the consumer good containing NORM is less than 6, the annual dose limit of 1 mSv is satisfied.

2.4 Applications

To apply the index for real sample, we preliminary analyzed the activity concentrations of the radionuclides for twenty consumer goods including the bracelets, necklaces, mats, pillows, etc. These samples were collected from several on-line and off-line markets in Korea. Because the quantity of sample was not enough to analyze the activity concentration using gamma spectroscopy, we used the inductively couples plasma-mass spectroscopy (ICP-MS). The samples were crushed and milled to a fine powder using milling machine (8530 Enclosed Shatterbox, Thomas Scientific, Swedesboro, NJ), then homogenized using 100 micrometer sieve. We treated the fine powder sample using fusion process (K2 PRIME fusing system, Katanax, Quebec, Canada). Fusion with $LiBO_2$ provides a rapid and simple means of sample preparation for ICP-MS. The fine powder samples were fused for 8 min at 1000℃ and dissolved in 5% HNO_3. Final sample solution was prepared after Fe co-precipitation and 3M HNO_3 dissolution. The analysis time and frequency were 30 seconds and the 3 times. Measurements made on the samples were within 1% relative standard deviation. As a result, we obtained the activity concentrations of the radionuclides ^{238}U and ^{232}Th except ^{40}K as shown in Table 4. Finally, we applied activity concentration limits for consumer goods and evaluated the index as shown in Table 4.

Table 4. Index Application for Twenty Consumer Goods

Samples	^{238}U [Bq·kg^{-1}]	^{232}Th [Bq·kg^{-1}]	Index	Evaluation
Goods-01	1380	7207	40.6	>6
Goods-02	54.6	528	2.8	
Goods-03	577	2368	13.8	>6
Goods-04	2810	11859	68.7	>6
Goods-05	1588	9825	54.4	>6
Goods-06	8.3	5.6	0.1	
Goods-07	89.5	37.0	0.5	
Goods-08	506	2871	16.0	>6
Goods-09	69.9	101	0.7	
Goods-10	42.3	5.4	0.2	
Goods-11	129	679	3.8	
Goods-12	270	2402	12.9	>6
Goods-13	359	2880	15.6	>6
Goods-14	41.8	13.3	0.2	
Goods-15	1.11	0.54	0	
Goods-16	4.12	0.63	0	
Goods-17	10.2	51.3	0.3	
Goods-18	939	7004	38.2	>6
Goods-19	264	2246	12.1	>6
Goods-20	19.0	6.46	0.1	

3. RESULTS AND DISCUSSION

As shown in Table 4, though we did not consider radioactivity of ^{40}K, indexes of the some samples are more than 6. Most of these consumer goods over index 6 are anion necklaces and bracelets including some Monazite ingredient. Because the Monazite has high radioactivity of thorium, it is necessary to screen the consumer goods using this gradient by index. However, this index concept using small room model is very conservative, for the consumer goods over than index 6, it is necessary to reevaluate the absorbed dose considering real usage scenario and material characteristics.

4. CONCLUSION

To screen the consumer goods in contact with body, we assumed the small room model based on room model and derived the activity concentration limits. The activity concentration limits for ^{238}U series, ^{232}Th series and ^{40}K are 300, 200 and 3000 Bq·kg^{-1}, respectively, and when indexes I for the consumer goods are less than 6, the annual dose limit of 1mSv is satisfied.

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