ABSORBED INTERNAL DOSE CONVERSION COEFFICIENTS FOR DOMESTIC REFERENCE ANIMALS AND PLANT

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This paper describes the methodology of calculating the internal dose conversion coefficient in order to assess the radiological impact on non-human species. This paper also presents the internal dose conversion coefficients of 25 radionuclides (^{3}H, ^{7}Be, ^{14}C, ^{40}K, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{99}Tc, ^{106}Ru, ^{129}I, ^{131}I, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{144}Ce, ^{238}U, ^{239}Pu, ^{240}Pu) for domestic seven reference animals (roe deer, rat, frog, snake, Chinese minnow, bee, and earthworm) and one reference plant (pine tree). The uniform isotropic model was applied in order to calculate the internal dose conversion coefficients. The calculated internal dose conversion coefficient (μGyd^{-1} per Bqkg^{-1}) ranged from 10^{-6} to 10^{-2} according to the type of radionuclides and organisms studied. It turns out that the internal does conversion coefficient was higher for alpha radionuclides, such as ^{238}U, ^{239}Pu, and ^{240}Pu, and for large organisms, such as roe deer and pine tree. The internal dose conversion coefficients of ^{239}Pu, ^{240}Pu, ^{238}U, ^{14}C, ^{3}H and ^{99}Tc were independent of the organism.

KEYWORDS : Uniform Isotropic Model, Internal Dose Conversion Factor, Non-human Species, Reference Animals and Plants

1. INTRODUCTION

Traditionally, radiation protection has focused on the radiation exposure of human beings. Recently, since the Rio Declaration emphasized the issue of sustainable development [1], the protection of the environment from the effects of ionizing radiations has become a key subject for all relevant international organizations in the field of radiation protection. There have been a number of international meetings that have tried to exchange information on the subject [2-4]. Based on all these international activities, the International Commission on Radiological Protection (ICRP) stressed the importance of environmental protection from ionizing radiations in the new recommendation issued in 2007 [5], and subsequently has made efforts in setting up a methodology that can assess the radiological impact of ionizing radiations on non human species.

Animals and plants in the ecosystem are exposed to environmental radioactivity both externally and internally. Internal exposure arises from the bioaccumulation of radionuclides in organisms throughout the food chain network. The extent of the internal exposure is influenced by several factors, such as the concentration of radioactivity in an organism, the size of the organism, and the type of radionuclides. Internal dose conversion coefficients have been derived by a number of approaches for the purpose of assessing radiological impact on non-human species. Amiro [6] calculated the radiological dose conversion factors for generic non-human biota with a conservative assumption that all energies emitted by radionuclide from within the organism are fully absorbed by the organism. Higley et al. [7] also calculated the internal dose conversion coefficient for a biota by using a similar assumption (the organism is extremely large) for a general screening purpose. However, these assumptions are reasonable for a certain type of low-energy radiation that has a short transport distance in the material, such as alpha particles and low-energy electrons. In recent years, more realistic approaches that considered the finite organism size and the intensity of the emitted energy have been attempted by several researchers [8-10]. Ulanovsky and Pröhl [9] proposed a practical method for assessing the dose conversion coefficients for aquatic biota. They applied the Monte Carlo simulation in order to account for the effect of the sizes of the organism and energy intensity. Taranenko et al. [10] presented a dosimetric model by using Monte Carlo simulation in order to calculate the absorbed dose rate conversion coefficients for some terrestrial biota. These two studies have been adopted in order to calculate the dose conversion coefficients for ICRP reference biota [5]. More recently, in the Environment Modeling for Radiation Safety (EMRAS) joint program of the International Atomic Energy Agency (IAEA), a comparison between dosimetric models was attempted in order to understand the difference between models [11].

However, there has not been an attempt yet to calculate the dose conversion coefficients for domestic reference biota in Korea. In this paper, a uniform isotropic model that calculates the internal dose conversion coefficients is described, and a set of internal dose conversion coefficients of 25 radionuclides for 8 domestic reference organisms are presented forthe purpose of assessing the radiological impact of environmental radioactivity on non human species.

2. METHODS

2.1 Uniform Isotropic Model

The absorbed internal dose rate of an organism is simply calculated by

$$D_{\text{int}} = \sum_k C_k \times DCC_{\text{int},k} \tag{1}$$

where C_k (Bqkg^{-1} fresh weight) is the mean concentration of radionuclide k in the organism, and $DCC_{\text{int,k}}$ (μGyd^{-1} per Bqkg^{-1} fresh weight) is the internal dose rate conversion coefficient of the radionuclide k for the specified organism. In order to calculate the absorbed dose rate, the internal dose conversion coefficients are essential.

In the present study, the uniform isotropic model, which has also been adopted by Ulanovsky and Pröhl [9], was applied to calculate the internal dose conversion coefficient for selected domestic reference organisms that had the following assumptions:

- The target organism is present in an infinite homogeneous environmental media.
- The activity of an organism is uniform throughout its body.
- The densities of the environmental medium and the organism's body are equal.

The third assumption is reasonable for an aquatic system where the difference in density between water and an organism is small. However, this method was also applied to other media because the effect of the density of surrounding media on the energy absorption is known to be small. It is known that for a spherical organism that has a mass of 1mg in water and in air the difference in the absorbed fraction would appear to be about 6% for a photon energy of 1.5MeV, while the difference is less than 1% for a photon energy of 0.15MeV. The effect of the difference in density is higher for a smaller mass and higher photon energy [12].

With the above assumptions, the unweighted internal dose conversion coefficients for a specific radionuclide (μGyd^{-1} per Bqkg^{-1}) can be calculated by

$$DCC_{\text{int}} = \sum_i E_i y_i \phi_\alpha(E_i) + \sum_i E_i y_i \phi_\gamma(E_i) + \int N_\beta(E) E \phi_\beta(E) dE \tag{2}$$

where α, β and γ denote the radiation type emitted by each radionuclide, E_i (MeV) and y_i (decay^{-1}) are the energy and yield of the discrete energy radiations per decay of the radionuclide, $N_\beta(E)$ (decay^{-1}MeV^{-1}) is the energy spectrum of β-particles, and $\phi(E)$ is the absorbed energy fraction, which is defined as the fraction of energy emitted by a decaying radionuclide that is absorbed within the organism, and it is dependent on the type of radiation and the energy of the radiation emitted.

In order to calculate the internal dose conversion coefficients by Eq.(2), the values of E_i, y_i, $N_\beta(E)$, and $\phi(E)$ should be known. Among the values, the values for the first three constants are taken from the ICRP data book, and the last one is calculated by the Monte Carlo simulation method for a specified energy and target geometry.

2.2 Absorbed Energy Fraction

The absorbed energy fraction (ϕ) in Eq.(2) is a fundamental quantity for estimating the internal radiation dose rate. The value is dependent on the shape and size of organisms, as well as the radiation energy. As usual, the shape and size of biota that live in ecosystems vary greatly, and thus, it is impractical to consider the detailed geometry of each organism. Therefore, most approaches for calculating the dose conversion coefficient for non-human species assume a target organism of a simplified shape, such as a sphere, cylinder, or ellipsoid. Ulanovsky and Pröhl [9] proposed an empirical equation to calculate the absorbed energy fraction of organisms of a non-spherical shape (ellipsoid) by using the absorbed fraction of a spherical shape and the rescaling factor as follows:

$$\phi(E) = RF(E, M, \eta) \times \phi_s(E) \tag{3}$$

$$RF(E, M, \eta) = (1 - |1-\eta|^{1/s})^s \tag{4}$$

$$\eta = \frac{1}{(\xi\chi)^{0.333}} \left(\frac{3}{1+\xi^{-1.6075} + \chi^{-1.6075}} \right)^{0.622}, \ \xi = b/a, \ \chi = c/a \tag{5}$$

$$s = a_1 + \frac{a_2}{1+\left(\frac{r_o}{x_o}\right)^{b_1}} + \frac{c_1}{d_1 + \log^2\left(\frac{r_o}{x_1}\right)} \tag{6}$$

$$r_o = \frac{R_o}{\Lambda(E_\beta)} \text{ (electrons)} \tag{7}$$

$$r_o = \frac{R_o}{\lambda(E_\lambda)} \text{ (photons)} \quad (8)$$

where *RF* is the rescaling factor, which is the function of *E*(energy), *M*(mass of organism), and η(ratio of surface area of ellipsoidal shape to that of sphere). The value of *RF* is one for a spherical type, where η is the non-sphericity of the target, the ratio of the surface areas of an ellipsoid, and a sphere with the same mass. *a*, *b* and *c* are the lengths of the major, 1st minor, and 2nd minor axes of an ellipsoid, respectively. a_1, a_2, b_1, c_1, d_1, x_o and x_1 in Eq.(6) are the empirical parameters. $\Lambda(E)$ is the Continuous Slowing-Down Approximation (CSDA) range of electrons in water [13], and $\lambda(E)$ is the mean free path (*mfp*) of photons in water [14]. r_o and R_o are the scaled radius and radius of the equal-mass sphere, respectively. ϕ_s is the absorbed fraction for a spherical organism that has the same mass with a target organism of ellipsoidal type. The values of ϕ_s for the electron and photon are calculated by the Monte Carlo simulation with the following assumptions:

- Radiation source: electron and photon
- Energy range (*E*): 0.01MeV to 5MeV
- Energy cut-off: 1keV for electron, 10keV for photon
- Mass of organism (*M*): 10^{-6} kg to 10^{3} kg, which corresponds to the sphere radius of 0.062cm to 62cm (density=1g/cm^3). The range of mass covers most adult organisms in aquatic and terrestrial ecosystems, except for extremely small organisms, such as bacteria, or extremely large organisms, such as elephants.
- Surrounding medium: a cube with the dimension of 100m $\times$ 100m $\times$ 100m. This size is sufficiently large compared to the mean free path of photons in water (for example, the photon mean free path is about 30cm when E=3MeV).
- All of the targets are in the center of the surrounding cube medium.

Low-energy radiations, such as all α-particles and β with less than 10keV, even cannot escape materials like the tissues of organisms, so that the value of absorption fractions of a low energy radiation are assumed to be one, i.e. $\phi_\alpha = \phi_{low-energy-\beta} = 1$.

2.3 Internal Doe Conversion Coefficient

Figure1 shows the flow chart to calculate the internal dose conversion coefficients. For a specified organism that has an elliptical shape, the mass (*M*), the equal-mass radius (R_o), and the non-sphericity factor (η) are first determined from the target size (*a*, *b* and *c*), and then the Rescaling Factor (*RF*) for an energy *E* is calculated from the values of η and R_o with values of $\Lambda(E_\beta)$ for the electron or $\lambda(E_\gamma)$ for the photons. The absorbed fraction (ϕ) of a target organism for a mono-energy (*E*) is calculated from the *RF* and the ϕ_s–*E*–*M* table. The internal dose conversion coefficient for a specified radionuclide is finally calculated by Eq.(2) with the transformation data of radionuclides

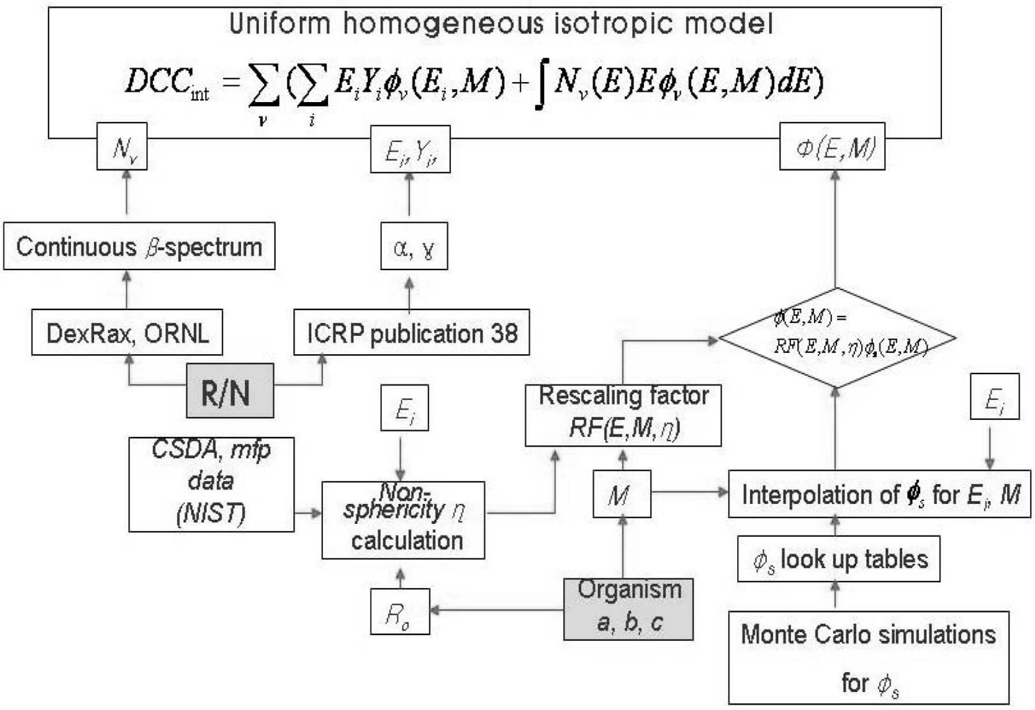

Fig. 1. Flow Chart for Calculating the Internal Dose Conversion Coefficient

Table 1. Selected Radionuclides for Internal Dose Conversion Coefficients

R/Ns	Half-lives	Progeny included in the DCC calculation of the parent radionuclides
H-3	12.35 years	-
C-14	5,730 years	-
K-40	1.28E9 years	-
Cr-51	20.7 years	-
Mn-54	312.5 years	-
Co-58	70.8 days	-
Co-60	5.271 years	-
Zn-65	63.98 days	-
Sr-90	29.12 years	Y-90 (64 hours)
Nb-95	35.15 days	-
Zr-95	63.98 days	-
Tc-99	211,100 years	-
Ru-106	368.2 days	Rh-106 (29.9 sec.)
I-129	1.57E7 years	-
I-131	8.04 days	-
Cs-134	2.06 years	-
Cs-137	30 years	Ba-137m (2.552 min.)
Ba-140	12.74 days	La-140 (40.272 h)
La-140	40.27 h	-
Ce-144	284.3 days	Pr-144 (17.28 min.), Pr144m (7.2min.)
U-238	4.47E9 years	-
Pu-239	2,4065 days	-
Pu-240	6,537 years	-

(E_i and Y_i), which were taken from the ICRP 38[15], and with the β-energy spectrum (E_i vs N_β) for the electrons, which was extracted from the DexRax32 code of the Oak Ridge National Laboratories, USA [16].

The radionuclides for the internal dose conversion coefficients, which were selected based on the planning for the Environmental Radiation Monitoring of the Gyeongju intermediate and low level radioactive waste repository, are listed in Table 1. The daughter radionuclides, which are the secular equilibrium with the parent radionuclide, are needed to be considered in calculating the radiation dose rate because they have an impact on the organism's radiation together with the parent radionuclide. In the present study, the progenies with half lives less than 10 days of each radionuclide were implicitly incorporated in the calculation of the internal dose conversion coefficients of its parent radionuclide, with the assumption that the daughter radionuclides follow the same metabolism in the organism as the parent radionuclide.

3. RESULTS AND DISCUSSION

3.1 Absorbed Energy Fraction for a Spherical Shape, ϕ_s

Figure 2 shows the absorbed energy fraction of the electron (ϕ_β) and photon (ϕ_γ) for the targets of the spherical shape, which was computed by the MCNP code [17]. The absorbed fraction ranges from an order of 10^{-5} for the high-energy photons and small size (mass) organisms to unity for low energy and large organisms. The mean free path of the photon is considerably longer than the transport distances of electrons in the material, and thus the energy absorption of the photon within organisms is less than that of the electron. This leads to a higher internal absorbed

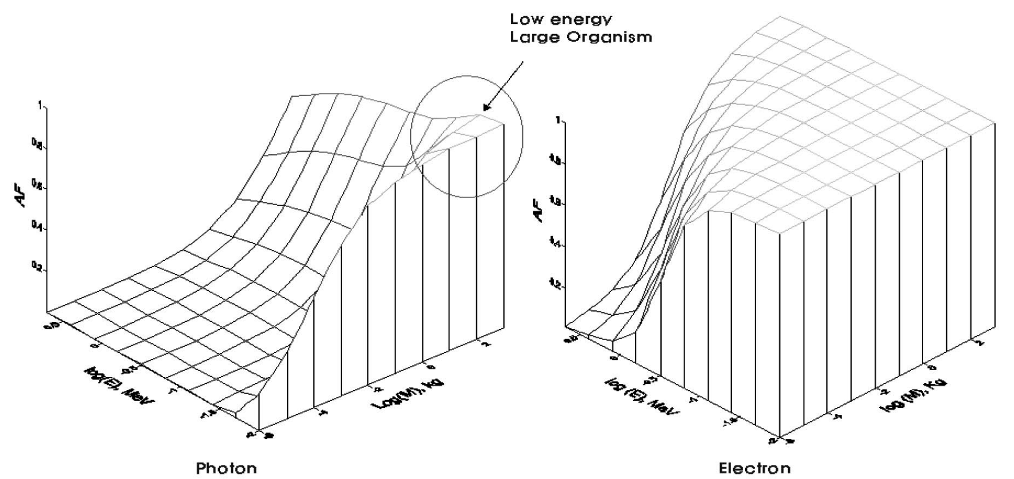

Fig. 2. Effect of Mass (M) and Energy (E) of Electron and Photon on the Absorbed Fraction (ϕ) for the Spherical Shape of Target

fraction for the electron than for the photon.

The absorbed energy fractions in Figure 2 are made as a ϕ_s–E–M table for the electron and photon. The values of ϕ_β and ϕ_γ for a specified energy and mass are determined by the interpolation when applied to the internal dose conversion coefficients calculation.

3.2 Internal Dose Conversion Coefficient

Table 2 shows the domestic reference organisms, which were selected based on the new recommendations from the ICRP [5]. The size of the organisms was taken from the "Endemic Species of Korea" [18]. The shape of all the organisms was assumed to be ellipsoid. For an ellipsoid, a, b, and c is respectively the lengths of the major, 1st minor, and 2nd minor axes. The density of the organisms was assumed to be 1 g/cm^3.

The internal dose conversion coefficients of the radionuclides for 8 selected domestic reference organisms are listed in Table 3. From the table, the following results can be summarized:

1) The internal dose conversion coefficients show a range from 10^{-6} to 10^{-2} according to the type of radionuclide and to the size of the organism.
2) The values appear higher for alpha emitters, such as ^{239}Pu, ^{240}Pu and ^{238}U, and for large organisms, such as roe deer and pine tree. This is because the radiation energy is deposited more in organisms when the energy is low and the organism is large.
3) The internal dose conversion coefficients for ^{239}Pu, ^{240}Pu, ^{238}U, ^{14}C, ^{3}H and ^{99}Tc are shown to be the same for all the organisms considered. This result arises from the fact that the transport distance of dominant radiations emitted from such radionuclides is very short in these materials, so that all radiations are deposited, even in small organisms, such as bees.

On the other hand, the internal dose conversion coefficients were also calculated with the assumption that ϕ =1 for all organisms. This assumption means that all energy emitted by radionuclides from within the organism is absorbed by the organism. The calculated values are shown in the last column in Table 3. They are the same as Amiro's results [6] that were obtained with the same assumption. Actually, the conservative value for the radionuclide corresponds to the upper bound of the internal dose conversion coefficient for the radionuclide because of full energy absorption. The dose conversion coefficient for an organism of a finite size is always equal to or less than the upper bound value if the same number of daughters were considered in the calculation of the dose conversion coefficient. It can be seen that the internal dose conversion coefficients of ^{239}Pu, ^{240}Pu, ^{238}U, ^{14}C, ^{3}H and ^{99}Tc for an organism of a finite size are the same as the upper bound of each radionuclide. For alpha particles, such as ^{239}Pu, ^{240}Pu and ^{238}U, the total internal dose is dominated by the α dose rather than the β+γ dose, and the total dose for ^{14}C, ^{3}H and ^{99}Tc is dominated by a low-energy beta. These properties are applied with the assumption that the value of absorption fraction of a low energy radiation is one. Consequently, the internal dose conversion coefficients for such radionuclides appear independent of the organism.

To test the validity of the present approach, a comparison exercise was performed. The internal dose conversion coefficients of ^{3}H, ^{14}C, ^{90}Sr, ^{137}Cs, ^{60}Co, and ^{238}U for five ICRP reference animals (Table 4) were calculated with the present approach. They were compared with three other results for the same organism that were presented for the inter-comparison in the Biota Working Group of the Environmental Modeling for Radiation Safety (EMARS) program of the International Atomic Energy Agency (IAEA) [11]. The comparison results are given in Table 5. The present results are almost the same or agreed well within 10% of the results from the other approaches for

Table 2. Selected Domestic Reference Animals and Plant

Organism	Ecosystem	Size* (cm)			Mass**, M (g)
		a major axis	b major axis	c major axis	
Pine tree	Terrestrial	1000	30	30	471238.8
Rat	Terrestrial	10	3	2.5	39.4
Roe deer	Terrestrial	105	50	50	13744.5
Frog	Terrestrial	3.2	3	2	10.0
Snake	Terrestrial	85	1	1	44.5
Chinese minnow	Freshwater	8	3	1	12.6
Bee	Terrestrial	1.8	0.5	0.5	0.24
Earthworm	Terrestrial	9.5	0.4	0.4	0.8

* Shape of all organisms is assumed to be an ellipsoid of $\frac{x^2}{(a/2)^2}+\frac{y^2}{(b/2)^2}+\frac{z^2}{(c/2)^2}=1$

** Mass is calculated from the equation: $M=\frac{4}{3}\pi(a/2)(b/2)(c/2)\rho$, where ρ is water density (= 1g/cm^3)

Table 3. Internal Absorbed Dose Rate Conversion Coefficients for 8 Domestic Reference Organisms and for 25 Radionuclides (μGy/d per Bq/kg)

R/N	Organisms								
	bee	earthworm	frog	rat	snake	Roe-deer	Chinese minnow	Pine tree	Conservative values (ϕ=1)
Ba-140	8.20E-03	7.90E-03	1.20E-02	1.20E-02	1.00E-02	2.80E-02	1.10E-02	2.40E-02	4.60E-02
Be-7	4.60E-06	5.20E-06	2.20E-05	2.70E-05	1.40E-05	3.70E-04	1.70E-05	2.90E-04	6.80E-04
C-14	6.70E-04	6.80E-04	6.80E-04	6.80E-04	6.80E-04	6.80E-04	6.80E-04	6.80E-04	6.80E-04
Ce-144	7.60E-03	7.50E-03	1.50E-02	1.50E-02	1.20E-02	1.90E-02	1.30E-02	1.90E-02	1.90E-02
Co-58	5.20E-04	5.30E-04	8.70E-04	9.80E-04	7.40E-04	7.30E-03	7.90E-04	5.80E-03	1.40E-02
Co-60	1.40E-03	1.50E-03	2.20E-03	2.40E-03	1.90E-03	1.70E-02	2.00E-03	1.40E-02	3.60E-02
C-r51	6.90E-05	7.00E-05	8.20E-05	8.50E-05	7.70E-05	3.10E-04	7.90E-05	2.60E-04	5.00E-04
Cs-134	2.10E-03	2.10E-03	2.80E-03	3.00E-03	2.50E-03	1.30E-02	2.70E-03	1.10E-02	2.40E-02
Cs-137	2.90E-03	2.80E-03	3.60E-03	3.70E-03	3.40E-03	7.80E-03	3.50E-03	6.80E-03	1.20E-02
Fe-59	1.60E-03	1.60E-03	2.00E-03	2.10E-03	1.90E-03	9.40E-03	1.90E-03	7.50E-03	1.80E-02
H-3	7.90E-05	7.90E-05	7.90E-05	7.90E-05	7.90E-05	7.90E-05	7.90E-05	7.90E-05	7.90E-05
I-129	8.90E-04	8.90E-04	9.30E-04	9.40E-04	9.10E-04	1.20E-03	9.20E-04	1.10E-03	1.20E-03
I-131	2.40E-03	2.30E-03	2.70E-03	2.80E-03	2.60E-03	5.50E-03	2.70E-03	4.90E-03	7.90E-03
K-40	4.40E-03	4.10E-03	6.60E-03	6.70E-03	5.80E-03	8.10E-03	6.30E-03	7.90E-03	9.40E-03
La-140	4.70E-03	4.50E-03	7.50E-03	7.80E-03	6.40E-03	2.20E-02	7.00E-03	1.90E-02	3.90E-02
Mn-54	1.20E-04	1.40E-04	3.90E-04	4.80E-04	2.80E-04	5.90E-03	3.30E-04	4.50E-03	1.20E-02
Nb-95	6.60E-04	6.80E-04	9.20E-04	1.00E-03	8.20E-04	6.00E-03	8.60E-04	4.80E-03	1.10E-02
Pu-239	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02
Pu-240	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02	7.20E-02
Ru-106	6.10E-03	6.00E-03	1.50E-02	1.50E-02	1.00E-02	2.10E-02	1.30E-02	2.10E-02	2.20E-02
Sr-90	7.80E-03	7.60E-03	1.30E-02	1.40E-02	1.10E-02	1.50E-02	1.20E-02	1.50E-02	1.60E-02
Tc-99	1.30E-03	1.30E-03	1.40E-03	1.40E-03	1.40E-03	1.40E-03	1.40E-03	1.40E-03	1.40E-03
U-238	5.90E-02	5.90E-02	5.90E-02	5.90E-02	5.90E-02	5.90E-02	5.90E-02	5.90E-02	5.90E-02
Zn-65	1.50E-04	1.70E-04	3.40E-04	4.00E-04	2.70E-04	4.00E-03	3.00E-04	3.10E-03	8.10E-03
Zr-95	1.60E-03	1.60E-03	1.90E-03	2.00E-03	1.80E-03	6.80E-03	1.80E-03	5.60E-03	1.20E-02

Table 4. ICRP Organisms Used for Calculation Comparison [12]

organism	Size (cm)			Mass (g)	Ecosystem
	a	b	c		
Salmonid egg	0.25	0.25	0.25	8.2E-3	Freshwater
Earthworm	10	1	1	5.2	Terrestrial
Frog	8	3	25	31	Freshwater
Rat	20	6	5	310	Terrestrial
Duck	30	10	8	1,300	Freshwater

all radionuclide and organisms considered, indicating that the internal dose conversion coefficients for the domestic reference organisms in the present work were calculated reasonably well. It is interesting that the AECL's result

Table 5. Comparison of Internal Dose Conversion Coefficients for ICRP Organisms (μGy/h per Bq/kg)

Nuclide		Organisms				
		Salmonid egg	Earthworm	Frog	Rat	Duck
^{3}H	AECL	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
	ERICA	-	3.3E-6	3.3E-6	3.3E-6	3.3E-6
	RESRAD-BIOTA	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
	This work	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
^{14}C	AECL	2.8E-5	2.8E-5	2.8E-5	2.8E-5	2.8E-5
	ERICA	-	2.8E-5	2.8E-5	2.9E-5	2.9E-5
	RESRAD-BIOTA	2.8E-5	2.8E-5	2.9E-5	2.9E-5	2.9E-5
	This work	2.8E-5	2.8E-5	2.8E-5	2.8E-5	2.8E-5
^{90}Sr	AECL	1.4E-4	5.1E-4	5.7E-4	6.1E-4	6.3E-4
	ERICA	-	5.2E-4	5.9E-4	6.2E-4	6.3E-4
	RESRAD-BIOTA	2.0E-4	5.1E-4	6.0E-4	6.2E-4	6.3E-4
	This work	1.9E-4	4.5E-4	5.7E-4	6.1E-4	6.3E-4
^{137}Cs	AECL	7.9E-5	1.4E-4	1.5E-4	1.6E-4	1.8E-4
	ERICA	-	1.4E-4	1.5E-4	1.7E-4	1.9E-4
	RESRAD-BIOTA	1.0E-4	1.4E-4	1.6E-4	1.7E-4	1.9E-4
	This work	9.3E-5	1.4E-4	1.5E-4	1.7E-4	1.9E-4
^{60}Co	AECL	5.0E-5	-	9.9E-5	-	2.0E-4
	ERICA	-	7.7E-5	1.1E-4	1.7E-4	2.4E-4
	RESRAD-BIOTA	5.7E-5	7.8E-5	1.1E-4	1.7E-4	2.3E-4
	This work	5.1E-5	7.4E-5	1.0E-4	1.5E-4	2.2E-4
^{238}U	AECL	5.3E-3	2.4E-3	5.7E-3	2.4E-3	5.7E-3
	ERICA	-	2.4E-3	2.4E-3	2.4E-3	2.4E-3
	RESRAD-BIOTA	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3
	This work	2.5E-3	2.5E-3	2.5E-3	2.5E-3	2.5E-3

* Details of AECL(Canada), ERICA(EU), and RESRAD-BIOTA(USA) approach are given elsewhere[11]

for ^{238}U was larger by a factor of about 2, compared to the results from the other approaches, including the present work. The higher value for ^{238}U from AECL was attributed to the assumption that ^{238}U was in secular equilibrium with ^{234}U. Among the daughters (^{234}Th, ^{234}mPa, ^{234}P, and ^{234}U) of ^{238}U, ^{234}U is known to be the most dominant factor, inducing the difference in value within the estimation of the internal dose conversion coefficient.

4. CONCLUSION

In order to assess the radiological impact of environmental radioactivity on non-human species, the internal dose conversion coefficients of 25 radionuclides for the selected domestic reference organisms were calculated by the uniform isotropic model. The calculated internal dose conversion coefficients were in the range of 10^{-6} to 10^{-2} according to the type of radionuclide and organism. The values were generally higher for low-energy emitting radionuclides and for large organisms. The internal dose conversion coefficients for ^{239}Pu, ^{240}Pu, ^{238}U, ^{14}C, ^{3}H and ^{99}Tc were independent of the organism. Through a model comparison test, the present approach has been verified to be sufficiently reasonable in estimating the internal dose conversion coefficients of non-human species.

The internal and external dose conversion coefficients for the domestic reference organisms are basic components of the non-human species dose assessment tool (called K-BIOTA) that is being developed by the Korea Atomic Energy Research Institute. The present internal dose conversion coefficients will be used as a component of input data for the assessment code. At present, the external dose conversion coefficients for the same reference organisms are also being calculated by using the Monte Carlo simulation that considers the difference in the density between an organism and an environmental medium as a radiation source. The results of the external dose conversion coefficients will be available soon those interested.

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REFERENCES

[1] UNCED, *Rio Declaration on environment and development*, United Nations Conference on Environment and Development, (1992).
[2] UNSCEAR, *Effect of Radiation on the Environment*, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, Annex 1, United Nations, New York, (1996).
[3] OECD/NEA, "Radiological Protection of the Environment-The Path Forward to a New Policy?," *Workshop Proceedings from NEA Forum*, Taormina, Italy, 12-14 February 2002, OECD, Paris, (2002).
[4] IAEA, "Protection of the Environment from the Effect of Ionizing Radiation," *International Conference*, Stockholm, 6-10 October, (2003).
[5] ICRP, *Recommendations of the ICRP*, Publication 103, (2008).
[6] B.D. Amiro, "Radiological Dose Conversion Factors for Generic Non-human Biota used for Screening Potential Ecological Impacts," *J. Environmental Radioactivity*, Vol.35, No.1, p37-51, (1997).
[7] K.A. Higley, S.L. Domotor, E.J. Antonio, D.C. Kocher, "Derivation of a Screening Methodology for Evaluating Radiation Dose to Aquatic and Terrestrial biota," *J. Environmental Radioactivity*, Vol.66, p41-59, (2003).
[8] J. Vives i Batlle, S.R. Jones, J.M. Gomez-Ros, "A Method for Calculation of Dose per Unit Concentration Values for Aquatic Biota," *J. Radiol. Prot*., Vol.24, A13-A34, (2004).
[9] A. Ulanovsky, G. Pröhl, "A Practical Method for Assessment of Dose Conversion Coefficients for Aquatic Biota," *Radiat. Environ. Biophys*., Vol.45, p203-214, (2006).
[10] V. Taranenko, G. Pröhl, J.M. Comez-Ros, "Absorbed Dose Rate Conversion Coefficients for Reference Terrestrial Biota for External and Internal exposures," *J. Radiol. Prot*., Vol.24, A35-A62, (2004).
[11] J. Vivies i Batlle, M. Balonov, K. Beaugelin-Seiller, N.A. Bresford, J. Brown, J-J. Cheng, D. Coppelstone, M. Doi, V. Filistovic, V. Golikov, J. Horyna, A. Hosseini, B.J. Howard, S.R. Jones, S. Kamboj, A. Kryshev, T. Nedvechaite, G. Olyslaegers, G. Proel, T. Sazykina, A. Ulanovsky, S. Vivis Lynch, T. Yankovich, C. Yu, "Inter-comparison of Absorbed Dose Rates for Non-human Species," *Radiat. Environ. Biophys*, 46, 349-373, (2007).
[12] ICRP, *The concept and use of reference animals and plants for the purpose of environmental protection* (draft for discussion), In: Valentin J. (ed), ICRP publication XX, Annals of the ICRP, (2005).
[13] M.J. Berger, "ESTER, PSTAR, and ASTAR: computer programs for calculating stopping-power and range tables for electron, photons, and helium ions," National Institute of Standards and Technology Report NISTER 4999. NIST, Gaithersburg, MD (1999). *http://www.physics.nist.gov/Starl*
[14] J.R. Hubbel and S.M. Seltzer, "Tables X-ray mass attenuation coefficients and mass energy-absorption coefficients from 1keV to 20MeV for elements Z=1-92 and 48 additional substances of dosimetric interest," National Institute of Standards and Technology Report NISTER 5632. NIST, Gaithersburg, MD (1995). *http://www.physics.nist.gov/PhysRefData/XrayMassCoef/cover.html*
[15] ICRP, *Radionuclide Transformations: Energy and Intensity of Emissions*, Publication 38, (1983).
[16] K.F. Eckerman, R.J. Westfall, J.C. Ryman, M. Cristy, "Availability of Nuclear Decay Data in Electronic Form, including Beta Spectra not Previously Published," *Health Phys*, 67(4), p338-345, (1994).
[17] J.F. Briesmeister (ed), "*MCNP- A general Monte Carlo N-particle transport code: Version 4B*", LA-12625-M, version 4B, UC705, University of California, issued March (1997).
[18] ME, *Endemic Species of Korea*, Ministry of Environment of Korea, (2005).