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Methods for calculating dose conversion coefficients for terrestrial and aquatic biota

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Abstract

Plants and animals may be exposed to ionizing radiation from radionuclides in the environment. This paper describes the underlying data and assumptions to assess doses to biota due to internal and external exposure for a wide range of masses and shapes living in various habitats. A dosimetric module is implemented which is a user-friendly and flexible possibility to assess dose conversion coefficients for aquatic and terrestrial biota. The dose conversion coefficients have been derived for internal and various external exposure scenarios. The dosimetric model is linked to radionuclide decay and emission database, compatible with the ICRP Publication 38, thus providing a capability to compute dose conversion coefficients for any nuclide from the database and its daughter nuclides. The dosimetric module has been integrated into the ERICA Tool, but it can also be used as a stand-alone version.

Keywords: Internal exposure; External exposure; Dose conversion coefficients; Animals and plants; Aquatic; Terrestrial

1. Introduction

In the last years, the interest increased for assessment and evaluation of the radiological impact on wild living flora and fauna due to release of radionuclides to the environment. The consideration of the flora and fauna in the system of radiation protection requires reliable widely applicable models to assess doses to biota in different habitats from external and internal radiation sources. Dosimetric approaches and models have been developed since the late 1970s. In view of the variability of shapes, sizes, habitats and source−target relationships, the approaches being used have to compromise between the complexity of the modelling that is theoretically possible and the availability of relevant data and the practicability of the resulting model. The earlier studies (Amiro, 1997; Copplestone et al., 2001; DoE, 2002; IAEA, 1976, 1979, 1992; NCRP, 1991; Pentreath and Woodhead, 1988; Woodhead, 1970) are based on analytical models with often simplifying conservative assumptions that were developed for screening purposes.

More complex approaches, using Monte Carlo techniques for simulation of radiation transport in biota and the surrounding media to avoid too conservative estimations, were developed by Golikov and Brown (2003), Higley et al. (2003) and Beaugelin-Seiller et al. (2006). Within the FASSET project (Larsson, 2004), dosimetric models were developed for a wide range of aquatic and terrestrial organisms in different habitats (Vives i Battle et al., 2004; Taranenko et al., 2004). This dosimetric work was further developed in the ERICA project (Larsson, 2008; Ulanovsky and Pröhl, 2006) and summarized in a dosimetric module that has been integrated in the ERICA Tool (Børretzen et al., 2005; Brown et al., 2008) that enables estimations of internal and external exposures to biota that cover a wide range of body masses and habitats for all radionuclides listed in the electronic version of ICRP 38 (Eckerman et al., 1994; ICRP, 1983). This paper describes

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the underlying approaches and data that applied in the dosimetric module of the ERICA Tool.

2. Methodology and dosimetric approaches

2.1. Dose concept

The basic quantity for estimating exposures to ionizing radiation is the absorbed dose, which is defined as the amount of energy absorbed per unit mass in given organ or the whole organism, and it is given in units of *Gray* (Gy). Among various types of radiations that can contribute to the absorbed dose, the most important are α-, β-, and γ-radiation, whereas neutrons, heavy ions, fission fragments are less relevant under environmental conditions. For the same absorbed dose, different types of radiation are known to cause different effects. A radiation weighting factor that compares the effectiveness of the different types of radiation to the effectiveness of irradiation with 300 keV photons has been introduced to account for this different biological effectiveness for radiation protection of humans (ICRP, 2003). In the human dosimetric system, the product of the quality factor and the absorbed dose results in the equivalent dose with the unit *Sievert* (Sv); it has the advantage that allows comparing exposures from different radiation types on the basis of the biological effect.

The concept of equivalent dose for humans has to be modified before it can be applied to biota. The radiation quality factors currently applied in human dosimetry focus on stochastic effects. However, the investigation of effects of ionizing radiation to biota primarily aims on deterministic "umbrella" effects as morbidity, mortality, reduced reproductive success, and mutations induced in germ and somatic cells (Larsson, 2004). This means, the radiation weighting factors used for the dose assessment to humans are not directly applicable to assess doses and risks for biota; the discussion on appropriate radiation quality factors for biota, especially for α-radiation, is ongoing (Chambers et al., 2006).

2.2. Reference organisms

Since it is impossible to consider all species of flora and fauna explicitly in dose assessment, some reference organisms need to be selected as representative members of typical ecosystems. This approach allows reducing the assessment efforts and illustrates the range of possible exposures to ionizing radiation in typical ecosystems. The reference organism approach has been introduced previously (e.g., Larsson, 2004; Pentreath and Woodhead, 2001). The FASSET project defined the "reference organism" as a "series of entities that provides a basis for the estimation of the radiation dose rate to a range of organisms that are typical, or representative, of a contaminated environment". A comparable concept is discussed by the ICRP (2007) where a set of 12 more or less globally present reference animals and plants in different life stages (e.g., fish egg, adult fish) has been selected that represent a wide range of life forms (plants, animals), organisms' shapes and masses, ecosystems (terrestrial, aquatic) and habitats (air, soil, water, sediment). The reference organisms are summarized in Table 1.

2.3. General assumptions

Due to the enormous variability of biota in respect to size, shape and habitats, the dosimetric models assume a number of simplifications in order to cover a wide range of exposure situations. The most important simplifications are as follows:

- The shapes of the organisms are approximated by spheres and ellipsoids.
- For internal exposure, organs are not considered explicitly and the radioactivity assumed is homogeneously distributed in the whole body.
- An equilibrium concentration in the whole body is assumed, this means the radionuclide kinetic in the organism is not taken into account.
- For calculating external exposures, a variety of source–target relationships are considered that represent typical situations, e.g., the external exposure of a reference organisms that live on or in contaminated soil.

Table 1
Reference organisms in ERICA project (Larsson, 2008) and Reference Animals and Plants as defined by ICRP (2007)

ERICA reference organisms (example)	ICRP Reference Animals and Plants	Habitat	Mass (kg)
Terrestrial environment			
Soil invertebrate (earthworm)	Earthworm	In soil	5.24×10^{-3}
Detritivorous invertebrate (woodlouse)		On and in soil	1.70×10^{-4}
	Bee	In air	5.89×10^{-4}
Gastropod (snail)		On soil	1.40×10^{-3}
Lichen and bryophytes (Bryophite)		On soil	1.10×10^{-4}
Grasses and herbs	Wild grass	On soil	2.62×10^{-3}
Shrub		On soil	
Tree	Pine tree	On soil	4.71×10^{2}
Burrowing mammal (rat)	Rat	In soil	3.14×10^{-1}
Small mammal (rat)	Rat	On soil	3.14×10^{-1}
Large mammal (deer)	Deer	On soil	2.45×10^{2}
Bird	Duck	On soil	1.26
Bird	Duck	In air (3 m)	1.26
Bird egg	Duck egg	On soil	5.03×10^{-2}
Reptile (snake)		On soil	7.44×10^{-1}
Amphibian (frog)	Frog	On and in soil	3.14×10^{-2}
Marine environment			
Phytoplankton		In water	6.54×10^{-11}
Macroalgae	Brown seaweed	In water	6.54×10^{-3}
Vascular plant		In water	2.62×10^{-2}
Zooplankton		In water	6.14×10^{-5}
Polychaete worm		In water	1.73×10^{-2}
Benthic mollusc		In water	1.64×10^{-2}
Crustacean	Crab	In water	7.54×10^{-1}
Benthic fish	Flat fish	In water	1.31
Pelagic fish		In water	5.65×10^{-1}
(Wading) bird	Duck	In water	1.26
Mammal		In water	1.82×10^{2}
Reptile (marine turtle)		In water	1.39×10^{2}
Sea anemones/true corals		In water	1.77×10^{-3}
Colony of sea anemones/ true corals		In water	1.96×10^{2}
Freshwater environment			
Phytoplankton		In water	2.05×10^{-12}
Vascular plant		In water	1.05×10^{-3}
Zooplankton		In water	2.35×10^{-6}
Insect larvae		In water	1.77×10^{-5}
Bivalve mollusk		In water	7.07×10^{-2}
Gastropod		In water	3.53×10^{-3}
Crustacean		In water	1.57×10^{-5}
Benthic fish		In water	1.47
Pelagic fish	Salmonid/trout	In water	1.26
Bird	Duck	In water	1.26
Mammal		In water	3.90
Amphibian	Frog	In water	3.14×10^{-2}

Dose coefficients for environmental biota are commonly expressed as mean absorbed dose rates in the whole body per unit activity concentration of the given radionuclide. Dose coefficients for internal exposure are defined per average mass activity concentration in the whole body – $\mu Gy\,h^{-1}$ per $Bq\,kg^{-1}$. Dose coefficients for external exposure of aquatic species are expressed per average volume activity concentration – $\mu Gy\,h^{-1}$ per $Bq\,L^{-1}$. External exposure of terrestrial organisms has been considered in different