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Dose Coefficients for Non-human Biota Environmentally Exposed to Radiation

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[Guest] Editorial

TITLE OF EDITORIAL

To be drafted.

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REFERENCES

ABSTRACT

Dose coefficients for Non-human Biota Environmentally Exposed to Radiation

ICRP Publication 1XX

Approved by the Commission in Month 201Y

Abstract–The diversity of non-human biota is a specific challenge when developing and applying dosimetric models for assessing exposures of flora and fauna from radioactive sources in the environment. Dosimetric models, adopted in *Publication 108*, provide Dose coefficients (DCs) for a group of reference entities [ICRP's Reference Animals and Plants (RAPs)]. These models pragmatically assume simple body shapes with uniform composition and density, homogeneous internal contamination, limited sets of idealised sources of external exposure to ionising radiation for aquatic and terrestrial animals and plants, and truncated radioactive decay chains. This pragmatic methodology is further developed and systematically extended here. Significant methodological changes since *Publication 108* include: implementation of a new approach for external exposure of terrestrial animals with an extended set of environmental radioactive sources in soil and in air, considering an extended range of organisms and locations in contaminated terrain, transition to the contemporary radionuclide database of *Publication 107*, assessment-specific consideration of radioactive progeny contribution to DC of parent radionuclides, and use of generalised allometric relationships in the estimation of biokinetic or metabolic parameter values. These methodological developments result in changes to previously published tables of DCs for RAPs, and revised values are provided here. This report is also complemented by a new software tool, called BiotaDC, which enables the calculation of DCs for internal and external exposures of organisms with user-defined masses, shapes, and locations in the environment and for all radionuclides in *Publication 107*.

Keywords: Non-human biota; Radiological protection of the environment; Dose coefficients; Reference Animals and Plants; Dosimetry

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PREFACE

The dosimetric approach adopted by ICRP for non-human biota was summarised and presented in *Publication 108* (ICRP, 2008). Despite its extensive coverage, the report has been criticised as having methodological gaps or being restricted to the family of the ICRP Reference Animals and Plants. This report addresses such concerns and provides an extended methodology, a revised database and a software tool for more detailed calculations.

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The software tool BiotaDC (Annex C) was developed on behalf of ICRP by A. Ulanovsky and A. Ulanowski.

Helpful comments from Main Commission members J. Harrison and Jai-Ki Lee as well as instant and efficient assistance by N. Hamada are gratefully acknowledged.

MAIN POINTS

- The dosimetric approach adopted by ICRP for use in environmental risk assessments was introduced in *Publication 108* (ICRP, 2008b). Since then, the new developments and ICRP reports required a substantial revision of the approach. This report presents the revised and extended ICRP dosimetric framework for non-human biota.
- The Dose Coefficients (DCs) for external exposure of terrestrial biota have been substantially revised and extended. The current DCs are applicable to organisms with body masses in range from 1 mg to 10^3 kg, at heights above the ground surface from 0.1 to 500 m, for five types of environmental sources in soil and in ambient air.
- The DC computational engine transitioned from the radionuclide emission data of *Publication 38* to the contemporary dataset of *Publication 107*. The absorbed fractions and DCs for photons and electrons have been extended to maximum energy of 10 MeV to address radionuclide properties in the new database.
- The report is supplemented by tables of DCs for ICRP Reference Animals and Plants (RAPs). The data are compatible with those published previously but are recalculated with the new radionuclide emission data and presented in a new radionuclide-based layout, which highlights inter-species and inter-source variability of DCs, thus facilitating interpolation of DCs for practical dose assessments.
- The report discusses alternative methods of accounting for contributions of radioactive progeny to DCs. A method which uses ratio of time-integrated activities of the parent radionuclide and its radioactive progeny is shown as ‘fit for purpose’ for practical dose assessment tasks.
- The report introduces the software tool BiotaDC which is designed to allow assessment of DCs for user-defined types of biota exposed to any radionuclide in the current database. The tool provides various approaches to the inclusion of contributions from radioactive progeny.
- The report introduces some allometric equations for mammals formulated using a generalised approach which takes into account curvatures in the observed allometric relationships as well as quantifies their uncertainties.

GLOSSARY

Absorbed dose, D (ICRU, 2011)

The quotient of dε by dm, where dε is the mean energy imparted by ionising radiation to matter of mass dm. The unit of absorbed dose is J kg^{-1}, and its special name is gray (Gy).

Kerma, K (ICRU, 2011)

The quotient of dE_{tr} by dm, where dE_{tr} is the mean sum of the initial kinetic energies of all charged particles in a mass dm of a material by the uncharged particles incident on dm. The unit of kerma is J kg^{-1}, and its special name is gray (Gy).

Dose coefficient (for non-human biota), DC

A coefficient relating an absorbed dose rate in the whole body or in a part of it and radionuclide activity concentration in the body for internal exposure or in the environment in the case of external exposures. In the present report, for exposure to internally-distributed sources, DCs are formulated in units of dose rate (µGy h^{-1}) per unit activity concentration in the body (Bq kg^{-1}), while for external exposures, these dose rates are given as per unit mass (Bq kg^{-1}), surface (Bq m^{-2}) or volume (Bq L^{-1} or Bq m^{-3}) activity concentrations. As recommended by ICRP (2007) and applied already to dosimetric data for humans (ICRP, 2012), the term “dose coefficients” replaces here the previously used terms “dose conversion coefficients" and "dose conversion factors", thus resulting in harmonised dosimetric terminology across the ICRP publications.

Dose equivalent, H

The product of D and Q at a point in tissue, where D is the absorbed dose and Q is the quality factor for the specific radiation at this point, thus:

$H = D\,Q$

The unit of dose equivalent is J kg^{-1}, and its special name is sievert (Sv).

Dose limit

The value of the effective dose or the equivalent dose to individuals from planned exposure situations that shall not be exceeded.

Fluence, Φ (ICRU, 2011)

The quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da. The unit of fluence is m^{-2}.

Occupancy factor (for non-human biota)

For calculation of external doses, the occupancy factor is the fraction of time that an organism spends at a specified location in its habitat (whether underground, on the soil/sediment surface, or fully immersed in air or water).

Relative biological effectiveness, RBE (ICRP, 2010, 2013a,b)

A theoretical concept that expresses property of the given radiation type to affect living biological tissue. RBE is defined as the ratio of absorbed dose of a low-linear-energy-transfer reference radiation to absorbed dose of the radiation considered that gives an identical biological effect. RBE values vary with absorbed dose, dose rate, and biological endpoint considered.

Radiation weighting factor, w_R (ICRP, 2010, 2013a,b)

A practical method (function or numerical value) used to represent relative biological effectiveness for specific type of radiation, based on existing scientific knowledge and adopted by consensus or via recommendations. Within the system of human radiological protection, it is used to define and to derive the equivalent dose from the mean absorbed dose in an organ or tissue.

Superposition principle (dosimetry)

Superposition principle is based on additivity of absorbed dose, and means that the total dose in a target region created by independent radiation sources can be represented as a sum of doses created separately by each of these sources.

1. INTRODUCTION

(1) Radiological protection of the environment has increasingly attracted attention during the last decades, and the International Commission on Radiological Protection (ICRP) has addressed this topic in a series of reports (ICRP, 2003a, 2008b, 2009, 2014). Assessment of the potential radiation impact of environmental contamination with radionuclides in order to prevent or reduce radiation effects among living organisms requires assessments of radiation doses. The diversity of flora and fauna with regard to habitats, lifestyles, body shapes and masses, feeding, metabolism and exposure conditions creates a specific challenge when developing and applying dosimetric models for assessing exposures of animals and plants from radioactivity in the environment. As an attempt to deal with the diversity of biota, a group of Reference Animals and Plants (RAPs) has been introduced by ICRP (2003a). Correspondingly, *Publication 108* (ICRP, 2008b) provided extensive sets of dose coefficients (DCs) for these reference entities.

(2) The current ICRP dosimetric approach for non-human biota has been outlined in *Publication 108* (ICRP, 2008b). The approach is based on extensive experience gained during decades of radioecological and dosimetric studies. It has a strong link to the methodology and data developed in the European Union (EU)-supported projects FASSET (Larsson, 2004) and ERICA (Larsson, 2008). The dosimetric data of *Publication 108* were calculated using essentially the same methodology and computational tools as those of the ERICA assessment tool (Brown et al., 2008) and used the radionuclide emission database of *Publication 38* (ICRP, 1983).

(3) Although extensive, the set of published DCs for non-human biota has been sometimes regarded as limited, either because of the restricted set of RAPs considered or because of DCs missing for certain radionuclides or particular exposure geometries. These limitations and some internal inconsistencies have now been addressed and this report updates the ICRP dosimetric approach for non-human biota with new data and methods that have emerged since *Publication 108.* The report presents revised and new dosimetric methodology and data as well as it introduces new versatile software tool.

2. MAIN ASSUMPTIONS AND TERMS

(4) The current ICRP dosimetric approach for non-human biota uses the concept of absorbed dose, i.e. the mean radiation energy absorbed per unit mass of matter. The main dosimetric quantities, primarily as DCs, are correspondingly defined in terms of absorbed dose.

(5) The effects of radiation on living tissues are known to depend on the type and energy of radiation or, more precisely, on density of ionisation produced by the radiation in tissue, which is expressed by the linear energy transfer (LET). These effects are accounted for in human radiological protection dosimetry by introducing the concept of equivalent dose. The latter is calculated from absorbed dose using radiation weighting factors (w_R) that numerically express radiation quality in respect to specific protection endpoints (ICRP, 2003b, 2007). Radiological protection endpoints for animals and plants (ICRP, 2014a) differ from those for humans; nevertheless, a similar concept of w_R can be adopted for non-human biota (Table 2.1). Numerical values of w_R for various non-human organisms are subject to discussion, and ICRP has not yet made recommendations on this topic; however, others (e.g. UNSCEAR, 2008; Higley et al., 2012) have published values. To facilitate the possible application of w_R to the DCs presented in Annex B of this report, fractions of the total dose due to different radiation types are provided separately. These radiation types are: (a) spontaneous fission fragments and α-recoil nuclei, (b) α-particles, (c) low-energy (E_β <10 keV) electrons and photons, and (d) higher-energy electrons and photons. Thus, weighted dose can be readily computed as a product of the DCs and the sum of the radiation fractions weighted with the values of the adopted w_R.

Table 2.1. Comparison of dosimetric quantities underlying the ICRP systems of radiological protection of human and non-human biota.

	Human	Non-human
Primary dose response	Absorbed dose (Gy) averaged over organ or tissue	Absorbed dose (Gy) whole body-averaged
Radiological protection endpoints	For individuals (gender-averaged), mostly, stochastic (late) effects	For populations, mostly tissue reactions (deterministic effects)
RBE relevance	At low doses and dose rates	At moderate and high doses and dose rates
Weighting for biological effectiveness of radiation	Radiation weighting factor, w_R, relating to stochastic effects (principally cancer)	Currently no recommended weighting factors
Dose adjusted for radiation quality	Equivalent dose (Sv)	Currently no recommended quantity; potentially, weighted absorbed dose (Gy)
Definition of control levels for radiological protection	Effective dose (Sv), weighted with tissue weighting factors, w_T, reflecting organ-specific risks of cancer and heritable effects	Derived Consideration Reference Level (mGy d^{-1}) in terms of weighted absorbed dose rates to the whole organism

RBE, relative biological effectiveness.

(6) Assessment of exposures of non-human biota in their natural environments can be a more complicated task than dealing with humans, because of the wider variability and vast

diversity of non-human biota and of their exposure conditions. It is also necessary to consider possible risks of importance in relation to exposures of non-human species, namely risks of population depletion. Consequently, the aim is to develop and use simple but plausible and robust models to deal with the diversity of environmental exposures of non-human biota. For example, only simplified shapes are used to describe the body of an organism, and no account is taken of their internal structures or organs. Additionally, metabolism and the biokinetic behaviour of radionuclides within organisms are not considered. The calculated DCs are defined per unit average concentrations of radionuclides in the body or in the surrounding media. Such definitions imply assumptions of uniform distribution of radioactivity throughout the body and in the surrounding environment.

(7) Assessment of internal doses requires knowledge of DCs and activity concentrations in the organisms' bodies. The latter is often unknown but is estimated using empirically defined transfer factors or by modelling transfer of radioactive materials in the environment and intake by the organisms of concern. Uncertainties of such model estimates can be high and significantly exceed those inherent to DCs.

3. DOSIMETRY SYSTEM OF ICRP FOR NON-HUMAN BIOTA

(8) The dosimetric approach adopted by ICRP and presented in *Publication 108* is, to a large extent, built around the uniform isotropic model introduced by Loevinger and Berman (1968, 1976). The model represents the organism and its environment as an infinite homogeneous medium uniformly filled by isotropic radiation sources. The model can be applied if the density and elemental composition of the organism's tissues are close to that of water, and if the distribution of radioactivity in the organism's body or in the surrounding environment can be assumed to be uniform. Aquatic organisms closely match the conditions of this uniform isotropic model, and thus the model naturally appears as a plausible choice for modelling radiation exposures of aquatic biota.

(9) Under the assumptions of the uniform isotropic model, the dose rate per unit activity concentration remains the same in every point of the medium and is equal to the 'full absorption limit', which is numerically expressed as the total energy emitted by the radiation source per single event of radioactive decay (nuclear transformation):

$$D_\infty = C\left(\sum\nolimits_i Y_i E_i + \int N(E)\,E\,dE\right) \qquad (1)$$

where D_∞ (µGy h^{-1} Bq^{-1} kg) is the total absorbed dose rate per unit activity concentration in the medium; $C = 5.767 \times 10^{-4}$ is the unit conversion constant; Y_i (Bq^{-1} s^{-1}) and E_i (MeV) are the yields and energies of discrete energy radiation (x rays and γ quanta, Auger and internal conversion electrons), respectively; and $N(E)$ (Bq^{-1} s^{-1} MeV^{-1}) is the spectrum of continuous energy radiation (i.e. electrons from β decay and bremsstrahlung photons).

(10) Within the framework of the uniform isotropic model, DCs for internal and external exposures can be expressed as fractions of the 'full absorption limit' value (Fig. 3.1). DCs for internal exposure, $DC_{\text{int}} = D(A \leftarrow A)$, are conveniently expressed by the absorbed fractions (AFs) ϕ, defined as a quotient of energy deposited in the body and the total energy emitted by radioactive sources in the body per single nuclear transformation (radioactive decay):

$$DC_{\text{int}} = C\left(\sum\nolimits_i Y_i\,E_i\,\phi(E_i) + \int N(E)\,E\,\phi(E)\,dE\right). \qquad (2)$$

Consequently, the dose rate of external exposure, $DCC_{ext} = D(A \leftarrow B)$, is simply a complement of the internal dose to the value of the 'full absorption limit' (Fig. 3.1):

$$DC_{ext} = D_\infty - DC_{\text{int}} = C\left(\sum\nolimits_i Y_i\,E_i\left(1-\phi(E_i)\right) + \int N(E)\,E\left(1-\phi(E)\right)dE\right). \quad (3)$$

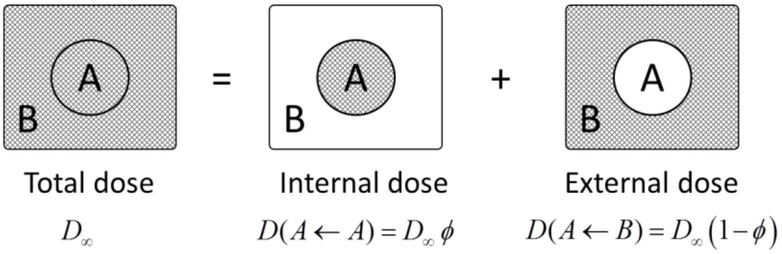

Fig. 3.1. Uniform isotropic model: the total dose for the organism *A* in the medium B is represented as a sum of doses from internal and external sources. Equations shown are for monoenergetic radiation after Ulanovsky and Pröhl (2012).

(11) Provided that radionuclide emission data are available, DC calculation for aquatic biota requires only knowledge of the AF for radiation of various types and energies and for bodies of various shapes and masses. Short-range radiations (α-particles, α-recoil nuclei, and spontaneous fission fragments) can be regarded as non-penetrating and all their energy is assumed to be deposited locally. In terms of the adopted approach, for all practical purposes, AFs for these radiation types are equal to one.

(12) AFs for penetrating radiation (photons and electrons) have been assessed based on systematically calculated energy-dependent AFs for simple spherical and ellipsoidal bodies surrounded by infinite water medium (Ulanovsky and Pröhl, 2006). The calculated photon and electron AFs were found to be smooth functions of particle energy and the mass of the organism's body; thus, AFs for other masses and energies could be easily derived by interpolation from the data provided.

(13) To facilitate interpolation of the AFs between different shapes, an analytical approximation was suggested (Ulanovsky and Pröhl, 2006), which provided a method for the transformation of AFs for spheres to those for arbitrary ellipsoidal bodies by means of a scaling factor. The scaling factor is a function of a 'non-sphericity parameter' η, which expresses the degree of deviation from sphericity for the given ellipsoidal shape. The parameter η is a quotient of the surface area of a sphere (S_0) and that of an ellipsoid (S) of equal volume (mass). Thus, for spheres, the parameter value is equal to one, whereas for non-spherical bodies, it varies between zero and one. The closer the parameter to zero, the more shape of the body deviates from a sphere. A value of zero for the parameter corresponds to an infinitesimally thin line or plane.

(14) The analytical approximation allows the calculation of photon and electron AFs for organisms with body masses in the range from 1 mg to 1000 kg and with body shapes from spherical ($\eta = 1$) to highly protracted or oblate ellipsoids ($\eta = 0.15$). The uncertainty of the approximation (expressed by absolute coefficient of variation) was shown not to exceed 15% for photons and 10% for electrons (Ulanovsky and Pröhl, 2006). Although the analytical approximation is defined for the above body mass range, a technique can be used to extrapolate DCs to mass values beyond this range. Such extrapolation exploits the fact that within the uniform isotropic model, neither external nor internal dose can exceed the 'full absorption limit'. Details and justification of the extrapolation technique can be found in Ulanovsky and Pröhl (2006).

(15) Amato et al. (2009, 2011, 2013, 2014) have recently reported alternative analytical approximations for AFs of γ-, β-, and α-radiations in ellipsoidal bodies. These approximations, being practical and computationally convenient, were developed for a limited set of ellipsoidal bodies and radionuclide sources, thus their applicability needs investigation, and thorough comparison with the approach adopted in *Publication 108* and this report appears to be necessary.

(16) Being originally developed for internal and external exposures of aquatic organisms, the analytical approximation of AFs for non-spherical bodies was applied to calculation of DCs for internal exposure of terrestrial animals and plants (Ulanovsky et al., 2008; Ulanovsky and Pröhl, 2008). AFs for aquatic organisms are somewhat higher than those for the similar terrestrial organisms, because of the effect of secondary radiation scattered back

from water medium surrounding an aquatic organism. However, in most practical cases, the effect of backscattered radiation can be safely neglected. For example, the calculation by Monte Carlo methods of DCs for a spherical organism with a mass of 1 mg in water and in air have shown that the overall contribution of the backscattered radiation is 6% for 1.5-MeV photons and less than 1% for 0.15-MeV photons (Ulanovsky et al., 2008a).

(17) External exposure of terrestrial animals and plants in most cases cannot be modelled using the uniform isotropic model; thus the DCs for external exposure of terrestrial animals were mostly based on results of various ad hoc models, primarily those developed in the framework of FASSET project (Taranenko et al., 2004). Namely, using a set of pre-defined terrestrial organisms with body masses varying from 0.17 g to 550 kg, DCs have been computed for monoenergetic photon sources in soil. Two types of source distribution in soil had been considered: planar at a depth of 0.5 g cm^{-2} and uniform volume distribution in the upper 10 cm of soil. Additionally, exposure of burrowing animals with masses from 0.17 g to 6.6 kg was estimated for location in the middle of 50-cm-thick source in the upper soil. External exposure of vegetation was estimated using simple models of infinite homogeneous layers of different thickness parallel to the ground, representing grasses, shrubs and trees.

(18) External exposure of terrestrial animals and plants was recognised as not adequately addressed by the ICRP dosimetric methodology, considering a narrower range of body masses than that for aquatic organisms, a limited set of environmental sources, and providing a very limited set of DCs for organisms located not on the ground surface but above it at various heights. Therefore, systematic extension of the dataset necessary for estimation of the external exposures of terrestrial organism appeared among the priority tasks in the extension and improvement of the existing methodology.

4. EXTENSION OF THE EXISTING ICRP DOSIMETRY SYSTEM

4.1. Ranges of applicability

(19) The extended dosimetry system presented in this report improves compatibility between the treatment of internal and external exposure of terrestrial organisms by providing DCs for the same range of body masses: from 1 mg to 1000 kg. Also, two new sources of external exposure of terrestrial organisms are added: infinitely deep uniform source in soil and uniformly contaminated air above the ground surface. Forms of biota, body masses and shapes, types of exposure, and radiation sources considered in the current dosimetry system are shown in Table 4.1.

4.2. Radionuclide emission data

(20) *Publication 107* (ICRP, 2008a) replaced *Publication 38* (ICRP, 1983) with an updated and significantly extended dataset, considering radiation emitted due to decay of 1252 radioactive isotopes of 97 elements. New DCs presented here have been recalculated using the radionuclide emission data of *Publication 107* and may therefore differ for the values given in *Publication 108*. The transition to the new database also necessitated the calculation of new photon and electron AFs up to 10 MeV to address maximum emitted energy for some additional radionuclides. As with the previous data from *Publication 38*, numerical integration of continuous spectra of β electrons is used in the DC calculation, thus accounting for different ranges of electrons of various energies in the same emission spectrum.

4.3. Models for external exposure

(21) For aquatic organisms, external exposure is treated under the assumptions of the uniform isotropic model, enabling both internal and external DCs to be coherently assessed by the same method and within the limits imposed on a body's mass and shape. The simplest geometry of an infinite medium is adequate for aquatic biota in water. Exposure of aquatic biota at the interface between water and sediment can be easily reduced to a simple exposure geometry by applying the superposition principle and accounting for the similar density of water (1000 kg m^{-3}) and underwater sediment (typically, around 1500 kg m^{-3}).

Table 4.1. Types of organisms, exposure conditions and dosimetric models represented in the current dosimetric methodology for non-human biota.

Environment	Biota	Exposure type and radiation source (units)	Exposure model	Body mass (kg)	Shapes	Non-sphericity	Interpolation
Aquatic	Animals plants[a]	Internal exposure, uniform source (Bq kg^{-1})	Uniform isotropic	10^{-6}–10^{3}	Spheres, ellipsoids	$0.15< \eta \leq 1.0$	Body mass, shape
	Animals plants[a]	External exposure, uniform source (Bq L^{-1})	Uniform isotropic	10^{-6}–10^{3}	Spheres, ellipsoids	$0.15< \eta \leq 1.0$	Body mass, shape
Terrestrial	Animals plants[a]	Internal exposure, uniform source (Bq kg^{-1})	Uniform isotropic	10^{-6}–10^{3}	Spheres, ellipsoids	$0.15< \eta \leq 1.0$	Body mass, shape
	Animals plants[a]	External exposure, 50-cm volume source in soil (Bq kg^{-1})	In soil	1.7×10^{-4}–6.6	Spheres, ellipsoids	pre-defined values	Body mass
	Animals plants[a]	External exposure, • air above ground (Bq m^{-3}) • plane source in soil (Bq m^{-2}) • 10-cm volume source in soil (Bq kg^{-1}) • infinite volume source in soil (Bq kg^{-1})	On and above the ground (0.1–500 m)	10^{-6}–10^{3}	Spheres	$\eta = 1.0$	Body mass, height above the ground
	Vegetation	External exposure, • plane in soil (Bq m^{-2}) • 10-cm volume sources in soil (Bq kg^{-1})	Above the ground	Density[b] (kg m^{-3}): 13.7 (grass) 3.4–6.8 (shrub) 2.3–2.9 (tree)	Infinite homogeneous slabs	n.a.[c]	Density

[a] Ignoring minor effects due to different chemical composition of tissue.

[b] Density of homogeneous mixture of biomass and air.

[c] Not applicable.

(22) Estimating DCs for external exposure of terrestrial animals and plants is a more complicated and laborious task. This is because of the considerable variations in exposure geometry, composition and the densities of soil, air and organic matter in the terrestrial environments that vary considerably. External exposure scenarios cannot, in general, be adequately taken into account by the uniform isotropic model.

(23) Current DCs for external exposure of terrestrial organisms are based on results obtained by Monte Carlo simulation of radiation transport in terrestrial environments (Taranenko et al., 2004; Ulanovsky, 2014), where only external exposure to photons was considered. Any contributions from α particles and electrons to external doses to terrestrial organisms were neglected because of their short range and due to the fact that radiosensitive tissues are usually covered by inert layers (e.g. dead skin, fur, feather, shell or bark), thus being located beyond the reach of low-penetrating radiation.

(24) Due to the complexity of the processes involved and the variation between terrestrial life forms, all possible exposure conditions cannot be addressed. Generalised representative cases as defined by source configuration and energy, contaminated media, organism sizes and source/target relative locations have therefore been selected for detailed consideration. DCs for any intermediate exposure configurations for which detailed calculations have not been made can then be deduced by interpolation between the calculated DCs. Here, the following source-target scenarios are considered (also see Table 4.1):

- External exposure of in-soil RAPs situated in the middle of a uniformly contaminated volume radionuclide source with a thickness of 50 cm.
- External exposure of animals and plants on and above the ground surface due to a planar radionuclide source at a depth of 0.5 g cm^{-2} in the soil, which can be regarded as representation of radioactivity freshly deposited on the ground, accounting for surface roughness and initial migration (Jacob and Paretzke, 1986).
- External exposure of animals and plants on and above the ground surface due to a uniformly contaminated volume radionuclide source within soil with a thickness of 10 cm, which can be treated as representative for an aged contamination of soil following substantial downward migration and activity redistribution.
- External exposure of animals and plants on and above the ground surface due to an infinitely deep radioactive source in soil, which can be regarded as a source representative of naturally occurring radionuclides or anthropogenic contamination of the environment strongly affected by downward migration, agriculture or decontamination practices.
- External exposure of animals and plants located on and above the ground surface due to immersion in air contaminated with radioactive materials.

(25) With the exception of in-soil exposure, all other scenarios have been systematically reassessed using the new approach (Ulanovsky, 2014). In the adopted approach, whole body doses arising from external exposure above the ground surface due to various photon sources in soil or in the ambient air can be estimated for arbitrary heights above the ground surface up to 500 m and for any organisms with body masses from 1 mg to 1000 kg. Such flexibility is possible due to the factorisation of the external dose into free-in-air kerma spectrum and energy-dependent ratios of whole body absorbed dose and air kerma.

(26) The free-in-air kerma K_{air} (ICRU, 2011) at height H above radioactively contaminated terrain with photon sources of energy E_x can be expressed as the integral of the mass-energy transfer factor for the specific differential photon fluence (spectrum) as follows:

$$K_{air}\left(E_x,H\right)=\int_0^{E_x}\frac{\mu_{tr}}{\rho}\left(E\right)E\frac{d\Phi}{dE}\left(E,E_x,H\right)dE=\int_0^{E_x}K\left(E,E_x,H\right)dE \qquad (4)$$

where $\frac{\mu_{tr}}{\rho}(E)$ is the mass-energy transfer coefficient (cm^2 g^{-1}), $\frac{d\Phi}{dE}(E, E_x, H)$ is the angle-integrated differential photon fluence per source particle (cm^{-2} γ^{-1} MeV^{-1}) and, correspondingly, $K(E, E_x, H)$ is the differential air kerma per source particle (Gy γ^{-1} MeV^{-1}).

(27) The differential air kerma is known to depend on the geometry of the terrain and of source distribution, on the distance between the source and the target biological receptor, on the soil density, the chemical composition and water content of the soil and physical properties of ambient air (Beck and de Planque, 1968; Jacob and Paretzke, 1986; Eckerman and Ryman, 1993; ICRU, 1994). Due to this dependence on multiple factors, Monte Carlo simulation of radiation transport in the environment is the only practical method of assessing the kerma spectra. Correspondingly, the kerma spectra were calculated for the sources detailed above in an idealised infinite terrain with homogeneous soil and plane ground interface (Ulanovsky, 2014). An example of the differential air kerma for two photon sources in soil, namely, planar at a depth of 0.5 g cm^{-2} and volume in the upper 10-cm-thick layer, at heights above ground of 1 and 500 m, is given in Fig. 4.1, where the kerma spectra are shown in group representation for 1-MeV source photons.

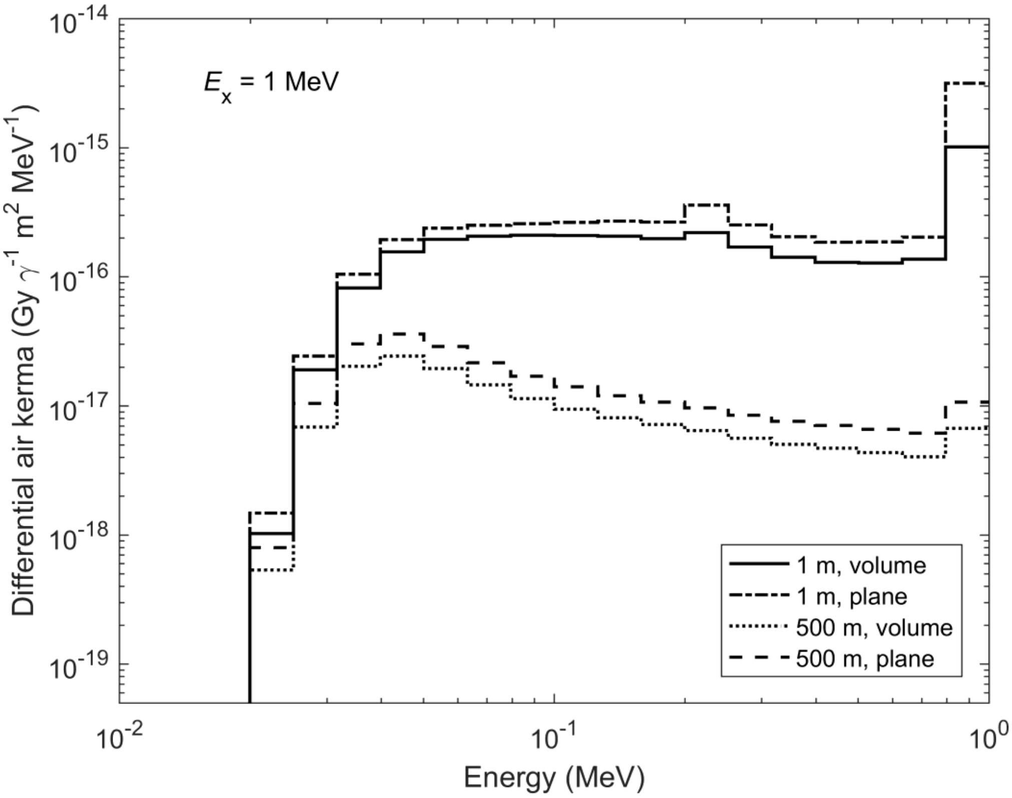

Fig. 4.1. Differential air kerma (kerma spectra) for planar at depth 0.5 g cm^{-2} and 10-cm-thick volume sources in soil at height 1 and 500 m above ground surface [based on data from Ulanovsky (2014)].

(28) Absorbed dose (per source particle) in an organism with body mass M located above contaminated soil or immersed in contaminated ambient air can be expressed via the

differential air kerma at the same location and organism-specific energy-dependent dose response:

$$D\left(E_x,H,M\right)=\int_0^{E_x} K\left(E,E_x,H\right)R\left(E,M\right)dE\,, \qquad (5)$$

where the dose response *R(E,M)* denotes a ratio of mean absorbed dose in the organism of mass *M* and the free-in-air kerma at the same location due to monoenergetic photons incident on the organism's body surface.

(29) The conversion factor *R(E,M)* generally depends on the energy and angular distribution of incident photon fluence as well as on the mass and geometric shape of the organism. When the dosimetric endpoint is the average absorbed dose in the whole body, the subtle effects of anisotropic angular dependence in the dose response can be neglected and angular-integrated kerma spectra can be used. Correspondingly, biota above ground can be modelled as tissue-equivalent spheres and their dose response per air kerma can be computed for isotropic photon fields.

(30) An example of the response *R(E,M)* is given in Fig. 4.2, where ratios of average whole-body absorbed dose and air kerma are shown as computed for tissue-equivalent spheres with masses from 1 mg to 1000 kg located in an isotropic field of monoenergetic photons with energies ranging from 10 keV to 10 MeV (Ulanovsky, 2014). It can be seen from Fig. 4.2 that the strong attenuation of low-energy photons in massive bodies leads to a reduction of the average absorbed dose when compared to free-in-air kerma. This is the case of 'opaque' bodies, which are 'non-transparent' to the specific radiation. A similar reduction of absorbed dose can be observed in the opposite case of low body masses and high energies of source photons; this is the case of bodies 'transparent' to radiation of the given energy. It is also worth noting that in the range of source energies from approximately 20 keV to 2 MeV and for bodies with masses from approximately 1 g to 100 kg, the absorbed dose-to-air kerma ratio does not vary much, showing values between 0.8 and 1.15, thus indicating that, for the given conditions, there may be negligible differences in absorbed dose in the whole body from the air kerma, such that air kerma can serve as a reasonable surrogate for the average whole-body absorbed dose.

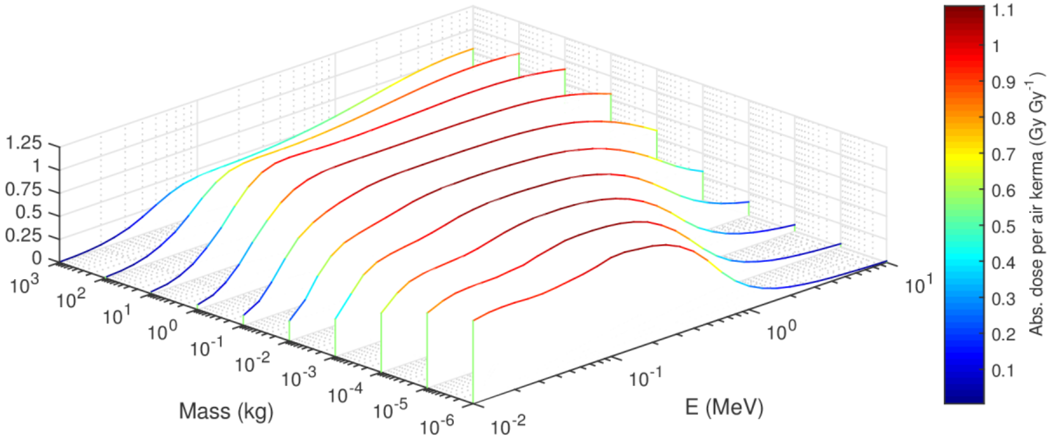

Fig. 4.2. Average absorbed dose per air kerma conversion factors (Gy Gy^{-1}) for tissue-equivalent spheres of various masses in an isotropic field of monoenergetic photons [Based on data from Ulanovsky (2014)].

(31) Use of spherical shapes for modelling bodies of various organisms that would be better represented by non-spherical shapes, introduces some uncertainties in modelled DCs and reduces their applicability as an assessment of average absorbed doses in the whole body. Realistic representation of the body shape and its internal structure as well as irradiation geometry might be important when dosimetric endpoints are absorbed doses in particular organs or exposure conditions suggest highly anisotropic irradiation of a static or slowly moving organism. However, if the study endpoint is the average absorbed dose in the whole body of an agile organism exposed in highly variable environmental conditions, then the absorbed dose-per-air kerma coefficients for simple spheres can be regarded as a reasonable approximation. An example is shown in Fig. 4.3, where absorbed dose-per-air kerma values for a 70-kg sphere (closed circles) and for a 70-kg ellipsoid with extensions 167.2 × 40 × 20 cm (closed squares) are compared to effective dose-per-kerma values from *Publication 116* (ICRP, 2010) for rotational (ROT-) and isotropic (ISO-) fields (open squares and circles, respectively). All response curves in the figure are remarkably similar and the effect of non-spherical body shape on the dose-kerma ratio *R(E,M)* is small.

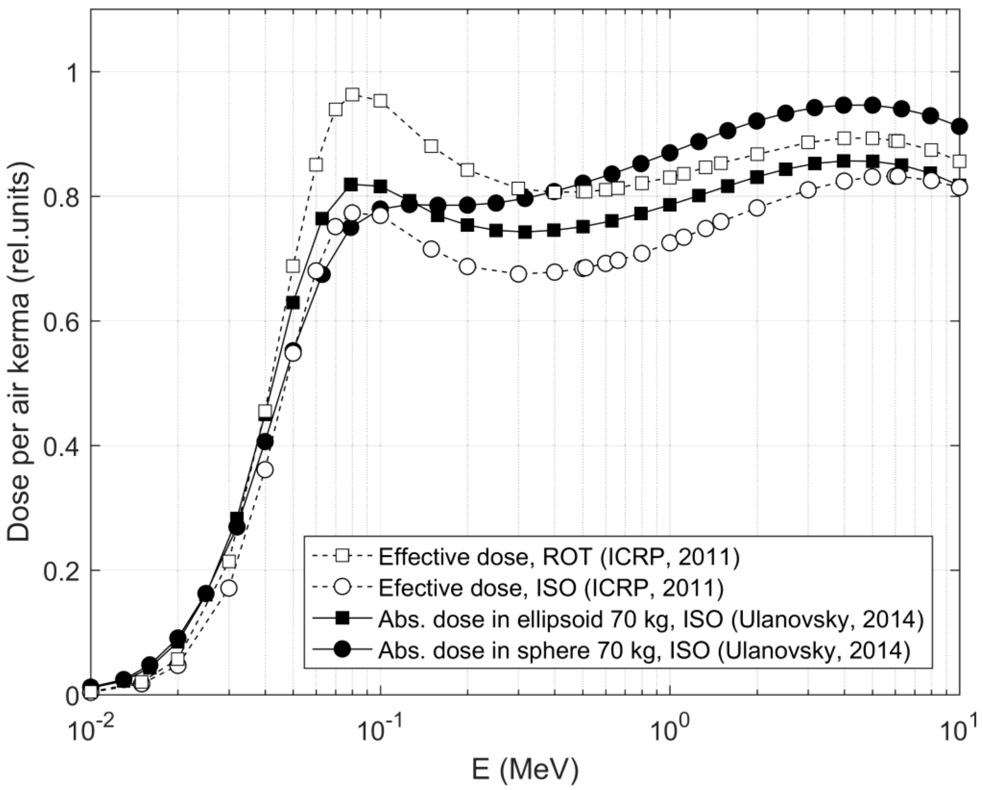

Fig. 4.3. Comparison of dose-per-kerma ratios (Gy Gy^{-1}) for a tissue-equivalent 70-kg sphere and a 70-kg ellipsoid in an isotropic field of mono-energetic photons (Ulanovsky, 2014) with effective dose per air kerma (Sv Gy^{-1}) for an adult human in ROT and ISO external photons fields (ICRP, 2010).

(32) Some of the earlier simpler models (Taranenko et al., 2004) are still used for the present tabulation of external exposure DCs for terrestrial plants. These models represent plants as uniform mixtures of biomass and air in the form of slabs placed above the ground. Grass is represented by a 10-cm-thick layer with density of 13.7 kg m^{-3}, bushes and shrub are described by a 90-cm-thick layer of density in the range 3.4–6.8 kg m^{-3} over the grass layer,

and trees are modelled as a 9-m-thick layer of density in the range 2.3–2.9 kg m^{-3} over the shrub layer. Such simple models may be inadequate for some specific assessments, e.g. when looking for realistic distribution of external doses in single plants or to external exposures from radioactive sources in air or distributed in soil depth. These DCs are given for only two types of radioactive sources in soil: planar at depth 0.5 g cm^{-2} and 10-cm-thick volume.

(33) The DCs for external exposures of terrestrial animals and plants were calculated for photon-emitting sources only, neglecting exposures to secondary photon radiation (bremsstrahlung) produced by electrons decelerating in matter. Effects of bremsstrahlung are generally weak and can be considered as corrections of a lower order to the dose estimates in many practical dose assessment tasks. However, external exposure in environments highly contaminated by pure β emitters, such as ^{90}Sr or ^{32}P, could be mostly due to penetrating secondary photon radiation. Such situations should be considered as non-standard and not covered within the framework of the currently adopted dosimetric approach, thus requiring special considerations and, possibly, development of new non-standard dose assessment techniques.

4.4. Effect of radioactive progeny to DC

(34) Decay products of many radionuclides are themselves radioactive and may contribute to radiation exposure. The contribution of radioactive progeny to radiation exposure of non-human biota is commonly attributed to the parent radionuclide, subject to various assumptions. The most common approach is a simple and pragmatic method in which only part of the full decay chain is taken into account assuming full equilibrium between the parent radionuclide and its progeny. Criteria for truncation of decay chains are commonly based on selection of an upper limit for physical half-life of a daughter to be accounted for in the given chain. Selection of the upper limit varies in the literature, with values of 1 d (Amiro, 1997), 30 d (Jones, 2000; DOE, 2002), 180 d (Yu et al., 1993), and 100 y (Higley et al., 2003). The approach adopted in *Publication 108* (ICRP, 2008b) was to apply a chain cut-off criterion of 10 d, as in the FASSET and ERICA projects (Larsson, 2004, 2008) and in the ERICA tool (Brown et al., 2008). Additionally, within the ERICA tool and the ICRP approach, the chain is cut at a daughter nuclide if its physical half-life is longer than that of the parent, because in such case the parent and the daughter would never reach equilibrium.

(35) Truncation of decay chains based on criteria of maximum allowed physical half-life of a daughter is a simple and pragmatic solution when dealing with a limited set of radionuclides of immediate practical importance for a specific assessment. However, depending on the assessment task, the chain truncation criteria may vary and need to be modified accordingly. Moreover, development of software tools for DC calculation, which use a comprehensive database of radionuclides, also requires the introduction of an accurate and flexible method for accounting for radioactive progeny. Even more importantly, it should be recognised that the method of cutting decay chain and assigning of equilibrium activity ratios to chain members implicitly assumes that the decay chain is linear, and the method may lead to ambiguous results when applied to complex, branching and merging, decay chains.

(36) More robust and flexible approaches, capable of addressing different exposure scenarios, can be formulated using weighting factors for the members of decay chains based on their time-integrated activities. Accounting only for radioactive decay, i.e. implying long retention in the organism relative to radioactive decay in case of internal exposure or no migration of radioactivity deposited in the environment, one can express the dose as follows:

$$D = \varepsilon_p \, \tilde{q}_p + \sum_j \varepsilon_j \, \tilde{q}_j = \tilde{q}_p \left(\varepsilon_p + \sum_j \varepsilon_j \, \frac{\tilde{q}_j}{\tilde{q}_p} \right), \tag{6}$$

where D is the absorbed dose (Gy); ε is the energy emitted per single decay of the parent (index p) and the daughter (index j) nuclides (J); and $\tilde{q}$ is the time-integrated activity concentration (Bq s kg^{-1}) of the parent and the daughter, similarly indexed. As seen from Eq. (6), the inclusion of radioactive progeny results in an increase of energy attributed to a single decay of the parent radionuclide and this effect is expressed via the relative number of radioactive decays of the daughter radionuclides per single decay of the parent one.

(37) Such an approach implemented within software tools for DC calculation can account for the contribution of radioactive progeny for all types of radioactive decay chains by numerical integration of the differential equations describing the decay chain. Correspondingly, the integration time can be selected to be pertinent to the specific assessment task, e.g. based on the lifetime and behaviour of the organism of concern, on exposure conditions in its habitat and temporal changes in radioactive contamination of the environment. An example of such an approach was provided by Ulanovsky (2014), where DCs for external exposure of terrestrial biota were computed for different averaging times depending on the environmental source: 15 d for a freshly deposited (planar) source in soil, 1 y for an aged (10-cm-thick volume) source in soil, and an infinite time (secular equilibrium ratios) for natural radionuclides uniformly distributed in the soil depth. For computation of DCs accounting for ingrowth of radioactive progeny within given time intervals, the special software tool can be used (see below).

4.5. DC tables and software tool BiotaDC

(38) This report is complemented by tables of DCs for RAPs (Annex B). The tables are given for the same list of radionuclides as in *Publication 108* (ICRP, 2008b), but have been recalculated using the new radiation emission dataset from *Publication 107* (ICRP, 2008a). Another distinctive feature of the new tables is their organisation and layout, which substantially differ from those used in *Publication 108*. The present tables are organised to present data on individual radionuclides, making it easier to identify inter-species and inter-source differences. As can be seen from the DC tables (Annex B), in many cases such differences can be regarded as insignificant or low, indicating that DCs are not among the main contributors to assessed uncertainties for exposure scenarios in these cases and that attention should be focussed on other, probably more significant, sources of uncertainty in the estimated doses.

(39) The current tables include DCs for external exposure of terrestrial animals and plants on and above the ground surface for radioactive sources in the upper 10 cm of soil and in the ambient air. Additionally, DCs are given for exposure below ground surface in soil of small animals (earthworm, frog and mouse). DCs for planar or infinitely deep sources in soil are not shown in the printed tables but they can be easily derived using the software tool BiotaDC (see Annex C). Similarly, DCs for flying organisms (bee, bird) are presented only for two exemplary values of flight height and the coefficients for other conditions, characterised by flight height and mass of the organism, can be also derived using the software tool. Table 4.2 shows the external exposure conditions considered in the published version of the DC tables.

Table 4.2. Summary of external exposure scenarios included in the DC tables (see Annex B).

Reference Animal and Plants (RAPs)	Aquatic environment	Terrestrial environment			
		In soil [a]	On soil [b]	Above soil [b]	Immersion in air
Bee			x	x (*H*=2 m)	x
Wild grass (spike)	x		x		x
Earthworm (elongated)		x	x		x
Frog	x	x	x		x
Rat		x	x		x
Duck	x		x	x (*H* = 10 m)	x
Deer			x		x
Pine tree trunk			x		
Brown seaweed	x				
Crab	x				
Trout	x				
Flatfish	x				

[a] Organism exposed in the middle of a 50-cm-thick uniform volume source in soil.

[b] Organism exposed on or above a 10-cm-thick uniform volume source in soil.

(40) To facilitate compatibility with previously published data, the DC tables are calculated here using the same criterion to account for the effect of radioactive progeny as in *Publication 108*, i.e. the decay chain is truncated at the first daughter nuclide with physical half-life of >10 d or that of the parent. Activity ratios between the parent radionuclide and progeny are calculated assuming secular equilibrium conditions.

(41) In *Publication 108*, DCs were given for adult forms of RAPs and for RAPs at various developmental stages (eggs, mass, larvae, etc). The tabulation presented here shows DCs only for adult forms of RAPs, for two reasons. First, as seen from the DC tables in Annex B, variability between DCs for many radionuclides can be regarded as insignificant and ignored, or differences resulting from the mass changes of one organism during development can be relatively easily determined by simple interpolation of the values shown for other RAPs. Second, the software tool BiotaDC (Annex C) is introduced with this report and can be used to generate DCs ‘on demand’ by means of a fully flexible user-friendly interface, accounting for non-standard (user-defined) organisms of specific shapes, body masses and under various exposure conditions, including different methods of accounting for the contribution from radioactive progeny.

(42) The current dosimetry system for non-human biota is built assuming uniform distribution of radioactivity in a homogeneous skeleton-less body. Although in many practically relevant cases these assumptions are reasonable and corresponding uncertainties in DCs are much less than those for other parameters important for dose assessment, there may be situations when the non-uniformity of activity distribution in the body becomes an important consideration in dose calculations. In such situations, simple scaling techniques can be used as suggested in *Publication 108* (ICRP, 2008b).

(43) Additionally, assessment of internal doses to organs can be done using known radionuclide activity in the organ and its mass and applying the assumptions of the uniform isotropic model. Specifically, this can be achieved by replacing the body of the whole organism with an artificial ‘body’ with the size and mass of the organ of interest. These tasks can be readily achieved by interpolating DCs using the published tables or by direct calculation using the software tool BiotaDC (Annex C).

(44) Radiation exposure due to inhalation of radioactively contaminated air is not yet explicitly considered in the current dosimetric approach, as it would require organism-

specific biokinetic data and models. Simplified methods can be applied to conservatively assess inhalation doses using allometric scaling.

(45) Allometric relationships appear as powerful tools in dealing with biota diversity. They numerically express similarities and common properties existing between various organisms. Recent studies (e.g. Kolokotrones et al., 2010) demonstrated that allometric relationships in the form of power law do not always satisfactorily describe biological properties of animals and plants. A concept of generalised allometric relationship was therefore suggested (Ulanovsky, 2016), and generalised allometric equations have been shown for breathing and basal metabolic rates of mammals (Annex A).

(46) As compared to *Publication 108* (ICRP, 2008) and the ERICA tool (Brown et al., 2008), the current methodology for assessment of external exposure DCs for terrestrial animals and plants has been systematically expanded and improved here. Further development might allow for a wider range of irradiation geometries and sources or account for different shapes of organisms' bodies by interpolation techniques. Estimates of organ doses due to external exposure may be required.

5. APPLICATION OF DC TO EXPOSURE ASSESSMENT

(47) This report describes methods and presents a set of DCs for animals and plants. DCs are essential for environmental dose assessments. It is often the case in practical assessments that uncertainties in DCs are small compared to other sources of uncertainty. Such uncertainties can originate from variability of environmental contamination, lifestyle, time spent by organisms in various habitats, and other factors. In this section, the basic principles of dose assessment are reviewed to indicate the place of DCs within an assessment framework, to emphasise simplifying assumptions, and to identify other essential components of the assessment.

(48) Radiological protection of non-human biota is formulated for biological endpoints at the level of populations (ICRP, 2014a), and it can thus be regarded as focussing on tissue reactions of radiation on populations, whereas human radiological protection requires the prevention of tissue reactions and minimisation of stochastic effects (ICRP, 2007). From a dosimetric viewpoint, the consideration of average whole-body dose in animals and plants as appropriate for the objectives of environmental radiological protection is a pragmatic decision. It may be that further analysis of possible tissue reactions may require consideration of organ doses under particular circumstances of exposure. In the protection system for humans (ICRP, 2007), limits are set on organ doses to prevent tissue reactions, while the limitation of stochastic effects employs the protection quantity, effective dose, which sums organ doses according to their contribution to overall stochastic risk (mainly cancer).

(49) For internal exposure, the dose, D (Gy), from radioactivity incorporated in the whole body and acquired during period ΔT can be written as follows:

$$D = \sum_{\nu} \int_{\Delta T} DC_{\nu}(t)\, q_{\nu}(t)\, dt \qquad (7)$$

where $DC_{\nu}(t)$ is the dose coefficient for radionuclide ν and its radioactive progeny at time t (Gy s^{-1} Bq^{-1} kg) and $q_{\nu}(t)$ is the time-dependent activity concentration of the parent radionuclide ν in the whole body (Bq kg^{-1}).

(50) The time dependence of DCs is due to temporal changes of the organism during the exposure time (e.g. growth or transformations) and also due to time-dependent activity ratios of the parent radionuclide and its radioactive progeny in a non-equilibrated decay chain. While the changes related to an organism's growth are generally ignored, changes due to transformations can be addressed by considering the organism at various developmental stages as different species. The latter, for example, was done in *Publication 108* where the adult forms of RAPs were supplemented by organism forms at various development stages (egg, egg mass, larvae, tadpole). The time dependence of DCs due to changes in activity ratios of the parent radionuclide and its radioactive progeny should also be considered, e.g. in the case of environmental contamination by ^{241}Pu, in-growth of the daughter ^{241}Am should be considered for organisms with lifetime of several years or more. As shown in Section 4.4, the contribution of radioactive progeny can be adequately taken into account by selecting appropriate time periods for the calculation of time-integrated activity ratios between the parent and daughter nuclides. The selection of integration times should be conditional on characteristics of the specific assessment task, including the contamination scenario, biota of concern, their behaviour etc.

(51) Eq. (7) represents the dose as the integral of the product of two time-dependent quantities, DC and the activity concentration in the organism. Provided the temporal changes in DCs are small, the equation can be factorised and shown in a simpler form:

$$D \approx \langle DC \rangle_{\Delta T} \sum_{v} \int_{\Delta T} q_v(t)\, dt\,, \tag{8}$$

where $\langle DC \rangle_{\Delta T}$ denotes the average DC for the parent radionuclide and radioactive progeny taken into account with weights derived from relative time-integrated activities for the period ΔT. The value of the time-integration period can be selected as pertinent to a specific assessment task.

(52) As seen from Eq. (7), another essential part of the dose assessment is an estimate of the time-dependent activity concentration in the whole body. If the activity concentration of the radionuclide is not measured, then it has to be estimated. Such estimation can become a challenging task. A widely used approach utilises concentration ratios (CRs), which are commonly applied to derive activity concentrations in the (whole) organism from activity concentration in the surrounding environment. *Publication 114* (ICRP, 2009) has summarised the available data on CRs for non-human biota found in the literature and presented evaluated data along with assessed uncertainties. However, estimates of CRs for many elements are missing or incomplete, while available CRs, being parameters implicitly including many processes assuming equilibrium, often show considerable uncertainties. Inherent uncertainties of CRs are mostly due to individual and environmental variability and non-equilibrium conditions. The latter source of uncertainty is due to the definition of CRs as an equilibrium constant CR between the biota and the surrounding environment.

(53) Non-equilibrium CRs can be expressed as the quotient of the time-dependent activity concentrations in the organism and that in the environment (water, soil, air). Environmental contamination can be highly variable in space and time. Provided that the activity concentration in the environment and intake pathways are known, the activity concentration in the organism's body could in principle be assessed using biokinetic modelling. However, this approach requires biokinetic data for individual radionuclides as well as physiological and anatomical data. Even a simple, single-compartmental, kinetic model is represented by a convolution integral between so-called 'intake' and 'retention' functions:

$$q(t) = \frac{1}{M} \int_0^t I(\tau, \ldots)\, s\, R(t - \tau, \ldots)\, d\tau \tag{9}$$

where M is the body mass (kg), intake function $I(\tau, \ldots)$ is the activity intake rate (Bq s^{-1}), s is the uptake fraction, and retention function $R(t\text{-}\tau, \ldots)$ is the function describing retention of activity in the body after excretion and radioactive decay. The intake function in turn depends on environmental and biological parameters and can be subject to large uncertainties. The retention function is typically expressed by the radioactive decay rate and the biological half-time of elimination. The latter are not readily available for many animals and plants and chemical elements and compounds. The same is true for the uptake fraction. Due to the diversity of biota, biological data needed in dose calculations cannot be measured or collected for every biological organism of interest. Thus, dosimetry of non-human biota relies on alternative methods: interpolations or use of allometric laws, which exploit similarities between similar organisms (see examples in Annex A). However, a growing number of simplified methods and techniques have been suggested, which begin to address this issue based on first-order kinetics or other more advanced approaches factorising metabolism and/or food chain transfers (e.g. Sazykina, 2000; Vives i Batlle et al., 2008; Kryshev et al., 2012; Keum et al., 2015).

(54) Use of CRs is a very approximate way to assess activity concentration in the whole organism, and uncertainty is generally high. Gathering and systematisation of information on biokinetic behaviour of radionuclides in animals and plants would lead to more flexible and realistic dosimetric models. Some models are already available, opening the possibility of time-dependent assessment under non-equilibrium conditions, such as those following the Fukushima accident (Kryshev et al., 2012; Vives i Batlle et al., 2014).

(55) The whole-body dose from external exposure, D (Gy), acquired by the organism during the period ΔT can be represented as follows:

$$D = \int_{\Delta T} \sum_{k} \omega_k \sum_{s} \sum_{\nu} DCC_{s,\nu}(t)\, q_{s,\nu}(t)\, dt\,, \qquad (10)$$

where ω_k is the time share spent by the organisms in the specific location k, $q_{s,\nu}(t)$ is the activity concentration of radionuclide ν, s denotes specific type (or geometry) of radiation source most relevant to the given location k.

(56) The life history of the organism, the time fraction spent by an organism in various parts of the heterogeneous environment, the distributions of radioactive contamination and the radionuclide composition of the contamination can be complicated and time-dependent. Such complicated exposure scenarios have to be represented by superposition of simpler ones. If occupancy fractions are not known, then they have to be implied or derived from biological data. Data on contamination of the environment in specific locations may have considerable uncertainty originating from various sources, including spatial variability of the environmental contamination, scarcity of measured data (e.g. sampling is done on certain locations not in the whole area), or use of radionuclide dispersion and/or radioecological transfer modelling in cases where there are no measurement data.

(57) This report currently does not address exposure from radon isotopes, which for some organisms and some environments may contribute significantly to exposure of biota, either from natural or anthropogenic-enhanced sources. Assessing doses of radiation exposure due to radon isotopes and their progeny commonly appears as a difficult task due to complicated processes of radon effluence, build-up of radioactive progeny, transport in air, chemical forms and attachment to aerosols, intake, deposition and retention of radon-related radioactivity in the body of living organisms. Even for human, radon dosimetry remains under development and ICRP still plans to apply standard biokinetic and dosimetric models to derive human dose coefficients relevant to radon exposure (ICRP, 2010). The diversity of non-human biota, expressed by their biological, morphological, and metabolic differences, makes radon dosimetry for biota even more complicated task than that for human, thus use of simplified and conservative methods (models) appears in this case as rational and appropriate. This issue is going to be addressed in further and future work.

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ANNEX A. GENERALISED ALLOMETRIC RELATIONSHIPS

(A 1) Despite extreme variability, living organisms display similarities of certain basic characteristics. So-called allometric laws can be used to express such similarities within groups of living organisms, e.g. mammals, insects, warm- or cold-blooded species. Allometric models relate quantitative parameters such as breathing rates or metabolic rates, with the mass of their bodies. Originating from findings made in late 19th century (Rubner, 1883) and based on the so-called Kleiber law (Kleiber, 1947), allometry has also been the subject of more recent studies (e.g. Nagy, 2005; White and Seymour, 2005; Marquet et al., 2005; West and Brown, 2005).

(A 2) Allometric relationships are commonly expressed as a power function of mass:

$$Y = a M^{b}, \tag{A.1}$$

which in log-log scale, appears as a simple linear regression equation:

$$y = \alpha + b x, \tag{A.2}$$

where $y = \ln Y$, $x = \ln M$, and $\alpha = \ln a$.

(A 3) The validity of a simple allometric relationship (A.1) is supported by numerous experimental observations. However, the experimental data also suggest deviations from this simple linear behaviour (e.g. Kolokotrones et al., 2010). Based on experimentally observed non-linearity of the allometric data, straightforward polynomial generalisations of linear regression may be used (Ulanovsky, 2016) to test statistical significance of non-linear effects in allometric relationships:

$$y = \sum_{n=0}^{K} \beta_n x^n , \tag{A.3}$$

or, using conventional notation, as

$$Y = a^{*} M^{b^{*}}, \tag{A.4}$$

where the generalised allometric coefficients are defined as:

$$\begin{aligned} a^{*} &= \exp(\beta_0), \\ b^{*} &= \sum_{n=1}^{K} \beta_n \left(\ln M\right)^{n-1}. \end{aligned} \tag{A.5}$$

(A 4) The generalised allometric Eqs. (A.4) and (A.5) were used to approximate breathing rates for terrestrial mammals using data from Bide et al. (2000) who assembled a dataset from 146 studies covering 2616 animals and 18 species ranging from mice at 12 g body mass to horses and a giraffe at ca. 500 kg body mass. The breathing rate data from Bide et al. (2000) have been normalised per body mass and refitted (without excluding so-called ‘outliers’) using polynomial regression of logarithmically transformed variables. Polynomials with degrees from 0 to 3 have been applied, and the second-order polynomial has been found as the best model, based on the Akaike information criterion (AIC) (e.g. Anderson, 2008). Residuals have been found to be distributed normally (see parameters in Table A.1). Consequently, breathing rates for terrestrial mammals can be represented as follows:

$$B = \exp\left(\beta_0\right) M^{1+\beta_1+\beta_2 \ln M}, \tag{A.6}$$

where parameter values are given in Table A.1. The data and the fitted approximation are shown in Fig. A.1.

Table A.1. Fitted parameter values for ventilation rates for mammals.

Parameter	Value	Standard deviation	Correlation matrix			Residuals
			β_0	β_1	β_2	
β_0	−3.562	4.96×10^{-2}	1.0	0.098	−0.512	Distributed log-normally (GM = 1, GSD = 1.55)
β_1	−0.226	1.93×10^{-2}	0.098	1.0	−0.778	
β_2	7.26×10^{-3}	4.45×10^{-3}	−0.512	−0.778	1.0	

GM, geometric mean. GSD, geometric standard deviation.

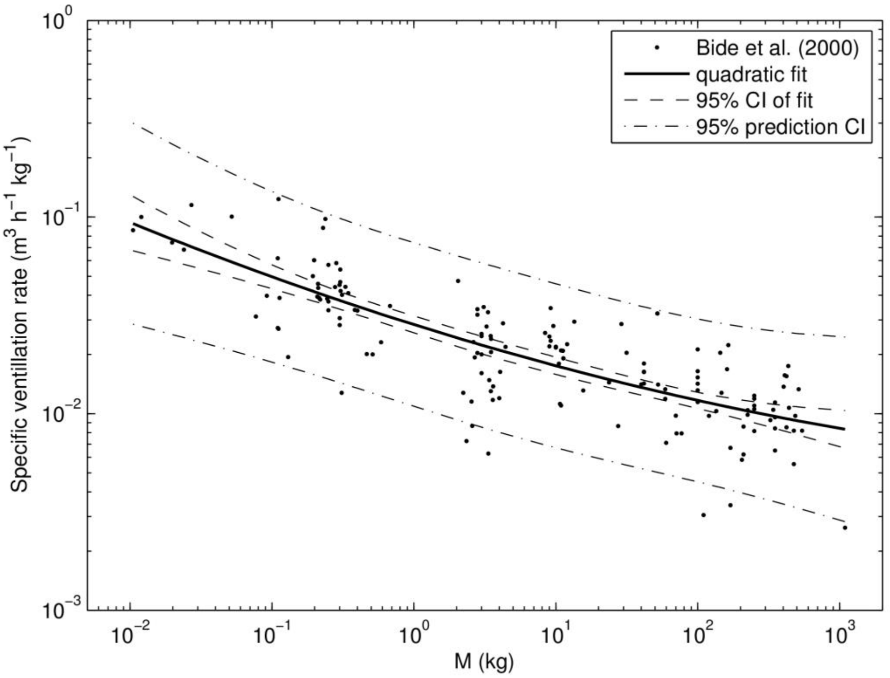

Fig. A.1. Fit of specific ventilation rates from Bide et al. (2000) using a generalised allometric equation [Eq. (A.6)]. CI, confidence interval.

(A 5) Indicated by dashed lines in Fig. A.1 are the 95% confidence intervals for the predicted dependence, which should not be confused with 95% prediction intervals, shown as dash-dotted lines, since the latter represents a variance of the sample on which the regression is constructed. In the case of a zero-order polynomial, these correspond to conventional variance of the sample mean and the sample variance. Variability can be characterised by a geometric standard deviation (GSD) of 1.55, which means that the ratio of 97.5% to 2.5% percentiles equals approximately to 5.6.

(A 6) Another example of how the generalised allometric relationships describe non-linear effects observed in biological data can be shown using an approximation of the basal metabolic rate (BMR) for terrestrial mammals. As suggested by Kleiber (1975), the specific BMR, i.e. energy of metabolism per unit body mass, can serve as an indicator of rates of biological processes resulting in elimination of substances from the organism (Kleiber, 1975; Fagerström et al., 1977). Thus, the BMR can be used for scaling biological half-time of well-studied mammals (e.g. human) to other animals, for which no sufficient information exist.

(A 7) Fitting has been performed using the measured BMR included in the PanTHERIA database (Jones et al., 2009), which includes data for mammals with body masses from gramme to hundreds of kilogrammes. For these animals, the BMR is strongly correlated with mass and varies by four orders of magnitude. The data have been fit using a generalised allometric Eq. (A.4) and the resulting approximation appears as follows:

$$BMR = \exp\left(\beta_0\right) M^{1+\beta_1+\beta_2 \ln M}, \qquad \text{(A.7)}$$

where the parameters values can be found in Table A.2. Similarly to fitting of the breathing rate, a second-order polynomial has been found as a best model in AIC-sense. Uncertainty of the residuals can be characterised by a GSD of 1.47, which corresponds to a ratio of 97.5% to 2.5% percentiles being equal to approximately 4.6.

Table A.2. Parameter values of generalised allometric equation for basal metabolic rate (BMR).

Parameter	Value	Standard deviation	Correlation matrix			Residuals
			β_0	β_1	β_2	
β_0	0.9394	2.36×10^{-2}	1	0.1646	−0.6059	Distributed log-normally (GM = 1, GSD = 1.47)
β_1	−0.2734	6.98×10^{-3}	0.1646	1	0.4087	
β_2	0.01425	2.20×10^{-3}	−0.6059	0.4087	1	

GM, geometric mean. GSD, geometric standard deviation.

(A 8) The data and the fitted approximation are shown in Fig. A.2.

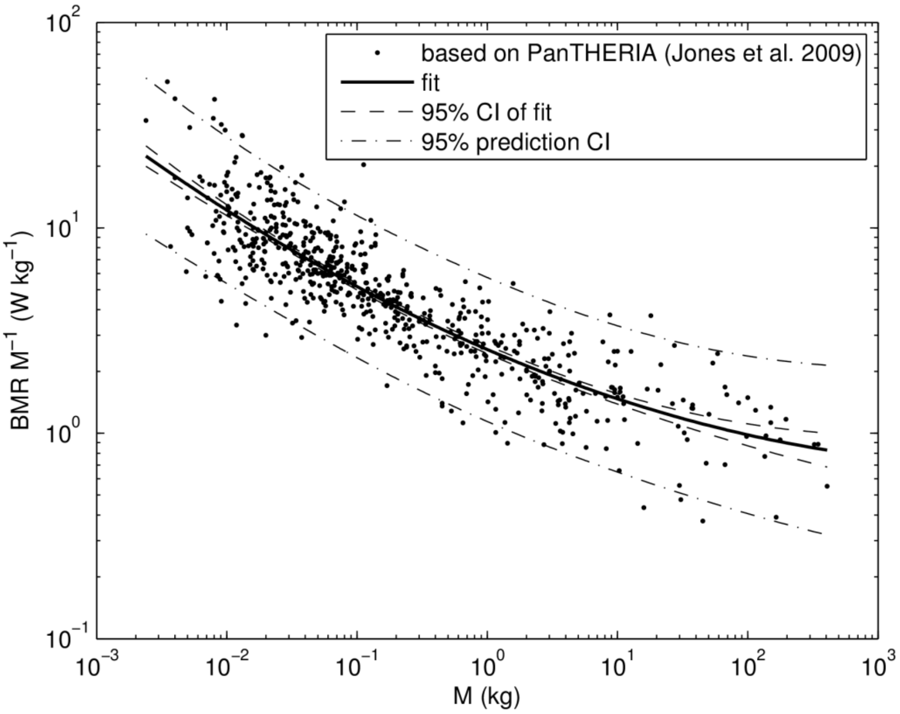

Fig. A.2. Scaled basal metabolic rate (BMR) for mammals: points show data derived from the PanTHERIA database (Jones et al., 2009), the solid line is a fit using approximation [Eq. (A.7)], the dashed line shows 95% confidence interval (CI) of the fit, and the dash-dotted line represents the 95% prediction bands.

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ANNEX B. DOSE COEFFICIENTS FOR NON-HUMAN BIOTA

(B 1) DCs shown in the following tables are presented as dose rates (μGy h^{-1}) per unit activity concentration in the given media, i.e. (Bq kg^{-1}) for internal exposure and external exposure of terrestrial organisms, (Bq L^{-1}) for external exposure of aquatic organisms, and (Bq m^{-3}) for external exposure of terrestrial organisms immersed in radioactively contaminated air above ground.

(B 2) DCs for external exposure of aquatic organisms are computed for infinite water medium. DCs can be also applied to assess external exposure from radioactivity in bed sediments, provided that density and chemical composition of the sediments are close to those of water medium.

(B 3) DCs for external exposure of terrestrial organisms are presented for exposure:

- ‘in-soil’: for organisms exposed in the middle of a 50-cm-thick uniform source in soil;
- ‘on-soil’: for organisms exposed on the ground surface to a 10-cm-thick uniform source in soil;
- ‘above soil’: for organisms exposed at a specified height (bee at 2 m, duck at 10 m) above the ground surface to a 10-cm-thick uniform source in soil;
- ‘immersion in air’: for organisms exposed on or above the ground surface to uniformly contaminated ambient air.

(B 4) The energy emitted by radioactive progeny is added to DCs according to the method used in *Publication 108*, i.e. the decay chain is truncated at the first daughter with physical half-life of >10 d or that of the parent, and equilibrium conditions are assumed to exist between the parent and daughters in the truncated decay chain.

(B 5) The organisms listed in the tables are those from the terrestrial environment, followed by aquatic organisms. Each group is sorted according to increasing organism mass. DCs for internal exposure are followed by a set of fractions representing the contributions of various radiation types to the internal dose. Specifically, f_0 represents the contribution of fission fragments and α-recoil nuclei, f_1 – α-particles, f_2 – low-energy β- and γ-radiation (E <10 keV), and f_3 – other β- and γ-radiations (E >10 keV). The fractions can be used to modify the absorbed dose rate by radiation weighting factors, which account for the different radiobiological effectiveness of various radiation types.

Table B.1. Dose coefficients for non-human biota exposed to radioactive isotopes of Ag (Z = 47).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{110m}Ag (progeny included: ^{110}Ag)										
Bee	6.1×10^{-5}	0.000	0.000	0.011	0.989	–	–	5.5×10^{-4}	5.4×10^{-4}	6.9×10^{-4}
Wild grass (spike)	7.2×10^{-5}	0.000	0.000	0.009	0.991	1.6×10^{-3}	–	5.4×10^{-4}	–	7.0×10^{-4}
Earthworm	7.6×10^{-5}	0.000	0.000	0.009	0.991	–	1.5×10^{-3}	5.8×10^{-4}	–	7.0×10^{-4}
Frog	1.1×10^{-4}	0.000	0.000	0.006	0.994	1.5×10^{-3}	1.4×10^{-3}	5.9×10^{-4}	–	7.1×10^{-4}
Rat	1.8×10^{-4}	0.000	0.000	0.004	0.996	–	1.4×10^{-3}	5.8×10^{-4}	–	7.1×10^{-4}
Duck	2.7×10^{-4}	0.000	0.000	0.002	0.998	1.4×10^{-3}	–	5.7×10^{-4}	5.2×10^{-4}	7.5×10^{-4}
Deer	9.8×10^{-4}	0.000	0.000	0.001	0.999	–	–	3.8×10^{-4}	–	4.6×10^{-4}
Pine tree (trunk)	8.7×10^{-4}	0.000	0.000	0.001	0.999	–	–	4.4×10^{-4}	–	–
Brown seaweed	1.7×10^{-4}	0.000	0.000	0.004	0.996	1.5×10^{-3}	–	–	–	–
Crab	2.3×10^{-4}	0.000	0.000	0.003	0.997	1.4×10^{-3}	–	–	–	–
Trout	2.4×10^{-4}	0.000	0.000	0.003	0.997	1.4×10^{-3}	–	–	–	–
Flatfish	1.8×10^{-4}	0.000	0.000	0.004	0.996	1.5×10^{-3}	–	–	–	–

Table B.2. Dose coefficients for non-human biota exposed to radioactive isotopes of Am (Z = 95).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{241}Am (progeny included: none)										
Bee	3.2×10^{-3}	0.016	0.976	0.001	0.006	–	–	2.1×10^{-6}	2.0×10^{-6}	5.3×10^{-6}
Wild grass (spike)	3.2×10^{-3}	0.016	0.976	0.001	0.006	1.5×10^{-5}	–	3.0×10^{-6}	–	4.7×10^{-6}
Earthworm	3.2×10^{-3}	0.016	0.976	0.001	0.006	–	5.7×10^{-6}	2.0×10^{-6}	–	4.7×10^{-6}
Frog	3.2×10^{-3}	0.016	0.976	0.001	0.006	1.3×10^{-5}	5.6×10^{-6}	2.0×10^{-6}	–	4.4×10^{-6}
Rat	3.2×10^{-3}	0.016	0.975	0.001	0.007	–	5.2×10^{-6}	1.9×10^{-6}	–	4.0×10^{-6}
Duck	3.2×10^{-3}	0.016	0.975	0.001	0.007	1.0×10^{-5}	–	1.8×10^{-6}	1.5×10^{-6}	4.5×10^{-6}
Deer	3.2×10^{-3}	0.016	0.973	0.001	0.010	–	–	7.5×10^{-7}	–	1.5×10^{-6}
Pine tree (trunk)	3.2×10^{-3}	0.016	0.973	0.001	0.010	–	–	1.9×10^{-6}	–	–
Brown seaweed	3.2×10^{-3}	0.016	0.975	0.001	0.007	1.2×10^{-5}	–	–	–	–
Crab	3.2×10^{-3}	0.016	0.975	0.001	0.007	1.1×10^{-5}	–	–	–	–
Trout	3.2×10^{-3}	0.016	0.975	0.001	0.007	1.1×10^{-5}	–	–	–	–
Flatfish	3.2×10^{-3}	0.016	0.975	0.001	0.007	1.2×10^{-5}	–	–	–	–

Table B.3. Dose coefficients for non-human biota exposed to radioactive isotopes of Ba (Z = 56).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{140}Ba (progeny included: ^{140}La)										
Bee	4.2×10^{-4}	0.000	0.000	0.017	0.983	–	–	4.6×10^{-4}	4.5×10^{-4}	6.2×10^{-4}
Wild grass (spike)	4.6×10^{-4}	0.000	0.000	0.015	0.985	1.5×10^{-3}	–	4.7×10^{-4}	–	6.7×10^{-4}
Earthworm	4.6×10^{-4}	0.000	0.000	0.015	0.985	–	1.3×10^{-3}	5.2×10^{-4}	–	6.8×10^{-4}
Frog	5.2×10^{-4}	0.000	0.000	0.014	0.986	1.4×10^{-3}	1.3×10^{-3}	5.5×10^{-4}	–	7.1×10^{-4}
Rat	5.9×10^{-4}	0.000	0.000	0.012	0.988	–	1.2×10^{-3}	5.5×10^{-4}	–	7.2×10^{-4}
Duck	6.7×10^{-4}	0.000	0.000	0.011	0.989	1.3×10^{-3}	–	5.5×10^{-4}	5.0×10^{-4}	7.6×10^{-4}
Deer	1.3×10^{-3}	0.000	0.000	0.005	0.995	–	–	3.9×10^{-4}	–	4.9×10^{-4}
Pine tree (trunk)	1.2×10^{-3}	0.000	0.000	0.006	0.994	–	–	3.8×10^{-4}	–	–
Brown seaweed	5.7×10^{-4}	0.000	0.000	0.012	0.988	1.4×10^{-3}	–	–	–	–
Crab	6.4×10^{-4}	0.000	0.000	0.011	0.989	1.3×10^{-3}	–	–	–	–
Trout	6.4×10^{-4}	0.000	0.000	0.011	0.989	1.3×10^{-3}	–	–	–	–
Flatfish	5.9×10^{-4}	0.000	0.000	0.012	0.988	1.3×10^{-3}	–	–	–	–

Table B.4. Dose coefficients for non-human biota exposed to radioactive isotopes of C (Z = 6).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{14}C (progeny included: none)										
Bee	2.8×10^{-5}	0.000	0.000	0.011	0.989	–	–	0	0	0
Wild grass (spike)	2.8×10^{-5}	0.000	0.000	0.011	0.989	1.3×10^{-7}	–	0	–	0
Earthworm	2.8×10^{-5}	0.000	0.000	0.011	0.989	–	0	0	–	0
Frog	2.9×10^{-5}	0.000	0.000	0.011	0.989	5.9×10^{-8}	0	0	–	0
Rat	2.9×10^{-5}	0.000	0.000	0.011	0.989	–	0	0	–	0
Duck	2.9×10^{-5}	0.000	0.000	0.011	0.989	1.8×10^{-8}	–	0	0	0
Deer	2.9×10^{-5}	0.000	0.000	0.011	0.989	–	–	0	–	0
Pine tree (trunk)	2.9×10^{-5}	0.000	0.000	0.011	0.989	–	–	0	–	–
Brown seaweed	2.9×10^{-5}	0.000	0.000	0.011	0.989	2.2×10^{-8}	–	–	–	–
Crab	2.9×10^{-5}	0.000	0.000	0.011	0.989	2.2×10^{-8}	–	–	–	–
Trout	2.9×10^{-5}	0.000	0.000	0.011	0.989	1.8×10^{-8}	–	–	–	–
Flatfish	2.9×10^{-5}	0.000	0.000	0.011	0.989	1.8×10^{-8}	–	–	–	–

Table B.5. Dose coefficients for non-human biota exposed to radioactive isotopes of Ca (Z = 20).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{45}Ca (progeny included: none)										
Bee	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	–	1.8×10^{-13}	6.5×10^{-14}	1.4×10^{-12}
Wild grass (spike)	4.4×10^{-5}	0.000	0.000	0.005	0.995	4.4×10^{-7}	–	4.2×10^{-13}	–	6.5×10^{-13}
Earthworm	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	3.4×10^{-13}	1.0×10^{-13}	–	5.3×10^{-13}
Frog	4.4×10^{-5}	0.000	0.000	0.005	0.995	2.0×10^{-7}	3.3×10^{-13}	6.1×10^{-14}	–	3.1×10^{-13}
Rat	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	2.7×10^{-13}	2.9×10^{-14}	–	1.5×10^{-13}
Duck	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.4×10^{-8}	–	1.9×10^{-14}	2.8×10^{-16}	1.6×10^{-13}
Deer	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	–	2.4×10^{-15}	–	1.9×10^{-14}
Pine tree (trunk)	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	–	5.2×10^{-17}	–	–
Brown seaweed	4.4×10^{-5}	0.000	0.000	0.005	0.995	8.0×10^{-8}	–	–	–	–
Crab	4.4×10^{-5}	0.000	0.000	0.005	0.995	7.5×10^{-8}	–	–	–	–
Trout	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.4×10^{-8}	–	–	–	–
Flatfish	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.6×10^{-8}	–	–	–	–

Table B.6. Dose coefficients for non-human biota exposed to radioactive isotopes of Cd (Z = 48).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{109}Cd (progeny included: none)										
Bee	4.9×10^{-5}	0.000	0.000	0.075	0.925	–	–	1.8×10^{-6}	1.6×10^{-6}	6.2×10^{-6}
Wild grass (spike)	5.0×10^{-5}	0.000	0.000	0.073	0.927	1.3×10^{-5}	–	2.2×10^{-6}	–	5.1×10^{-6}
Earthworm	5.0×10^{-5}	0.000	0.000	0.073	0.927	–	3.5×10^{-6}	1.6×10^{-6}	–	4.9×10^{-6}
Frog	5.3×10^{-5}	0.000	0.000	0.070	0.930	1.0×10^{-5}	3.4×10^{-6}	1.5×10^{-6}	–	4.2×10^{-6}
Rat	5.6×10^{-5}	0.000	0.000	0.066	0.934	–	3.0×10^{-6}	1.1×10^{-6}	–	3.1×10^{-6}
Duck	5.8×10^{-5}	0.000	0.000	0.064	0.936	5.2×10^{-6}	–	9.2×10^{-7}	6.6×10^{-7}	3.3×10^{-6}
Deer	6.2×10^{-5}	0.000	0.000	0.060	0.940	–	–	3.2×10^{-7}	–	6.8×10^{-7}
Pine tree (trunk)	6.2×10^{-5}	0.000	0.000	0.059	0.941	–	–	7.4×10^{-7}	–	–
Brown seaweed	5.5×10^{-5}	0.000	0.000	0.067	0.933	7.9×10^{-6}	–	–	–	–
Crab	5.7×10^{-5}	0.000	0.000	0.064	0.936	5.8×10^{-6}	–	–	–	–
Trout	5.7×10^{-5}	0.000	0.000	0.064	0.936	5.6×10^{-6}	–	–	–	–
Flatfish	5.6×10^{-5}	0.000	0.000	0.066	0.934	7.1×10^{-6}	–	–	–	–

Table B.7. Dose coefficients for non-human biota exposed to radioactive isotopes of Ce (Z = 58).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{141}Ce (progeny included: none)										
Bee	9.5×10^{-5}	0.000	0.000	0.009	0.991	–	–	1.2×10^{-5}	1.2×10^{-5}	1.7×10^{-5}
Wild grass (spike)	9.7×10^{-5}	0.000	0.000	0.009	0.991	4.6×10^{-5}	–	1.3×10^{-5}	–	1.6×10^{-5}
Earthworm	9.7×10^{-5}	0.000	0.000	0.009	0.991	–	2.7×10^{-5}	1.2×10^{-5}	–	1.6×10^{-5}
Frog	1.0×10^{-4}	0.000	0.000	0.008	0.992	4.3×10^{-5}	2.7×10^{-5}	1.2×10^{-5}	–	1.6×10^{-5}
Rat	1.0×10^{-4}	0.000	0.000	0.008	0.992	–	2.6×10^{-5}	1.2×10^{-5}	–	1.6×10^{-5}
Duck	1.1×10^{-4}	0.000	0.000	0.008	0.992	3.7×10^{-5}	–	1.2×10^{-5}	1.1×10^{-5}	1.7×10^{-5}
Deer	1.3×10^{-4}	0.000	0.000	0.007	0.993	–	–	6.5×10^{-6}	–	8.1×10^{-6}
Pine tree (trunk)	1.3×10^{-4}	0.000	0.000	0.006	0.994	–	–	1.0×10^{-5}	–	–
Brown seaweed	1.0×10^{-4}	0.000	0.000	0.008	0.992	4.1×10^{-5}	–	–	–	–
Crab	1.1×10^{-4}	0.000	0.000	0.008	0.992	3.8×10^{-5}	–	–	–	–
Trout	1.1×10^{-4}	0.000	0.000	0.008	0.992	3.8×10^{-5}	–	–	–	–
Flatfish	1.0×10^{-4}	0.000	0.000	0.008	0.992	4.0×10^{-5}	–	–	–	–
^{144}Ce (progeny included: ^{144m}Pr ^{144}Pr)										
Bee	4.1×10^{-4}	0.000	0.000	0.002	0.998	–	–	8.1×10^{-6}	8.0×10^{-6}	1.1×10^{-5}
Wild grass (spike)	5.2×10^{-4}	0.000	0.000	0.001	0.999	2.6×10^{-4}	–	8.4×10^{-6}	–	1.2×10^{-5}
Earthworm	5.4×10^{-4}	0.000	0.000	0.001	0.999	–	2.1×10^{-5}	8.8×10^{-6}	–	1.2×10^{-5}
Frog	6.5×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-4}	2.1×10^{-5}	9.0×10^{-6}	–	1.2×10^{-5}
Rat	7.0×10^{-4}	0.000	0.000	0.001	0.999	–	2.0×10^{-5}	9.0×10^{-6}	–	1.2×10^{-5}
Duck	7.2×10^{-4}	0.000	0.000	0.001	0.999	5.6×10^{-5}	–	8.9×10^{-6}	8.1×10^{-6}	1.3×10^{-5}
Deer	7.6×10^{-4}	0.000	0.000	0.001	0.999	–	–	5.8×10^{-6}	–	7.3×10^{-6}
Pine tree (trunk)	7.6×10^{-4}	0.000	0.000	0.001	0.999	–	–	6.7×10^{-6}	–	–
Brown seaweed	6.7×10^{-4}	0.000	0.000	0.001	0.999	1.1×10^{-4}	–	–	–	–
Crab	7.2×10^{-4}	0.000	0.000	0.001	0.999	6.3×10^{-5}	–	–	–	–
Trout	7.2×10^{-4}	0.000	0.000	0.001	0.999	6.3×10^{-5}	–	–	–	–
Flatfish	6.7×10^{-4}	0.000	0.000	0.001	0.999	1.1×10^{-4}	–	–	–	–

Table B.8. Dose coefficients for non-human biota exposed to radioactive isotopes of Cf (Z = 98).

RAPs	Internal exposure					External exposure				
	$(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ kg})$	f_0	f_1	f_2	f_3	Aquatic $(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ L})$	In-soil $(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ kg})$	On-ground $(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ kg})$	Above-ground $(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ kg})$	Immersion in air $(\mu\text{Gy h}^{-1}\text{ Bq}^{-1}\text{ m}^3)$
^{252}Cf (progeny included: none)										
Bee	6.9×10^{-3}	0.494	0.495	0.000	0.010	–	–	7.3×10^{-5}	7.1×10^{-5}	9.7×10^{-5}
Wild grass (spike)	6.9×10^{-3}	0.493	0.494	0.000	0.013	3.2×10^{-4}	–	8.4×10^{-5}	–	1.0×10^{-4}
Earthworm	6.9×10^{-3}	0.492	0.493	0.000	0.014	–	2.3×10^{-4}	8.2×10^{-5}	–	1.1×10^{-4}
Frog	6.9×10^{-3}	0.490	0.491	0.000	0.019	2.8×10^{-4}	2.3×10^{-4}	8.7×10^{-5}	–	1.1×10^{-4}
Rat	7.0×10^{-3}	0.489	0.490	0.000	0.022	–	2.2×10^{-4}	8.9×10^{-5}	–	1.2×10^{-4}
Duck	7.0×10^{-3}	0.487	0.488	0.000	0.024	2.4×10^{-4}	–	8.8×10^{-5}	8.0×10^{-5}	1.2×10^{-4}
Deer	7.1×10^{-3}	0.479	0.480	0.000	0.040	–	–	6.2×10^{-5}	–	8.0×10^{-5}
Pine tree (trunk)	7.1×10^{-3}	0.481	0.482	0.000	0.037	–	–	6.9×10^{-5}	–	–
Brown seaweed	7.0×10^{-3}	0.489	0.490	0.000	0.021	2.6×10^{-4}	–	–	–	–
Crab	7.0×10^{-3}	0.488	0.489	0.000	0.023	2.5×10^{-4}	–	–	–	–
Trout	7.0×10^{-3}	0.488	0.489	0.000	0.023	2.4×10^{-4}	–	–	–	–
Flatfish	7.0×10^{-3}	0.489	0.490	0.000	0.021	2.6×10^{-4}	–	–	–	–

Table B.9. Dose coefficients for non-human biota exposed to radioactive isotopes of Cl (Z = 17).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{36}Cl (progeny included: none)										
Bee	1.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	3.7×10^{-8}	3.6×10^{-8}	4.5×10^{-8}
Wild grass (spike)	1.5×10^{-4}	0.000	0.000	0.000	1.000	9.7×10^{-6}	–	2.9×10^{-8}	–	4.4×10^{-8}
Earthworm	1.5×10^{-4}	0.000	0.000	0.000	1.000	–	7.5×10^{-8}	3.7×10^{-8}	–	4.4×10^{-8}
Frog	1.5×10^{-4}	0.000	0.000	0.000	1.000	4.1×10^{-6}	7.4×10^{-8}	3.7×10^{-8}	–	4.3×10^{-8}
Rat	1.6×10^{-4}	0.000	0.000	0.000	1.000	–	7.1×10^{-8}	3.6×10^{-8}	–	4.2×10^{-8}
Duck	1.6×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-6}	–	3.6×10^{-8}	3.2×10^{-8}	4.5×10^{-8}
Deer	1.6×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.2×10^{-8}	–	2.5×10^{-8}
Pine tree (trunk)	1.6×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.3×10^{-8}	–	–
Brown seaweed	1.6×10^{-4}	0.000	0.000	0.000	1.000	2.0×10^{-6}	–	–	–	–
Crab	1.6×10^{-4}	0.000	0.000	0.000	1.000	1.5×10^{-6}	–	–	–	–
Trout	1.6×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-6}	–	–	–	–
Flatfish	1.6×10^{-4}	0.000	0.000	0.000	1.000	1.8×10^{-6}	–	–	–	–

Table B.10. Dose coefficients for non-human biota exposed to radioactive isotopes of Cm (Z = 96).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{242}Cm (progeny included: none)										
Bee	3.6×10^{-3}	0.017	0.982	0.000	0.001	–	–	7.7×10^{-8}	5.7×10^{-8}	3.8×10^{-7}
Wild grass (spike)	3.6×10^{-3}	0.017	0.982	0.000	0.001	6.4×10^{-7}	–	1.3×10^{-7}	–	2.6×10^{-7}
Earthworm	3.6×10^{-3}	0.017	0.982	0.000	0.001	–	1.7×10^{-7}	6.3×10^{-8}	–	2.4×10^{-7}
Frog	3.6×10^{-3}	0.017	0.982	0.000	0.002	4.1×10^{-7}	1.6×10^{-7}	4.8×10^{-8}	–	1.8×10^{-7}
Rat	3.6×10^{-3}	0.017	0.982	0.000	0.002	–	1.4×10^{-7}	2.9×10^{-8}	–	1.1×10^{-7}
Duck	3.6×10^{-3}	0.017	0.982	0.000	0.002	1.5×10^{-7}	–	2.0×10^{-8}	8.7×10^{-9}	1.2×10^{-7}
Deer	3.6×10^{-3}	0.017	0.982	0.000	0.002	–	–	4.3×10^{-9}	–	1.6×10^{-8}
Pine tree (trunk)	3.6×10^{-3}	0.017	0.982	0.000	0.002	–	–	1.2×10^{-8}	–	–
Brown seaweed	3.6×10^{-3}	0.017	0.982	0.000	0.002	2.6×10^{-7}	–	–	–	–
Crab	3.6×10^{-3}	0.017	0.982	0.000	0.002	1.8×10^{-7}	–	–	–	–
Trout	3.6×10^{-3}	0.017	0.982	0.000	0.002	1.6×10^{-7}	–	–	–	–
Flatfish	3.6×10^{-3}	0.017	0.982	0.000	0.002	2.2×10^{-7}	–	–	–	–
^{243}Cm (progeny included: none)										
Bee	3.5×10^{-3}	0.016	0.961	0.002	0.020	–	–	2.4×10^{-5}	2.3×10^{-5}	3.2×10^{-5}
Wild grass (spike)	3.5×10^{-3}	0.016	0.961	0.002	0.021	7.5×10^{-5}	–	2.3×10^{-5}	–	3.1×10^{-5}
Earthworm	3.5×10^{-3}	0.016	0.961	0.002	0.021	–	5.0×10^{-5}	2.4×10^{-5}	–	3.0×10^{-5}
Frog	3.5×10^{-3}	0.016	0.960	0.002	0.022	7.1×10^{-5}	4.9×10^{-5}	2.4×10^{-5}	–	3.0×10^{-5}
Rat	3.5×10^{-3}	0.016	0.959	0.002	0.023	–	4.7×10^{-5}	2.3×10^{-5}	–	2.9×10^{-5}
Duck	3.5×10^{-3}	0.016	0.957	0.002	0.024	6.2×10^{-5}	–	2.3×10^{-5}	2.0×10^{-5}	3.1×10^{-5}
Deer	3.5×10^{-3}	0.016	0.947	0.002	0.035	–	–	1.3×10^{-5}	–	1.5×10^{-5}
Pine tree (trunk)	3.5×10^{-3}	0.016	0.947	0.002	0.035	–	–	1.8×10^{-5}	–	–
Brown seaweed	3.5×10^{-3}	0.016	0.959	0.002	0.023	6.8×10^{-5}	–	–	–	–
Crab	3.5×10^{-3}	0.016	0.958	0.002	0.024	6.4×10^{-5}	–	–	–	–
Trout	3.5×10^{-3}	0.016	0.957	0.002	0.024	6.3×10^{-5}	–	–	–	–
Flatfish	3.5×10^{-3}	0.016	0.958	0.002	0.023	6.6×10^{-5}	–	–	–	–
^{244}Cm (progeny included: none)										
Bee	3.4×10^{-3}	0.016	0.982	0.000	0.001	–	–	6.8×10^{-8}	5.1×10^{-8}	3.3×10^{-7}
Wild grass (spike)	3.4×10^{-3}	0.016	0.982	0.000	0.001	5.6×10^{-7}	–	1.2×10^{-7}	–	2.3×10^{-7}
Earthworm	3.4×10^{-3}	0.016	0.982	0.000	0.001	–	1.5×10^{-7}	5.6×10^{-8}	–	2.1×10^{-7}
Frog	3.4×10^{-3}	0.016	0.982	0.000	0.001	3.6×10^{-7}	1.5×10^{-7}	4.4×10^{-8}	–	1.6×10^{-7}

Rat	3.4×10^{-3}	0.016	0.982	0.000	0.001	–	1.3×10^{-7}	2.8×10^{-8}	–	9.6×10^{-8}
Duck	3.4×10^{-3}	0.016	0.982	0.000	0.001	1.4×10^{-7}	–	2.0×10^{-8}	9.9×10^{-9}	1.1×10^{-7}
Deer	3.4×10^{-3}	0.016	0.982	0.000	0.001	–	–	5.6×10^{-9}	–	1.6×10^{-8}
Pine tree (trunk)	3.4×10^{-3}	0.016	0.982	0.000	0.001	–	–	1.3×10^{-8}	–	–
Brown seaweed	3.4×10^{-3}	0.016	0.982	0.000	0.001	2.3×10^{-7}	–	–	–	–
Crab	3.4×10^{-3}	0.016	0.982	0.000	0.001	1.6×10^{-7}	–	–	–	–
Trout	3.4×10^{-3}	0.016	0.982	0.000	0.001	1.5×10^{-7}	–	–	–	–
Flatfish	3.4×10^{-3}	0.016	0.982	0.000	0.001	2.0×10^{-7}	–	–	–	–

Table B.11. Dose coefficients for non-human biota exposed to radioactive isotopes of Co (Z = 27).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{57}Co (progeny included: none)										
Bee	1.3×10^{-5}	0.000	0.000	0.700	0.300	–	–	1.7×10^{-5}	1.7×10^{-5}	2.4×10^{-5}
Wild grass (spike)	1.4×10^{-5}	0.000	0.000	0.680	0.320	6.9×10^{-5}	–	2.1×10^{-5}	–	2.3×10^{-5}
Earthworm	1.4×10^{-5}	0.000	0.000	0.673	0.327	–	4.0×10^{-5}	1.7×10^{-5}	–	2.3×10^{-5}
Frog	1.6×10^{-5}	0.000	0.000	0.602	0.398	6.7×10^{-5}	4.0×10^{-5}	1.7×10^{-5}	–	2.3×10^{-5}
Rat	1.9×10^{-5}	0.000	0.000	0.496	0.504	–	3.8×10^{-5}	1.6×10^{-5}	–	2.3×10^{-5}
Duck	2.4×10^{-5}	0.000	0.000	0.400	0.600	5.9×10^{-5}	–	1.6×10^{-5}	1.5×10^{-5}	2.4×10^{-5}
Deer	6.2×10^{-5}	0.000	0.000	0.158	0.842	–	–	9.1×10^{-6}	–	1.2×10^{-5}
Pine tree (trunk)	6.3×10^{-5}	0.000	0.000	0.156	0.844	–	–	1.6×10^{-5}	–	–
Brown seaweed	1.9×10^{-5}	0.000	0.000	0.508	0.492	6.4×10^{-5}	–	–	–	–
Crab	2.2×10^{-5}	0.000	0.000	0.433	0.567	6.1×10^{-5}	–	–	–	–
Trout	2.3×10^{-5}	0.000	0.000	0.421	0.579	6.0×10^{-5}	–	–	–	–
Flatfish	2.0×10^{-5}	0.000	0.000	0.479	0.521	6.3×10^{-5}	–	–	–	–
^{58}Co (progeny included: none)										
Bee	2.5×10^{-5}	0.000	0.000	0.117	0.883	–	–	2.4×10^{-4}	2.3×10^{-4}	3.0×10^{-4}
Wild grass (spike)	2.9×10^{-5}	0.000	0.000	0.104	0.896	5.5×10^{-4}	–	1.9×10^{-4}	–	3.0×10^{-4}
Earthworm	3.0×10^{-5}	0.000	0.000	0.100	0.900	–	5.2×10^{-4}	2.4×10^{-4}	–	3.0×10^{-4}
Frog	4.3×10^{-5}	0.000	0.000	0.071	0.929	5.4×10^{-4}	5.1×10^{-4}	2.5×10^{-4}	–	3.0×10^{-4}
Rat	6.8×10^{-5}	0.000	0.000	0.046	0.954	–	4.9×10^{-4}	2.4×10^{-4}	–	2.9×10^{-4}
Duck	9.9×10^{-5}	0.000	0.000	0.032	0.968	4.8×10^{-4}	–	2.4×10^{-4}	2.1×10^{-4}	3.1×10^{-4}
Deer	3.6×10^{-4}	0.000	0.000	0.009	0.991	–	–	1.5×10^{-4}	–	1.8×10^{-4}
Pine tree (trunk)	3.2×10^{-4}	0.000	0.000	0.010	0.990	–	–	1.5×10^{-4}	–	–
Brown seaweed	6.2×10^{-5}	0.000	0.000	0.050	0.950	5.2×10^{-4}	–	–	–	–
Crab	8.7×10^{-5}	0.000	0.000	0.036	0.964	4.9×10^{-4}	–	–	–	–
Trout	8.9×10^{-5}	0.000	0.000	0.035	0.965	4.9×10^{-4}	–	–	–	–
Flatfish	6.8×10^{-5}	0.000	0.000	0.046	0.954	5.1×10^{-4}	–	–	–	–
^{60}Co (progeny included: none)										
Bee	6.5×10^{-5}	0.000	0.000	0.003	0.997	–	–	4.4×10^{-4}	4.3×10^{-4}	5.8×10^{-4}
Wild grass (spike)	7.4×10^{-5}	0.000	0.000	0.003	0.997	1.4×10^{-3}	–	4.8×10^{-4}	–	6.1×10^{-4}
Earthworm	7.7×10^{-5}	0.000	0.000	0.002	0.998	–	1.3×10^{-3}	4.9×10^{-4}	–	6.3×10^{-4}
Frog	1.1×10^{-4}	0.000	0.000	0.002	0.998	1.4×10^{-3}	1.3×10^{-3}	5.1×10^{-4}	–	6.4×10^{-4}

Rat	1.6×10^{-4}	0.000	0.000	0.001	0.999	–	1.2×10^{-3}	5.1×10^{-4}	–	6.5×10^{-4}
Duck	2.4×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-3}	–	5.1×10^{-4}	4.6×10^{-4}	6.8×10^{-4}
Deer	8.5×10^{-4}	0.000	0.000	0.000	1.000	–	–	3.6×10^{-4}	–	4.4×10^{-4}
Pine tree (trunk)	7.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	3.9×10^{-4}	–	–
Brown seaweed	1.5×10^{-4}	0.000	0.000	0.001	0.999	1.4×10^{-3}	–	–	–	–
Crab	2.1×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-3}	–	–	–	–
Trout	2.1×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-3}	–	–	–	–
Flatfish	1.6×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-3}	–	–	–	–

Table B.12. Dose coefficients for non-human biota exposed to radioactive isotopes of Cr (Z = 24).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{51}Cr (progeny included: none)										
Bee	3.0×10^{-6}	0.000	0.000	0.919	0.081	–	–	8.5×10^{-6}	8.3×10^{-6}	1.0×10^{-5}
Wild grass (spike)	3.1×10^{-6}	0.000	0.000	0.887	0.113	1.8×10^{-5}	–	6.4×10^{-6}	–	9.8×10^{-6}
Earthworm	3.2×10^{-6}	0.000	0.000	0.877	0.123	–	1.6×10^{-5}	8.4×10^{-6}	–	9.7×10^{-6}
Frog	3.6×10^{-6}	0.000	0.000	0.769	0.231	1.7×10^{-5}	1.5×10^{-5}	8.4×10^{-6}	–	9.6×10^{-6}
Rat	4.5×10^{-6}	0.000	0.000	0.623	0.377	–	1.5×10^{-5}	8.2×10^{-6}	–	9.4×10^{-6}
Duck	5.6×10^{-6}	0.000	0.000	0.500	0.500	1.6×10^{-5}	–	8.0×10^{-6}	7.2×10^{-6}	9.9×10^{-6}
Deer	1.5×10^{-5}	0.000	0.000	0.192	0.808	–	–	4.8×10^{-6}	–	5.3×10^{-6}
Pine tree (trunk)	1.5×10^{-5}	0.000	0.000	0.196	0.804	–	–	5.1×10^{-6}	–	–
Brown seaweed	4.3×10^{-6}	0.000	0.000	0.650	0.350	1.7×10^{-5}	–	–	–	–
Crab	5.2×10^{-6}	0.000	0.000	0.541	0.459	1.6×10^{-5}	–	–	–	–
Trout	5.3×10^{-6}	0.000	0.000	0.530	0.470	1.6×10^{-5}	–	–	–	–
Flatfish	4.6×10^{-6}	0.000	0.000	0.616	0.384	1.7×10^{-5}	–	–	–	–

Table B.13. Dose coefficients for non-human biota exposed to radioactive isotopes of Cs (Z = 55).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{134}Cs (progeny included: none)										
Bee	9.7×10^{-5}	0.000	0.000	0.003	0.997	–	–	3.4×10^{-4}	3.3×10^{-4}	4.2×10^{-4}
Wild grass (spike)	1.1×10^{-4}	0.000	0.000	0.003	0.997	8.9×10^{-4}	–	3.1×10^{-4}	–	4.2×10^{-4}
Earthworm	1.1×10^{-4}	0.000	0.000	0.003	0.997	–	8.3×10^{-4}	3.5×10^{-4}	–	4.2×10^{-4}
Frog	1.3×10^{-4}	0.000	0.000	0.002	0.998	8.6×10^{-4}	8.2×10^{-4}	3.5×10^{-4}	–	4.2×10^{-4}
Rat	1.7×10^{-4}	0.000	0.000	0.002	0.998	–	7.8×10^{-4}	3.5×10^{-4}	–	4.1×10^{-4}
Duck	2.2×10^{-4}	0.000	0.000	0.001	0.999	7.7×10^{-4}	–	3.4×10^{-4}	3.1×10^{-4}	4.4×10^{-4}
Deer	6.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.2×10^{-4}	–	2.6×10^{-4}
Pine tree (trunk)	5.8×10^{-4}	0.000	0.000	0.001	0.999	–	–	2.5×10^{-4}	–	–
Brown seaweed	1.6×10^{-4}	0.000	0.000	0.002	0.998	8.3×10^{-4}	–	–	–	–
Crab	2.0×10^{-4}	0.000	0.000	0.002	0.998	7.9×10^{-4}	–	–	–	–
Trout	2.0×10^{-4}	0.000	0.000	0.001	0.999	7.9×10^{-4}	–	–	–	–
Flatfish	1.7×10^{-4}	0.000	0.000	0.002	0.998	8.2×10^{-4}	–	–	–	–
^{135}Cs (progeny included: none)										
Bee	5.1×10^{-5}	0.000	0.000	0.004	0.996	–	–	0	0	0
Wild grass (spike)	5.1×10^{-5}	0.000	0.000	0.004	0.996	6.1×10^{-7}	–	0	–	0
Earthworm	5.1×10^{-5}	0.000	0.000	0.004	0.996	–	0	0	–	0
Frog	5.1×10^{-5}	0.000	0.000	0.004	0.996	2.8×10^{-7}	0	0	–	0
Rat	5.1×10^{-5}	0.000	0.000	0.004	0.996	–	0	0	–	0
Duck	5.1×10^{-5}	0.000	0.000	0.004	0.996	9.0×10^{-8}	–	0	0	0
Deer	5.1×10^{-5}	0.000	0.000	0.004	0.996	–	–	0	–	0
Pine tree (trunk)	5.1×10^{-5}	0.000	0.000	0.004	0.996	–	–	0	–	–
Brown seaweed	5.1×10^{-5}	0.000	0.000	0.004	0.996	1.1×10^{-7}	–	–	–	–
Crab	5.1×10^{-5}	0.000	0.000	0.004	0.996	1.1×10^{-7}	–	–	–	–
Trout	5.1×10^{-5}	0.000	0.000	0.004	0.996	9.0×10^{-8}	–	–	–	–
Flatfish	5.1×10^{-5}	0.000	0.000	0.004	0.996	9.3×10^{-8}	–	–	–	–
^{136}Cs (progeny included: none)										
Bee	9.1×10^{-5}	0.000	0.000	0.007	0.993	–	–	4.6×10^{-4}	4.5×10^{-4}	5.8×10^{-4}
Wild grass (spike)	1.0×10^{-4}	0.000	0.000	0.007	0.993	1.2×10^{-3}	–	4.2×10^{-4}	–	5.9×10^{-4}
Earthworm	1.0×10^{-4}	0.000	0.000	0.007	0.993	–	1.1×10^{-3}	4.8×10^{-4}	–	5.9×10^{-4}
Frog	1.3×10^{-4}	0.000	0.000	0.005	0.995	1.2×10^{-3}	1.1×10^{-3}	4.9×10^{-4}	–	6.0×10^{-4}
Rat	1.8×10^{-4}	0.000	0.000	0.004	0.996	–	1.0×10^{-3}	4.8×10^{-4}	–	5.9×10^{-4}

Duck	2.5×10^{-4}	0.000	0.000	0.003	0.997	1.1×10^{-3}	–	4.7×10^{-4}	4.3×10^{-4}	6.3×10^{-4}
Deer	8.0×10^{-4}	0.000	0.000	0.001	0.999	–	–	3.1×10^{-4}	–	3.8×10^{-4}
Pine tree (trunk)	7.2×10^{-4}	0.000	0.000	0.001	0.999	–	–	3.4×10^{-4}	–	–
Brown seaweed	1.7×10^{-4}	0.000	0.000	0.004	0.996	1.1×10^{-3}	–	–	–	–
Crab	2.2×10^{-4}	0.000	0.000	0.003	0.997	1.1×10^{-3}	–	–	–	–
Trout	2.3×10^{-4}	0.000	0.000	0.003	0.997	1.1×10^{-3}	–	–	–	–
Flatfish	1.8×10^{-4}	0.000	0.000	0.004	0.996	1.1×10^{-3}	–	–	–	–
^{137}Cs (progeny included: ^{137m}Ba)										
Bee	1.3×10^{-4}	0.000	0.000	0.003	0.997	–	–	1.4×10^{-4}	1.3×10^{-4}	1.6×10^{-4}
Wild grass (spike)	1.4×10^{-4}	0.000	0.000	0.003	0.997	3.3×10^{-4}	–	1.1×10^{-4}	–	1.6×10^{-4}
Earthworm	1.4×10^{-4}	0.000	0.000	0.003	0.997	–	3.0×10^{-4}	1.4×10^{-4}	–	1.6×10^{-4}
Frog	1.5×10^{-4}	0.000	0.000	0.002	0.998	3.2×10^{-4}	3.0×10^{-4}	1.4×10^{-4}	–	1.6×10^{-4}
Rat	1.7×10^{-4}	0.000	0.000	0.002	0.998	–	2.8×10^{-4}	1.4×10^{-4}	–	1.6×10^{-4}
Duck	1.9×10^{-4}	0.000	0.000	0.002	0.998	2.8×10^{-4}	–	1.3×10^{-4}	1.2×10^{-4}	1.7×10^{-4}
Deer	3.4×10^{-4}	0.000	0.000	0.001	0.999	–	–	8.4×10^{-5}	–	9.9×10^{-5}
Pine tree (trunk)	3.2×10^{-4}	0.000	0.000	0.001	0.999	–	–	9.0×10^{-5}	–	–
Brown seaweed	1.7×10^{-4}	0.000	0.000	0.002	0.998	3.0×10^{-4}	–	–	–	–
Crab	1.8×10^{-4}	0.000	0.000	0.002	0.998	2.9×10^{-4}	–	–	–	–
Trout	1.8×10^{-4}	0.000	0.000	0.002	0.998	2.8×10^{-4}	–	–	–	–
Flatfish	1.7×10^{-4}	0.000	0.000	0.002	0.998	3.0×10^{-4}	–	–	–	–

Table B.14. Dose coefficients for non-human biota exposed to radioactive isotopes of Eu (Z = 63).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
						^{152}Eu (progeny included: none)				
Bee	7.3×10^{-5}	0.000	0.000	0.052	0.948	–	–	2.1×10^{-4}	2.1×10^{-4}	2.7×10^{-4}
Wild grass (spike)	8.0×10^{-5}	0.000	0.000	0.048	0.952	6.7×10^{-4}	–	2.2×10^{-4}	–	2.8×10^{-4}
Earthworm	8.1×10^{-5}	0.000	0.000	0.047	0.953	–	5.9×10^{-4}	2.3×10^{-4}	–	2.8×10^{-4}
Frog	1.0×10^{-4}	0.000	0.000	0.039	0.961	6.5×10^{-4}	5.8×10^{-4}	2.3×10^{-4}	–	2.9×10^{-4}
Rat	1.3×10^{-4}	0.000	0.000	0.030	0.970	–	5.6×10^{-4}	2.3×10^{-4}	–	2.8×10^{-4}
Duck	1.7×10^{-4}	0.000	0.000	0.023	0.977	5.9×10^{-4}	–	2.3×10^{-4}	2.0×10^{-4}	3.0×10^{-4}
Deer	4.7×10^{-4}	0.000	0.000	0.008	0.992	–	–	1.5×10^{-4}	–	1.8×10^{-4}
Pine tree (trunk)	4.3×10^{-4}	0.000	0.000	0.009	0.991	–	–	1.8×10^{-4}	–	–
Brown seaweed	1.2×10^{-4}	0.000	0.000	0.031	0.969	6.3×10^{-4}	–	–	–	–
Crab	1.5×10^{-4}	0.000	0.000	0.025	0.975	6.0×10^{-4}	–	–	–	–
Trout	1.6×10^{-4}	0.000	0.000	0.025	0.975	6.0×10^{-4}	–	–	–	–
Flatfish	1.3×10^{-4}	0.000	0.000	0.030	0.970	6.2×10^{-4}	–	–	–	–
						^{154}Eu (progeny included: none)				
Bee	1.5×10^{-4}	0.000	0.000	0.013	0.987	–	–	2.4×10^{-4}	2.4×10^{-4}	3.2×10^{-4}
Wild grass (spike)	1.6×10^{-4}	0.000	0.000	0.013	0.987	7.2×10^{-4}	–	2.4×10^{-4}	–	3.3×10^{-4}
Earthworm	1.6×10^{-4}	0.000	0.000	0.012	0.988	–	6.4×10^{-4}	2.6×10^{-4}	–	3.3×10^{-4}
Frog	1.8×10^{-4}	0.000	0.000	0.011	0.989	7.0×10^{-4}	6.3×10^{-4}	2.7×10^{-4}	–	3.4×10^{-4}
Rat	2.1×10^{-4}	0.000	0.000	0.009	0.991	–	6.0×10^{-4}	2.7×10^{-4}	–	3.4×10^{-4}
Duck	2.5×10^{-4}	0.000	0.000	0.008	0.992	6.3×10^{-4}	–	2.6×10^{-4}	2.4×10^{-4}	3.6×10^{-4}
Deer	5.7×10^{-4}	0.000	0.000	0.003	0.997	–	–	1.8×10^{-4}	–	2.2×10^{-4}
Pine tree (trunk)	5.2×10^{-4}	0.000	0.000	0.004	0.996	–	–	1.9×10^{-4}	–	–
Brown seaweed	2.1×10^{-4}	0.000	0.000	0.010	0.990	6.7×10^{-4}	–	–	–	–
Crab	2.4×10^{-4}	0.000	0.000	0.008	0.992	6.4×10^{-4}	–	–	–	–
Trout	2.4×10^{-4}	0.000	0.000	0.008	0.992	6.4×10^{-4}	–	–	–	–
Flatfish	2.1×10^{-4}	0.000	0.000	0.009	0.991	6.6×10^{-4}	–	–	–	–
						^{155}Eu (progeny included: none)				
Bee	3.8×10^{-5}	0.000	0.000	0.076	0.924	–	–	9.2×10^{-6}	9.0×10^{-6}	1.4×10^{-5}
Wild grass (spike)	3.8×10^{-5}	0.000	0.000	0.076	0.924	3.4×10^{-5}	–	8.5×10^{-6}	–	1.4×10^{-5}
Earthworm	3.8×10^{-5}	0.000	0.000	0.076	0.924	–	1.6×10^{-5}	9.1×10^{-6}	–	1.4×10^{-5}
Frog	3.9×10^{-5}	0.000	0.000	0.074	0.926	3.3×10^{-5}	1.6×10^{-5}	9.0×10^{-6}	–	1.3×10^{-5}
Rat	4.1×10^{-5}	0.000	0.000	0.071	0.929	–	1.5×10^{-5}	8.8×10^{-6}	–	1.3×10^{-5}

Duck	4.4×10^{-5}	0.000	0.000	0.066	0.934	2.8×10^{-5}	–	8.6×10^{-6}	7.8×10^{-6}	1.4×10^{-5}
Deer	6.3×10^{-5}	0.000	0.000	0.046	0.954	–	–	4.3×10^{-6}	–	5.9×10^{-6}
Pine tree (trunk)	6.4×10^{-5}	0.000	0.000	0.046	0.954	–	–	6.7×10^{-6}	–	–
Brown seaweed	4.1×10^{-5}	0.000	0.000	0.071	0.929	3.1×10^{-5}	–	–	–	–
Crab	4.3×10^{-5}	0.000	0.000	0.068	0.932	2.9×10^{-5}	–	–	–	–
Trout	4.4×10^{-5}	0.000	0.000	0.067	0.933	2.9×10^{-5}	–	–	–	–
Flatfish	4.2×10^{-5}	0.000	0.000	0.070	0.930	3.1×10^{-5}	–	–	–	–

Table B.15. Dose coefficients for non-human biota exposed to radioactive isotopes of H (Z = 1).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{3}H (progeny included: none)										
Bee	3.3×10^{-6}	0.000	0.000	0.675	0.325	–	–	0	0	0
Wild grass (spike)	3.3×10^{-6}	0.000	0.000	0.675	0.325	7.0×10^{-14}	–	0	–	0
Earthworm	3.3×10^{-6}	0.000	0.000	0.675	0.325	–	0	0	–	0
Frog	3.3×10^{-6}	0.000	0.000	0.675	0.325	2.6×10^{-12}	0	0	–	0
Rat	3.3×10^{-6}	0.000	0.000	0.675	0.325	–	0	0	–	0
Duck	3.3×10^{-6}	0.000	0.000	0.675	0.325	3.8×10^{-13}	–	0	0	0
Deer	3.3×10^{-6}	0.000	0.000	0.675	0.325	–	–	0	–	0
Pine tree (trunk)	3.3×10^{-6}	0.000	0.000	0.675	0.325	–	–	0	–	–
Brown seaweed	3.3×10^{-6}	0.000	0.000	0.675	0.325	1.0×10^{-14}	–	–	–	–
Crab	3.3×10^{-6}	0.000	0.000	0.675	0.325	9.8×10^{-15}	–	–	–	–
Trout	3.3×10^{-6}	0.000	0.000	0.675	0.325	3.8×10^{-13}	–	–	–	–
Flatfish	3.3×10^{-6}	0.000	0.000	0.675	0.325	8.1×10^{-13}	–	–	–	–

Table B.16. Dose coefficients for non-human biota exposed to radioactive isotopes of I (Z = 53).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{125}I (progeny included: none)										
Bee	1.3×10^{-5}	0.000	0.000	0.492	0.508	–	–	2.7×10^{-6}	2.5×10^{-6}	9.7×10^{-6}
Wild grass (spike)	1.4×10^{-5}	0.000	0.000	0.465	0.535	2.2×10^{-5}	–	3.2×10^{-6}	–	8.4×10^{-6}
Earthworm	1.4×10^{-5}	0.000	0.000	0.457	0.543	–	5.6×10^{-6}	2.6×10^{-6}	–	8.3×10^{-6}
Frog	1.7×10^{-5}	0.000	0.000	0.379	0.621	1.9×10^{-5}	5.4×10^{-6}	2.4×10^{-6}	–	7.6×10^{-6}
Rat	2.1×10^{-5}	0.000	0.000	0.302	0.698	–	4.8×10^{-6}	1.9×10^{-6}	–	6.0×10^{-6}
Duck	2.5×10^{-5}	0.000	0.000	0.256	0.744	1.0×10^{-5}	–	1.5×10^{-6}	1.0×10^{-6}	6.5×10^{-6}
Deer	3.4×10^{-5}	0.000	0.000	0.191	0.809	–	–	3.4×10^{-7}	–	1.1×10^{-6}
Pine tree (trunk)	3.4×10^{-5}	0.000	0.000	0.189	0.811	–	–	1.2×10^{-6}	–	–
Brown seaweed	2.0×10^{-5}	0.000	0.000	0.316	0.684	1.5×10^{-5}	–	–	–	–
Crab	2.4×10^{-5}	0.000	0.000	0.269	0.731	1.2×10^{-5}	–	–	–	–
Trout	2.4×10^{-5}	0.000	0.000	0.266	0.734	1.2×10^{-5}	–	–	–	–
Flatfish	2.2×10^{-5}	0.000	0.000	0.300	0.700	1.4×10^{-5}	–	–	–	–
^{129}I (progeny included: none)										
Bee	3.8×10^{-5}	0.000	0.000	0.133	0.867	–	–	1.5×10^{-6}	1.3×10^{-6}	5.2×10^{-6}
Wild grass (spike)	3.9×10^{-5}	0.000	0.000	0.132	0.868	1.3×10^{-5}	–	1.9×10^{-6}	–	4.5×10^{-6}
Earthworm	3.9×10^{-5}	0.000	0.000	0.132	0.868	–	3.6×10^{-6}	1.4×10^{-6}	–	4.5×10^{-6}
Frog	4.0×10^{-5}	0.000	0.000	0.127	0.873	1.2×10^{-5}	3.5×10^{-6}	1.3×10^{-6}	–	4.2×10^{-6}
Rat	4.3×10^{-5}	0.000	0.000	0.120	0.880	–	3.1×10^{-6}	1.1×10^{-6}	–	3.5×10^{-6}
Duck	4.5×10^{-5}	0.000	0.000	0.114	0.886	7.2×10^{-6}	–	9.3×10^{-7}	6.5×10^{-7}	4.0×10^{-6}
Deer	5.1×10^{-5}	0.000	0.000	0.101	0.899	–	–	2.3×10^{-7}	–	7.5×10^{-7}
Pine tree (trunk)	5.1×10^{-5}	0.000	0.000	0.101	0.899	–	–	8.9×10^{-7}	–	–
Brown seaweed	4.2×10^{-5}	0.000	0.000	0.121	0.879	9.9×10^{-6}	–	–	–	–
Crab	4.4×10^{-5}	0.000	0.000	0.116	0.884	8.0×10^{-6}	–	–	–	–
Trout	4.4×10^{-5}	0.000	0.000	0.116	0.884	7.8×10^{-6}	–	–	–	–
Flatfish	4.3×10^{-5}	0.000	0.000	0.120	0.880	9.3×10^{-6}	–	–	–	–
^{131}I (progeny included: none)										
Bee	1.1×10^{-4}	0.000	0.000	0.003	0.997	–	–	8.1×10^{-5}	7.9×10^{-5}	9.7×10^{-5}
Wild grass (spike)	1.1×10^{-4}	0.000	0.000	0.002	0.998	2.2×10^{-4}	–	7.7×10^{-5}	–	9.5×10^{-5}
Earthworm	1.1×10^{-4}	0.000	0.000	0.002	0.998	–	1.9×10^{-4}	8.2×10^{-5}	–	9.5×10^{-5}
Frog	1.2×10^{-4}	0.000	0.000	0.002	0.998	2.1×10^{-4}	1.9×10^{-4}	8.1×10^{-5}	–	9.5×10^{-5}

Rat	1.3×10^{-4}	0.000	0.000	0.002	0.998	–	1.8×10^{-4}	7.9×10^{-5}	–	9.2×10^{-5}
Duck	1.4×10^{-4}	0.000	0.000	0.002	0.998	1.9×10^{-4}	–	7.7×10^{-5}	7.0×10^{-5}	9.8×10^{-5}
Deer	2.5×10^{-4}	0.000	0.000	0.001	0.999	–	–	4.7×10^{-5}	–	5.4×10^{-5}
Pine tree (trunk)	2.5×10^{-4}	0.000	0.000	0.001	0.999	–	–	6.1×10^{-5}	–	–
Brown seaweed	1.3×10^{-4}	0.000	0.000	0.002	0.998	2.0×10^{-4}	–	–	–	–
Crab	1.4×10^{-4}	0.000	0.000	0.002	0.998	1.9×10^{-4}	–	–	–	–
Trout	1.4×10^{-4}	0.000	0.000	0.002	0.998	1.9×10^{-4}	–	–	–	–
Flatfish	1.3×10^{-4}	0.000	0.000	0.002	0.998	2.0×10^{-4}	–	–	–	–
^{132}I (progeny included: none)										
Bee	2.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	4.5×10^{-4}	4.4×10^{-4}	5.6×10^{-4}
Wild grass (spike)	2.6×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-3}	–	4.5×10^{-4}	–	5.6×10^{-4}
Earthworm	2.7×10^{-4}	0.000	0.000	0.000	1.000	–	1.2×10^{-3}	4.7×10^{-4}	–	5.7×10^{-4}
Frog	3.2×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-3}	1.2×10^{-3}	4.7×10^{-4}	–	5.7×10^{-4}
Rat	3.8×10^{-4}	0.000	0.000	0.000	1.000	–	1.1×10^{-3}	4.7×10^{-4}	–	5.6×10^{-4}
Duck	4.6×10^{-4}	0.000	0.000	0.000	1.000	1.1×10^{-3}	–	4.6×10^{-4}	4.2×10^{-4}	6.0×10^{-4}
Deer	1.0×10^{-3}	0.000	0.000	0.000	1.000	–	–	3.0×10^{-4}	–	3.6×10^{-4}
Pine tree (trunk)	9.7×10^{-4}	0.000	0.000	0.000	1.000	–	–	3.6×10^{-4}	–	–
Brown seaweed	3.7×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–
Crab	4.3×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–
Trout	4.4×10^{-4}	0.000	0.000	0.000	1.000	1.1×10^{-3}	–	–	–	–
Flatfish	3.8×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–
^{133}I (progeny included: none)										
Bee	2.0×10^{-4}	0.000	0.000	0.000	1.000	–	–	1.4×10^{-4}	1.4×10^{-4}	1.7×10^{-4}
Wild grass (spike)	2.2×10^{-4}	0.000	0.000	0.000	1.000	3.7×10^{-4}	–	1.2×10^{-4}	–	1.7×10^{-4}
Earthworm	2.2×10^{-4}	0.000	0.000	0.000	1.000	–	3.2×10^{-4}	1.5×10^{-4}	–	1.7×10^{-4}
Frog	2.4×10^{-4}	0.000	0.000	0.000	1.000	3.5×10^{-4}	3.2×10^{-4}	1.5×10^{-4}	–	1.7×10^{-4}
Rat	2.6×10^{-4}	0.000	0.000	0.000	1.000	–	3.0×10^{-4}	1.4×10^{-4}	–	1.7×10^{-4}
Duck	2.9×10^{-4}	0.000	0.000	0.000	1.000	3.1×10^{-4}	–	1.4×10^{-4}	1.3×10^{-4}	1.8×10^{-4}
Deer	4.5×10^{-4}	0.000	0.000	0.000	1.000	–	–	8.9×10^{-5}	–	1.0×10^{-4}
Pine tree (trunk)	4.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	9.8×10^{-5}	–	–
Brown seaweed	2.6×10^{-4}	0.000	0.000	0.000	1.000	3.3×10^{-4}	–	–	–	–
Crab	2.8×10^{-4}	0.000	0.000	0.000	1.000	3.1×10^{-4}	–	–	–	–
Trout	2.8×10^{-4}	0.000	0.000	0.000	1.000	3.1×10^{-4}	–	–	–	–
Flatfish	2.6×10^{-4}	0.000	0.000	0.000	1.000	3.3×10^{-4}	–	–	–	–

Table B.17. Dose coefficients for non-human biota exposed to radioactive isotopes of Ir (Z = 77).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{192}Ir (progeny included: none)										
Bee	1.2×10^{-4}	0.000	0.000	0.009	0.991	–	–	1.8×10^{-4}	1.7×10^{-4}	2.1×10^{-4}
Wild grass (spike)	1.3×10^{-4}	0.000	0.000	0.009	0.991	4.7×10^{-4}	–	1.6×10^{-4}	–	2.1×10^{-4}
Earthworm	1.3×10^{-4}	0.000	0.000	0.009	0.991	–	4.1×10^{-4}	1.8×10^{-4}	–	2.1×10^{-4}
Frog	1.4×10^{-4}	0.000	0.000	0.008	0.992	4.5×10^{-4}	4.0×10^{-4}	1.8×10^{-4}	–	2.0×10^{-4}
Rat	1.7×10^{-4}	0.000	0.000	0.007	0.993	–	3.8×10^{-4}	1.7×10^{-4}	–	2.0×10^{-4}
Duck	2.0×10^{-4}	0.000	0.000	0.006	0.994	4.0×10^{-4}	–	1.7×10^{-4}	1.5×10^{-4}	2.1×10^{-4}
Deer	4.3×10^{-4}	0.000	0.000	0.003	0.997	–	–	1.0×10^{-4}	–	1.2×10^{-4}
Pine tree (trunk)	4.2×10^{-4}	0.000	0.000	0.003	0.997	–	–	1.3×10^{-4}	–	–
Brown seaweed	1.6×10^{-4}	0.000	0.000	0.007	0.993	4.3×10^{-4}	–	–	–	–
Crab	1.8×10^{-4}	0.000	0.000	0.006	0.994	4.1×10^{-4}	–	–	–	–
Trout	1.9×10^{-4}	0.000	0.000	0.006	0.994	4.1×10^{-4}	–	–	–	–
Flatfish	1.7×10^{-4}	0.000	0.000	0.007	0.993	4.3×10^{-4}	–	–	–	–

Table B.18. Dose coefficients for non-human biota exposed to radioactive isotopes of K (Z = 19).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{40}K (progeny included: none)										
Bee	2.3×10^{-4}	0.000	0.000	0.001	0.999	–	–	2.4×10^{-5}	2.4×10^{-5}	3.2×10^{-5}
Wild grass (spike)	2.6×10^{-4}	0.000	0.000	0.001	0.999	1.3×10^{-4}	–	2.9×10^{-5}	–	3.4×10^{-5}
Earthworm	2.6×10^{-4}	0.000	0.000	0.001	0.999	–	8.0×10^{-5}	2.7×10^{-5}	–	3.5×10^{-5}
Frog	2.8×10^{-4}	0.000	0.000	0.001	0.999	1.1×10^{-4}	7.9×10^{-5}	2.9×10^{-5}	–	3.6×10^{-5}
Rat	3.0×10^{-4}	0.000	0.000	0.001	0.999	–	7.6×10^{-5}	2.9×10^{-5}	–	3.7×10^{-5}
Duck	3.1×10^{-4}	0.000	0.000	0.001	0.999	8.6×10^{-5}	–	2.9×10^{-5}	2.6×10^{-5}	3.9×10^{-5}
Deer	3.5×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.1×10^{-5}	–	2.6×10^{-5}
Pine tree (trunk)	3.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.4×10^{-5}	–	–
Brown seaweed	2.9×10^{-4}	0.000	0.000	0.001	0.999	9.8×10^{-5}	–	–	–	–
Crab	3.0×10^{-4}	0.000	0.000	0.001	0.999	8.8×10^{-5}	–	–	–	–
Trout	3.0×10^{-4}	0.000	0.000	0.001	0.999	8.7×10^{-5}	–	–	–	–
Flatfish	3.0×10^{-4}	0.000	0.000	0.001	0.999	9.6×10^{-5}	–	–	–	–

Table B.19. Dose coefficients for non-human biota exposed to radioactive isotopes of La (Z = 57).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{140}La (progeny included: none)										
Bee	2.5×10^{-4}	0.000	0.000	0.001	0.999	–	–	4.2×10^{-4}	4.1×10^{-4}	5.7×10^{-4}
Wild grass (spike)	2.8×10^{-4}	0.000	0.000	0.001	0.999	1.4×10^{-3}	–	4.4×10^{-4}	–	6.1×10^{-4}
Earthworm	2.9×10^{-4}	0.000	0.000	0.001	0.999	–	1.2×10^{-3}	4.8×10^{-4}	–	6.3×10^{-4}
Frog	3.4×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-3}	1.2×10^{-3}	5.1×10^{-4}	–	6.6×10^{-4}
Rat	4.0×10^{-4}	0.000	0.000	0.000	1.000	–	1.1×10^{-3}	5.1×10^{-4}	–	6.7×10^{-4}
Duck	4.7×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	5.1×10^{-4}	4.6×10^{-4}	7.1×10^{-4}
Deer	1.0×10^{-3}	0.000	0.000	0.000	1.000	–	–	3.6×10^{-4}	–	4.7×10^{-4}
Pine tree (trunk)	9.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	3.6×10^{-4}	–	–
Brown seaweed	3.8×10^{-4}	0.000	0.000	0.000	1.000	1.3×10^{-3}	–	–	–	–
Crab	4.4×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–
Trout	4.5×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–
Flatfish	4.0×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-3}	–	–	–	–

Table B.20. Dose coefficients for non-human biota exposed to radioactive isotopes of Mn (Z = 25).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{54}Mn (progeny included: none)										
Bee	7.8×10^{-6}	0.000	0.000	0.382	0.618	–	–	1.9×10^{-4}	1.9×10^{-4}	2.4×10^{-4}
Wild grass (spike)	1.1×10^{-5}	0.000	0.000	0.281	0.719	4.7×10^{-4}	–	1.6×10^{-4}	–	2.4×10^{-4}
Earthworm	1.2×10^{-5}	0.000	0.000	0.259	0.741	–	4.4×10^{-4}	2.0×10^{-4}	–	2.4×10^{-4}
Frog	2.3×10^{-5}	0.000	0.000	0.135	0.865	4.6×10^{-4}	4.4×10^{-4}	2.0×10^{-4}	–	2.4×10^{-4}
Rat	4.3×10^{-5}	0.000	0.000	0.071	0.929	–	4.2×10^{-4}	2.0×10^{-4}	–	2.4×10^{-4}
Duck	6.9×10^{-5}	0.000	0.000	0.044	0.956	4.2×10^{-4}	–	1.9×10^{-4}	1.7×10^{-4}	2.5×10^{-4}
Deer	2.9×10^{-4}	0.000	0.000	0.011	0.989	–	–	1.3×10^{-4}	–	1.5×10^{-4}
Pine tree (trunk)	2.6×10^{-4}	0.000	0.000	0.012	0.988	–	–	1.3×10^{-4}	–	–
Brown seaweed	3.9×10^{-5}	0.000	0.000	0.080	0.920	4.5×10^{-4}	–	–	–	–
Crab	6.0×10^{-5}	0.000	0.000	0.052	0.948	4.2×10^{-4}	–	–	–	–
Trout	6.2×10^{-5}	0.000	0.000	0.050	0.950	4.2×10^{-4}	–	–	–	–
Flatfish	4.4×10^{-5}	0.000	0.000	0.071	0.929	4.4×10^{-4}	–	–	–	–

Table B.21. Dose coefficients for non-human biota exposed to radioactive isotopes of Nb (Z = 41).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{94}Nb (progeny included: none)										
Bee	1.0×10^{-4}	0.000	0.000	0.001	0.999	–	–	3.3×10^{-4}	3.2×10^{-4}	4.1×10^{-4}
Wild grass (spike)	1.1×10^{-4}	0.000	0.000	0.001	0.999	8.9×10^{-4}	–	3.1×10^{-4}	–	4.1×10^{-4}
Earthworm	1.1×10^{-4}	0.000	0.000	0.001	0.999	–	8.3×10^{-4}	3.4×10^{-4}	–	4.1×10^{-4}
Frog	1.3×10^{-4}	0.000	0.000	0.001	0.999	8.6×10^{-4}	8.2×10^{-4}	3.4×10^{-4}	–	4.1×10^{-4}
Rat	1.7×10^{-4}	0.000	0.000	0.001	0.999	–	7.8×10^{-4}	3.4×10^{-4}	–	4.0×10^{-4}
Duck	2.2×10^{-4}	0.000	0.000	0.000	1.000	7.7×10^{-4}	–	3.3×10^{-4}	3.0×10^{-4}	4.3×10^{-4}
Deer	6.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.2×10^{-4}	–	2.6×10^{-4}
Pine tree (trunk)	5.7×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.5×10^{-4}	–	–
Brown seaweed	1.6×10^{-4}	0.000	0.000	0.001	0.999	8.3×10^{-4}	–	–	–	–
Crab	2.0×10^{-4}	0.000	0.000	0.001	0.999	7.9×10^{-4}	–	–	–	–
Trout	2.1×10^{-4}	0.000	0.000	0.001	0.999	7.9×10^{-4}	–	–	–	–
Flatfish	1.7×10^{-4}	0.000	0.000	0.001	0.999	8.2×10^{-4}	–	–	–	–
^{95}Nb (progeny included: none)										
Bee	3.0×10^{-5}	0.000	0.000	0.015	0.985	–	–	1.4×10^{-4}	1.3×10^{-4}	1.6×10^{-4}
Wild grass (spike)	3.3×10^{-5}	0.000	0.000	0.014	0.986	4.3×10^{-4}	–	1.5×10^{-4}	–	1.6×10^{-4}
Earthworm	3.4×10^{-5}	0.000	0.000	0.013	0.987	–	4.1×10^{-4}	1.4×10^{-4}	–	1.6×10^{-4}
Frog	4.4×10^{-5}	0.000	0.000	0.010	0.990	4.2×10^{-4}	4.0×10^{-4}	1.4×10^{-4}	–	1.7×10^{-4}
Rat	6.3×10^{-5}	0.000	0.000	0.007	0.993	–	3.8×10^{-4}	1.4×10^{-4}	–	1.6×10^{-4}
Duck	8.7×10^{-5}	0.000	0.000	0.005	0.995	3.8×10^{-4}	–	1.4×10^{-4}	1.2×10^{-4}	1.7×10^{-4}
Deer	2.9×10^{-4}	0.000	0.000	0.002	0.998	–	–	8.8×10^{-5}	–	1.0×10^{-4}
Pine tree (trunk)	2.6×10^{-4}	0.000	0.000	0.002	0.998	–	–	1.2×10^{-4}	–	–
Brown seaweed	5.9×10^{-5}	0.000	0.000	0.008	0.992	4.1×10^{-4}	–	–	–	–
Crab	7.8×10^{-5}	0.000	0.000	0.006	0.994	3.9×10^{-4}	–	–	–	–
Trout	8.0×10^{-5}	0.000	0.000	0.006	0.994	3.9×10^{-4}	–	–	–	–
Flatfish	6.3×10^{-5}	0.000	0.000	0.007	0.993	4.0×10^{-4}	–	–	–	–

Table B.22. Dose coefficients for non-human biota exposed to radioactive isotopes of Ni (Z = 28).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{59}Ni (progeny included: none)										
Bee	3.7×10^{-6}	0.000	0.000	1.000	0.000	–	–	1.1×10^{-8}	6.4×10^{-9}	5.7×10^{-8}
Wild grass (spike)	3.8×10^{-6}	0.000	0.000	1.000	0.000	2.0×10^{-7}	–	1.2×10^{-7}	–	3.0×10^{-8}
Earthworm	3.8×10^{-6}	0.000	0.000	1.000	0.000	–	1.0×10^{-7}	8.1×10^{-9}	–	2.5×10^{-8}
Frog	3.9×10^{-6}	0.000	0.000	1.000	0.000	8.7×10^{-8}	1.0×10^{-7}	6.4×10^{-9}	–	1.7×10^{-8}
Rat	3.9×10^{-6}	0.000	0.000	1.000	0.000	–	8.5×10^{-8}	5.1×10^{-9}	–	1.0×10^{-8}
Duck	4.0×10^{-6}	0.000	0.000	1.000	0.000	3.1×10^{-8}	–	4.6×10^{-9}	3.5×10^{-9}	1.1×10^{-8}
Deer	4.0×10^{-6}	0.000	0.000	0.999	0.001	–	–	2.5×10^{-9}	–	3.5×10^{-9}
Pine tree (trunk)	4.0×10^{-6}	0.000	0.000	0.999	0.001	–	–	2.5×10^{-9}	–	–
Brown seaweed	3.9×10^{-6}	0.000	0.000	1.000	0.000	3.7×10^{-8}	–	–	–	–
Crab	4.0×10^{-6}	0.000	0.000	1.000	0.000	3.5×10^{-8}	–	–	–	–
Trout	4.0×10^{-6}	0.000	0.000	1.000	0.000	3.1×10^{-8}	–	–	–	–
Flatfish	4.0×10^{-6}	0.000	0.000	1.000	0.000	3.1×10^{-8}	–	–	–	–
^{63}Ni (progeny included: none)										
Bee	1.0×10^{-5}	0.000	0.000	0.100	0.900	–	–	0	0	0
Wild grass (spike)	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.1×10^{-8}	–	0	–	0
Earthworm	1.0×10^{-5}	0.000	0.000	0.100	0.900	–	0	0	–	0
Frog	1.0×10^{-5}	0.000	0.000	0.100	0.900	4.0×10^{-9}	0	0	–	0
Rat	1.0×10^{-5}	0.000	0.000	0.100	0.900	–	0	0	–	0
Duck	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.2×10^{-9}	–	0	0	0
Deer	1.0×10^{-5}	0.000	0.000	0.100	0.900	–	–	0	–	0
Pine tree (trunk)	1.0×10^{-5}	0.000	0.000	0.100	0.900	–	–	0	–	–
Brown seaweed	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.7×10^{-9}	–	–	–	–
Crab	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.7×10^{-9}	–	–	–	–
Trout	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.2×10^{-9}	–	–	–	–
Flatfish	1.0×10^{-5}	0.000	0.000	0.100	0.900	1.1×10^{-9}	–	–	–	–

Table B.23. Dose coefficients for non-human biota exposed to radioactive isotopes of Np (Z = 93).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{237}Np (progeny included: none)										
Bee	2.8×10^{-3}	0.017	0.969	0.003	0.012	–	–	3.7×10^{-6}	3.5×10^{-6}	7.1×10^{-6}
Wild grass (spike)	2.8×10^{-3}	0.017	0.968	0.003	0.012	1.7×10^{-5}	–	4.1×10^{-6}	–	6.3×10^{-6}
Earthworm	2.8×10^{-3}	0.017	0.968	0.003	0.012	–	7.4×10^{-6}	3.6×10^{-6}	–	6.2×10^{-6}
Frog	2.8×10^{-3}	0.017	0.968	0.003	0.013	1.5×10^{-5}	7.3×10^{-6}	3.5×10^{-6}	–	5.8×10^{-6}
Rat	2.8×10^{-3}	0.017	0.967	0.003	0.013	–	6.8×10^{-6}	3.3×10^{-6}	–	5.2×10^{-6}
Duck	2.9×10^{-3}	0.017	0.967	0.003	0.014	1.2×10^{-5}	–	3.1×10^{-6}	2.8×10^{-6}	5.7×10^{-6}
Deer	2.9×10^{-3}	0.017	0.964	0.003	0.017	–	–	1.6×10^{-6}	–	2.2×10^{-6}
Pine tree (trunk)	2.9×10^{-3}	0.017	0.964	0.003	0.017	–	–	2.7×10^{-6}	–	–
Brown seaweed	2.8×10^{-3}	0.017	0.967	0.003	0.013	1.3×10^{-5}	–	–	–	–
Crab	2.8×10^{-3}	0.017	0.967	0.003	0.014	1.2×10^{-5}	–	–	–	–
Trout	2.8×10^{-3}	0.017	0.967	0.003	0.014	1.2×10^{-5}	–	–	–	–
Flatfish	2.8×10^{-3}	0.017	0.967	0.003	0.014	1.3×10^{-5}	–	–	–	–

Table B.24. Dose coefficients for non-human biota exposed to radioactive isotopes of P (Z = 15).

RAPs	Internal exposure					External exposure				
	$(\mu Gy\ h^{-1}\ Bq^{-1}\ kg)$	f_0	f_1	f_2	f_3	Aquatic $(\mu Gy\ h^{-1}\ Bq^{-1}\ L)$	In-soil $(\mu Gy\ h^{-1}\ Bq^{-1}\ kg)$	On-ground $(\mu Gy\ h^{-1}\ Bq^{-1}\ kg)$	Above-ground $(\mu Gy\ h^{-1}\ Bq^{-1}\ kg)$	Immersion in air $(\mu Gy\ h^{-1}\ Bq^{-1}\ m^3)$
^{32}P (progeny included: none)										
Bee	2.9×10^{-4}	0.000	0.000	0.000	1.000	–	–	0	0	0
Wild grass (spike)	3.3×10^{-4}	0.000	0.000	0.000	1.000	7.2×10^{-5}	–	0	–	0
Earthworm	3.3×10^{-4}	0.000	0.000	0.000	1.000	–	0	0	–	0
Frog	3.7×10^{-4}	0.000	0.000	0.000	1.000	3.1×10^{-5}	0	0	–	0
Rat	3.8×10^{-4}	0.000	0.000	0.000	1.000	–	0	0	–	0
Duck	3.9×10^{-4}	0.000	0.000	0.000	1.000	9.8×10^{-6}	–	0	0	0
Deer	4.0×10^{-4}	0.000	0.000	0.000	1.000	–	–	0	–	0
Pine tree (trunk)	4.0×10^{-4}	0.000	0.000	0.000	1.000	–	–	0	–	–
Brown seaweed	3.8×10^{-4}	0.000	0.000	0.000	1.000	2.4×10^{-5}	–	–	–	–
Crab	3.9×10^{-4}	0.000	0.000	0.000	1.000	1.2×10^{-5}	–	–	–	–
Trout	3.9×10^{-4}	0.000	0.000	0.000	1.000	1.1×10^{-5}	–	–	–	–
Flatfish	3.8×10^{-4}	0.000	0.000	0.000	1.000	2.2×10^{-5}	–	–	–	–
^{33}P (progeny included: none)										
Bee	4.3×10^{-5}	0.000	0.000	0.005	0.995	–	–	0	0	0
Wild grass (spike)	4.4×10^{-5}	0.000	0.000	0.005	0.995	4.2×10^{-7}	–	0	–	0
Earthworm	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	0	0	–	0
Frog	4.4×10^{-5}	0.000	0.000	0.005	0.995	1.9×10^{-7}	0	0	–	0
Rat	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	0	0	–	0
Duck	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.1×10^{-8}	–	0	0	0
Deer	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	–	0	–	0
Pine tree (trunk)	4.4×10^{-5}	0.000	0.000	0.005	0.995	–	–	0	–	–
Brown seaweed	4.4×10^{-5}	0.000	0.000	0.005	0.995	7.6×10^{-8}	–	–	–	–
Crab	4.4×10^{-5}	0.000	0.000	0.005	0.995	7.2×10^{-8}	–	–	–	–
Trout	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.1×10^{-8}	–	–	–	–
Flatfish	4.4×10^{-5}	0.000	0.000	0.005	0.995	6.2×10^{-8}	–	–	–	–

Table B.25. Dose coefficients for non-human biota exposed to radioactive isotopes of Pa (Z = 91).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{231}Pa (progeny included: none)										
Bee	2.9×10^{-3}	0.017	0.971	0.003	0.008	–	–	6.9×10^{-6}	6.7×10^{-6}	9.7×10^{-6}
Wild grass (spike)	2.9×10^{-3}	0.017	0.971	0.003	0.009	2.2×10^{-5}	–	7.1×10^{-6}	–	9.0×10^{-6}
Earthworm	2.9×10^{-3}	0.017	0.971	0.003	0.009	–	1.6×10^{-5}	6.8×10^{-6}	–	8.9×10^{-6}
Frog	2.9×10^{-3}	0.017	0.971	0.003	0.009	2.1×10^{-5}	1.6×10^{-5}	6.7×10^{-6}	–	8.6×10^{-6}
Rat	3.0×10^{-3}	0.017	0.970	0.003	0.010	–	1.5×10^{-5}	6.5×10^{-6}	–	8.1×10^{-6}
Duck	3.0×10^{-3}	0.017	0.969	0.003	0.010	1.7×10^{-5}	–	6.3×10^{-6}	5.7×10^{-6}	8.6×10^{-6}
Deer	3.0×10^{-3}	0.017	0.966	0.003	0.014	–	–	3.7×10^{-6}	–	4.3×10^{-6}
Pine tree (trunk)	3.0×10^{-3}	0.017	0.966	0.003	0.014	–	–	5.2×10^{-6}	–	–
Brown seaweed	3.0×10^{-3}	0.017	0.970	0.003	0.010	1.9×10^{-5}	–	–	–	–
Crab	3.0×10^{-3}	0.017	0.970	0.003	0.010	1.8×10^{-5}	–	–	–	–
Trout	3.0×10^{-3}	0.017	0.970	0.003	0.010	1.7×10^{-5}	–	–	–	–
Flatfish	3.0×10^{-3}	0.017	0.970	0.003	0.010	1.9×10^{-5}	–	–	–	–

Table B.26. Dose coefficients for non-human biota exposed to radioactive isotopes of Pb (Z = 82).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
						^{210}Pb (progeny included: ^{210}Bi ^{206}Hg)				
Bee	2.1×10^{-4}	0.000	0.000	0.026	0.974	–	–	1.8×10^{-7}	1.6×10^{-7}	6.1×10^{-7}
Wild grass (spike)	2.3×10^{-4}	0.000	0.000	0.025	0.975	2.5×10^{-5}	–	4.1×10^{-7}	–	4.8×10^{-7}
Earthworm	2.3×10^{-4}	0.000	0.000	0.025	0.975	–	6.1×10^{-7}	1.7×10^{-7}	–	4.6×10^{-7}
Frog	2.4×10^{-4}	0.000	0.000	0.023	0.977	1.1×10^{-5}	6.0×10^{-7}	1.6×10^{-7}	–	4.1×10^{-7}
Rat	2.4×10^{-4}	0.000	0.000	0.023	0.977	–	5.3×10^{-7}	1.4×10^{-7}	–	3.6×10^{-7}
Duck	2.5×10^{-4}	0.000	0.000	0.023	0.977	3.9×10^{-6}	–	1.3×10^{-7}	1.1×10^{-7}	4.1×10^{-7}
Deer	2.5×10^{-4}	0.000	0.000	0.022	0.978	–	–	4.5×10^{-8}	–	1.1×10^{-7}
Pine tree (trunk)	2.5×10^{-4}	0.000	0.000	0.022	0.978	–	–	1.4×10^{-7}	–	–
Brown seaweed	2.4×10^{-4}	0.000	0.000	0.023	0.977	7.1×10^{-6}	–	–	–	–
Crab	2.5×10^{-4}	0.000	0.000	0.023	0.977	4.5×10^{-6}	–	–	–	–
Trout	2.5×10^{-4}	0.000	0.000	0.023	0.977	4.0×10^{-6}	–	–	–	–
Flatfish	2.4×10^{-4}	0.000	0.000	0.023	0.977	6.2×10^{-6}	–	–	–	–

Table B.27. Dose coefficients for non-human biota exposed to radioactive isotopes of Po (Z = 84).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{210}Po (progeny included: none)										
Bee	3.1×10^{-3}	0.019	0.981	0.000	0.000	–	–	2.4×10^{-9}	2.3×10^{-9}	3.0×10^{-9}
Wild grass (spike)	3.1×10^{-3}	0.019	0.981	0.000	0.000	5.5×10^{-9}	–	1.9×10^{-9}	–	3.0×10^{-9}
Earthworm	3.1×10^{-3}	0.019	0.981	0.000	0.000	–	5.2×10^{-9}	2.5×10^{-9}	–	3.0×10^{-9}
Frog	3.1×10^{-3}	0.019	0.981	0.000	0.000	5.4×10^{-9}	5.1×10^{-9}	2.5×10^{-9}	–	3.0×10^{-9}
Rat	3.1×10^{-3}	0.019	0.981	0.000	0.000	–	4.9×10^{-9}	2.5×10^{-9}	–	3.0×10^{-9}
Duck	3.1×10^{-3}	0.019	0.981	0.000	0.000	4.8×10^{-9}	–	2.4×10^{-9}	2.2×10^{-9}	3.2×10^{-9}
Deer	3.1×10^{-3}	0.019	0.981	0.000	0.000	–	–	1.6×10^{-9}	–	1.9×10^{-9}
Pine tree (trunk)	3.1×10^{-3}	0.019	0.981	0.000	0.000	–	–	1.6×10^{-9}	–	–
Brown seaweed	3.1×10^{-3}	0.019	0.981	0.000	0.000	5.2×10^{-9}	–	–	–	–
Crab	3.1×10^{-3}	0.019	0.981	0.000	0.000	4.9×10^{-9}	–	–	–	–
Trout	3.1×10^{-3}	0.019	0.981	0.000	0.000	4.9×10^{-9}	–	–	–	–
Flatfish	3.1×10^{-3}	0.019	0.981	0.000	0.000	5.1×10^{-9}	–	–	–	–

Table B.28. Dose coefficients for non-human biota exposed to radioactive isotopes of Pu (Z = 94).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{238}Pu (progeny included: none)										
Bee	3.2×10^{-3}	0.017	0.981	0.000	0.002	–	–	7.8×10^{-8}	6.0×10^{-8}	3.7×10^{-7}
Wild grass (spike)	3.2×10^{-3}	0.017	0.981	0.000	0.002	6.1×10^{-7}	–	1.4×10^{-7}	–	2.6×10^{-7}
Earthworm	3.2×10^{-3}	0.017	0.981	0.000	0.002	–	1.7×10^{-7}	6.2×10^{-8}	–	2.4×10^{-7}
Frog	3.2×10^{-3}	0.017	0.981	0.000	0.002	3.7×10^{-7}	1.6×10^{-7}	4.6×10^{-8}	–	1.7×10^{-7}
Rat	3.2×10^{-3}	0.017	0.981	0.000	0.002	–	1.4×10^{-7}	2.7×10^{-8}	–	1.0×10^{-7}
Duck	3.2×10^{-3}	0.017	0.981	0.000	0.002	1.3×10^{-7}	–	1.9×10^{-8}	8.8×10^{-9}	1.1×10^{-7}
Deer	3.2×10^{-3}	0.017	0.981	0.000	0.002	–	–	3.9×10^{-9}	–	1.4×10^{-8}
Pine tree (trunk)	3.2×10^{-3}	0.017	0.981	0.000	0.002	–	–	1.0×10^{-8}	–	–
Brown seaweed	3.2×10^{-3}	0.017	0.981	0.000	0.002	2.3×10^{-7}	–	–	–	–
Crab	3.2×10^{-3}	0.017	0.981	0.000	0.002	1.6×10^{-7}	–	–	–	–
Trout	3.2×10^{-3}	0.017	0.981	0.000	0.002	1.4×10^{-7}	–	–	–	–
Flatfish	3.2×10^{-3}	0.017	0.981	0.000	0.002	1.9×10^{-7}	–	–	–	–
^{239}Pu (progeny included: ^{235m}U)										
Bee	3.0×10^{-3}	0.017	0.982	0.001	0.001	–	–	4.6×10^{-8}	3.6×10^{-8}	1.9×10^{-7}
Wild grass (spike)	3.0×10^{-3}	0.017	0.982	0.001	0.001	2.9×10^{-7}	–	6.7×10^{-8}	–	1.3×10^{-7}
Earthworm	3.0×10^{-3}	0.017	0.982	0.001	0.001	–	9.3×10^{-8}	3.8×10^{-8}	–	1.2×10^{-7}
Frog	3.0×10^{-3}	0.017	0.982	0.001	0.001	1.9×10^{-7}	9.0×10^{-8}	3.1×10^{-8}	–	9.0×10^{-8}
Rat	3.0×10^{-3}	0.017	0.982	0.001	0.001	–	7.9×10^{-8}	2.2×10^{-8}	–	5.7×10^{-8}
Duck	3.0×10^{-3}	0.017	0.982	0.001	0.001	8.4×10^{-8}	–	1.8×10^{-8}	1.3×10^{-8}	6.1×10^{-8}
Deer	3.0×10^{-3}	0.017	0.982	0.001	0.001	–	–	7.3×10^{-9}	–	1.3×10^{-8}
Pine tree (trunk)	3.0×10^{-3}	0.017	0.982	0.001	0.001	–	–	1.2×10^{-8}	–	–
Brown seaweed	3.0×10^{-3}	0.017	0.982	0.001	0.001	1.3×10^{-7}	–	–	–	–
Crab	3.0×10^{-3}	0.017	0.982	0.001	0.001	9.5×10^{-8}	–	–	–	–
Trout	3.0×10^{-3}	0.017	0.982	0.001	0.001	8.9×10^{-8}	–	–	–	–
Flatfish	3.0×10^{-3}	0.017	0.982	0.001	0.001	1.1×10^{-7}	–	–	–	–
^{240}Pu (progeny included: none)										
Bee	3.0×10^{-3}	0.017	0.981	0.000	0.002	–	–	7.5×10^{-8}	5.7×10^{-8}	3.5×10^{-7}
Wild grass (spike)	3.0×10^{-3}	0.017	0.981	0.000	0.002	5.7×10^{-7}	–	1.3×10^{-7}	–	2.4×10^{-7}
Earthworm	3.0×10^{-3}	0.017	0.981	0.000	0.002	–	1.6×10^{-7}	6.0×10^{-8}	–	2.2×10^{-7}
Frog	3.0×10^{-3}	0.017	0.981	0.000	0.002	3.5×10^{-7}	1.5×10^{-7}	4.5×10^{-8}	–	1.6×10^{-7}
Rat	3.0×10^{-3}	0.017	0.981	0.000	0.002	–	1.3×10^{-7}	2.7×10^{-8}	–	9.5×10^{-8}

Duck	3.0×10^{-3}	0.017	0.981	0.000	0.002	1.3×10^{-7}	–	1.9×10^{-8}	9.0×10^{-9}	1.0×10^{-7}
Deer	3.0×10^{-3}	0.017	0.981	0.000	0.002	–	–	4.1×10^{-9}	–	1.4×10^{-8}
Pine tree (trunk)	3.0×10^{-3}	0.017	0.981	0.000	0.002	–	–	9.8×10^{-9}	–	–
Brown seaweed	3.0×10^{-3}	0.017	0.981	0.000	0.002	2.2×10^{-7}	–	–	–	–
Crab	3.0×10^{-3}	0.017	0.981	0.000	0.002	1.5×10^{-7}	–	–	–	–
Trout	3.0×10^{-3}	0.017	0.981	0.000	0.002	1.4×10^{-7}	–	–	–	–
Flatfish	3.0×10^{-3}	0.017	0.981	0.000	0.002	1.8×10^{-7}	–	–	–	–
^{241}Pu (progeny included: none)										
Bee	3.1×10^{-6}	0.000	0.022	0.639	0.338	–	–	2.2×10^{-10}	2.1×10^{-10}	3.5×10^{-10}
Wild grass (spike)	3.1×10^{-6}	0.000	0.022	0.639	0.338	9.4×10^{-10}	–	2.6×10^{-10}	–	3.3×10^{-10}
Earthworm	3.1×10^{-6}	0.000	0.022	0.639	0.338	–	4.8×10^{-10}	2.1×10^{-10}	–	3.2×10^{-10}
Frog	3.1×10^{-6}	0.000	0.022	0.639	0.338	8.9×10^{-10}	4.8×10^{-10}	2.1×10^{-10}	–	3.1×10^{-10}
Rat	3.1×10^{-6}	0.000	0.022	0.639	0.338	–	4.5×10^{-10}	2.0×10^{-10}	–	3.0×10^{-10}
Duck	3.1×10^{-6}	0.000	0.022	0.639	0.338	7.5×10^{-10}	–	2.0×10^{-10}	1.8×10^{-10}	3.2×10^{-10}
Deer	3.1×10^{-6}	0.000	0.022	0.639	0.338	–	–	1.1×10^{-10}	–	1.5×10^{-10}
Pine tree (trunk)	3.1×10^{-6}	0.000	0.022	0.639	0.338	–	–	2.0×10^{-10}	–	–
Brown seaweed	3.1×10^{-6}	0.000	0.022	0.639	0.338	8.3×10^{-10}	–	–	–	–
Crab	3.1×10^{-6}	0.000	0.022	0.639	0.338	7.8×10^{-10}	–	–	–	–
Trout	3.1×10^{-6}	0.000	0.022	0.639	0.338	7.7×10^{-10}	–	–	–	–
Flatfish	3.1×10^{-6}	0.000	0.022	0.639	0.338	8.1×10^{-10}	–	–	–	–

Table B.29. Dose coefficients for non-human biota exposed to radioactive isotopes of Ra (Z = 88).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{226}Ra (progeny included: ^{222}Rn ^{218}Po ^{214}Pb ^{218}At ^{214}Bi ^{218}Rn ^{210}Tl ^{214}Po)										
Bee	1.5×10^{-2}	0.018	0.953	0.000	0.029	–	–	2.9×10^{-4}	2.8×10^{-4}	3.7×10^{-4}
Wild grass (spike)	1.5×10^{-2}	0.018	0.950	0.000	0.033	1.1×10^{-3}	–	3.3×10^{-4}	–	3.9×10^{-4}
Earthworm	1.5×10^{-2}	0.018	0.949	0.000	0.033	–	8.9×10^{-4}	3.2×10^{-4}	–	4.0×10^{-4}
Frog	1.5×10^{-2}	0.018	0.945	0.000	0.038	1.0×10^{-3}	8.8×10^{-4}	3.3×10^{-4}	–	4.1×10^{-4}
Rat	1.5×10^{-2}	0.018	0.941	0.000	0.042	–	8.4×10^{-4}	3.3×10^{-4}	–	4.2×10^{-4}
Duck	1.5×10^{-2}	0.017	0.937	0.000	0.045	8.9×10^{-4}	–	3.3×10^{-4}	3.0×10^{-4}	4.4×10^{-4}
Deer	1.5×10^{-2}	0.017	0.909	0.000	0.073	–	–	2.3×10^{-4}	–	2.8×10^{-4}
Pine tree (trunk)	1.5×10^{-2}	0.017	0.914	0.000	0.069	–	–	2.7×10^{-4}	–	–
Brown seaweed	1.5×10^{-2}	0.018	0.942	0.000	0.040	9.7×10^{-4}	–	–	–	–
Crab	1.5×10^{-2}	0.017	0.938	0.000	0.044	9.1×10^{-4}	–	–	–	–
Trout	1.5×10^{-2}	0.017	0.938	0.000	0.044	9.0×10^{-4}	–	–	–	–
Flatfish	1.5×10^{-2}	0.018	0.941	0.000	0.041	9.5×10^{-4}	–	–	–	–
^{228}Ra (progeny included: ^{228}Ac)										
Bee	2.3×10^{-4}	0.000	0.000	0.040	0.960	–	–	1.6×10^{-4}	1.6×10^{-4}	2.0×10^{-4}
Wild grass (spike)	2.5×10^{-4}	0.000	0.000	0.037	0.963	5.2×10^{-4}	–	1.7×10^{-4}	–	2.1×10^{-4}
Earthworm	2.5×10^{-4}	0.000	0.000	0.036	0.964	–	4.5×10^{-4}	1.7×10^{-4}	–	2.1×10^{-4}
Frog	2.8×10^{-4}	0.000	0.000	0.033	0.967	4.9×10^{-4}	4.4×10^{-4}	1.7×10^{-4}	–	2.1×10^{-4}
Rat	3.1×10^{-4}	0.000	0.000	0.030	0.970	–	4.2×10^{-4}	1.7×10^{-4}	–	2.1×10^{-4}
Duck	3.4×10^{-4}	0.000	0.000	0.027	0.973	4.3×10^{-4}	–	1.7×10^{-4}	1.5×10^{-4}	2.2×10^{-4}
Deer	5.6×10^{-4}	0.000	0.000	0.016	0.984	–	–	1.1×10^{-4}	–	1.4×10^{-4}
Pine tree (trunk)	5.3×10^{-4}	0.000	0.000	0.017	0.983	–	–	1.4×10^{-4}	–	–
Brown seaweed	3.0×10^{-4}	0.000	0.000	0.031	0.969	4.7×10^{-4}	–	–	–	–
Crab	3.2×10^{-4}	0.000	0.000	0.028	0.972	4.4×10^{-4}	–	–	–	–
Trout	3.3×10^{-4}	0.000	0.000	0.028	0.972	4.4×10^{-4}	–	–	–	–
Flatfish	3.0×10^{-4}	0.000	0.000	0.030	0.970	4.6×10^{-4}	–	–	–	–

Table B.30. Dose coefficients for non-human biota exposed to radioactive isotopes of Ru (Z = 44).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{103}Ru (progeny included: ^{103m}Rh)										
Bee	6.2×10^{-5}	0.000	0.000	0.029	0.971	–	–	8.7×10^{-5}	8.5×10^{-5}	1.0×10^{-4}
Wild grass (spike)	6.4×10^{-5}	0.000	0.000	0.028	0.972	2.8×10^{-4}	–	1.0×10^{-4}	–	1.0×10^{-4}
Earthworm	6.5×10^{-5}	0.000	0.000	0.028	0.972	–	2.6×10^{-4}	8.7×10^{-5}	–	1.0×10^{-4}
Frog	7.2×10^{-5}	0.000	0.000	0.025	0.975	2.7×10^{-4}	2.6×10^{-4}	8.7×10^{-5}	–	1.0×10^{-4}
Rat	8.6×10^{-5}	0.000	0.000	0.021	0.979	–	2.4×10^{-4}	8.5×10^{-5}	–	9.9×10^{-5}
Duck	1.0×10^{-4}	0.000	0.000	0.018	0.982	2.4×10^{-4}	–	8.3×10^{-5}	7.5×10^{-5}	1.1×10^{-4}
Deer	2.4×10^{-4}	0.000	0.000	0.008	0.992	–	–	5.2×10^{-5}	–	6.0×10^{-5}
Pine tree (trunk)	2.3×10^{-4}	0.000	0.000	0.008	0.992	–	–	8.0×10^{-5}	–	–
Brown seaweed	8.3×10^{-5}	0.000	0.000	0.022	0.978	2.6×10^{-4}	–	–	–	–
Crab	9.6×10^{-5}	0.000	0.000	0.019	0.981	2.5×10^{-4}	–	–	–	–
Trout	9.8×10^{-5}	0.000	0.000	0.019	0.981	2.5×10^{-4}	–	–	–	–
Flatfish	8.6×10^{-5}	0.000	0.000	0.021	0.979	2.6×10^{-4}	–	–	–	–
^{106}Ru (progeny included: ^{106}Rh)										
Bee	3.8×10^{-4}	0.000	0.000	0.004	0.996	–	–	4.5×10^{-5}	4.4×10^{-5}	5.5×10^{-5}
Wild grass (spike)	5.1×10^{-4}	0.000	0.000	0.003	0.997	4.3×10^{-4}	–	4.1×10^{-5}	–	5.5×10^{-5}
Earthworm	5.4×10^{-4}	0.000	0.000	0.003	0.997	–	1.1×10^{-4}	4.6×10^{-5}	–	5.5×10^{-5}
Frog	6.9×10^{-4}	0.000	0.000	0.002	0.998	2.5×10^{-4}	1.1×10^{-4}	4.6×10^{-5}	–	5.5×10^{-5}
Rat	7.6×10^{-4}	0.000	0.000	0.002	0.998	–	1.0×10^{-4}	4.6×10^{-5}	–	5.4×10^{-5}
Duck	7.9×10^{-4}	0.000	0.000	0.002	0.998	1.5×10^{-4}	–	4.5×10^{-5}	4.0×10^{-5}	5.7×10^{-5}
Deer	8.8×10^{-4}	0.000	0.000	0.002	0.998	–	–	2.8×10^{-5}	–	3.3×10^{-5}
Pine tree (trunk)	8.8×10^{-4}	0.000	0.000	0.002	0.998	–	–	3.3×10^{-5}	–	–
Brown seaweed	7.2×10^{-4}	0.000	0.000	0.002	0.998	2.2×10^{-4}	–	–	–	–
Crab	7.8×10^{-4}	0.000	0.000	0.002	0.998	1.6×10^{-4}	–	–	–	–
Trout	7.8×10^{-4}	0.000	0.000	0.002	0.998	1.6×10^{-4}	–	–	–	–
Flatfish	7.2×10^{-4}	0.000	0.000	0.002	0.998	2.2×10^{-4}	–	–	–	–

Table B.31. Dose coefficients for non-human biota exposed to radioactive isotopes of S (Z = 16).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{35}S (progeny included: none)										
Bee	2.8×10^{-5}	0.000	0.000	0.013	0.987	–	–	0	0	0
Wild grass (spike)	2.8×10^{-5}	0.000	0.000	0.013	0.987	1.4×10^{-7}	–	0	–	0
Earthworm	2.8×10^{-5}	0.000	0.000	0.013	0.987	–	0	0	–	0
Frog	2.8×10^{-5}	0.000	0.000	0.013	0.987	6.2×10^{-8}	0	0	–	0
Rat	2.8×10^{-5}	0.000	0.000	0.013	0.987	–	0	0	–	0
Duck	2.8×10^{-5}	0.000	0.000	0.013	0.987	1.9×10^{-8}	–	0	0	0
Deer	2.8×10^{-5}	0.000	0.000	0.013	0.987	–	–	0	–	0
Pine tree (trunk)	2.8×10^{-5}	0.000	0.000	0.013	0.987	–	–	0	–	–
Brown seaweed	2.8×10^{-5}	0.000	0.000	0.013	0.987	2.4×10^{-8}	–	–	–	–
Crab	2.8×10^{-5}	0.000	0.000	0.013	0.987	2.3×10^{-8}	–	–	–	–
Trout	2.8×10^{-5}	0.000	0.000	0.013	0.987	1.9×10^{-8}	–	–	–	–
Flatfish	2.8×10^{-5}	0.000	0.000	0.013	0.987	1.9×10^{-8}	–	–	–	–

Table B.32. Dose coefficients for non-human biota exposed to radioactive isotopes of Sb (Z = 51).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{124}Sb (progeny included: none)										
Bee	1.7×10^{-4}	0.000	0.000	0.001	0.999	–	–	3.2×10^{-4}	3.1×10^{-4}	4.1×10^{-4}
Wild grass (spike)	2.0×10^{-4}	0.000	0.000	0.001	0.999	1.1×10^{-3}	–	3.5×10^{-4}	–	4.4×10^{-4}
Earthworm	2.0×10^{-4}	0.000	0.000	0.001	0.999	–	9.7×10^{-4}	3.5×10^{-4}	–	4.5×10^{-4}
Frog	2.4×10^{-4}	0.000	0.000	0.000	1.000	1.0×10^{-3}	9.5×10^{-4}	3.7×10^{-4}	–	4.7×10^{-4}
Rat	2.9×10^{-4}	0.000	0.000	0.000	1.000	–	9.1×10^{-4}	3.7×10^{-4}	–	4.7×10^{-4}
Duck	3.5×10^{-4}	0.000	0.000	0.000	1.000	9.4×10^{-4}	–	3.7×10^{-4}	3.3×10^{-4}	5.0×10^{-4}
Deer	8.2×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.6×10^{-4}	–	3.2×10^{-4}
Pine tree (trunk)	7.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	2.9×10^{-4}	–	–
Brown seaweed	2.8×10^{-4}	0.000	0.000	0.000	1.000	1.0×10^{-3}	–	–	–	–
Crab	3.3×10^{-4}	0.000	0.000	0.000	1.000	9.6×10^{-4}	–	–	–	–
Trout	3.3×10^{-4}	0.000	0.000	0.000	1.000	9.6×10^{-4}	–	–	–	–
Flatfish	2.9×10^{-4}	0.000	0.000	0.000	1.000	1.0×10^{-3}	–	–	–	–
^{125}Sb (progeny included: none)										
Bee	6.0×10^{-5}	0.000	0.000	0.052	0.948	–	–	9.3×10^{-5}	9.1×10^{-5}	1.1×10^{-4}
Wild grass (spike)	6.2×10^{-5}	0.000	0.000	0.050	0.950	2.5×10^{-4}	–	8.6×10^{-5}	–	1.1×10^{-4}
Earthworm	6.3×10^{-5}	0.000	0.000	0.050	0.950	–	2.2×10^{-4}	9.4×10^{-5}	–	1.1×10^{-4}
Frog	7.0×10^{-5}	0.000	0.000	0.044	0.956	2.4×10^{-4}	2.2×10^{-4}	9.4×10^{-5}	–	1.1×10^{-4}
Rat	8.3×10^{-5}	0.000	0.000	0.038	0.962	–	2.1×10^{-4}	9.2×10^{-5}	–	1.1×10^{-4}
Duck	9.9×10^{-5}	0.000	0.000	0.032	0.968	2.1×10^{-4}	–	8.9×10^{-5}	8.1×10^{-5}	1.2×10^{-4}
Deer	2.2×10^{-4}	0.000	0.000	0.014	0.986	–	–	5.6×10^{-5}	–	6.4×10^{-5}
Pine tree (trunk)	2.1×10^{-4}	0.000	0.000	0.015	0.985	–	–	6.8×10^{-5}	–	–
Brown seaweed	8.1×10^{-5}	0.000	0.000	0.039	0.961	2.3×10^{-4}	–	–	–	–
Crab	9.3×10^{-5}	0.000	0.000	0.034	0.966	2.2×10^{-4}	–	–	–	–
Trout	9.4×10^{-5}	0.000	0.000	0.033	0.967	2.2×10^{-4}	–	–	–	–
Flatfish	8.4×10^{-5}	0.000	0.000	0.037	0.963	2.3×10^{-4}	–	–	–	–

Table B.33. Dose coefficients for non-human biota exposed to radioactive isotopes of Se (Z = 34).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{75}Se (progeny included: none)										
Bee	1.3×10^{-5}	0.000	0.000	0.222	0.778	–	–	8.6×10^{-5}	8.4×10^{-5}	1.0×10^{-4}
Wild grass (spike)	1.4×10^{-5}	0.000	0.000	0.196	0.804	2.2×10^{-4}	–	7.4×10^{-5}	–	1.0×10^{-4}
Earthworm	1.5×10^{-5}	0.000	0.000	0.189	0.811	–	1.7×10^{-4}	8.5×10^{-5}	–	1.0×10^{-4}
Frog	2.1×10^{-5}	0.000	0.000	0.137	0.863	2.1×10^{-4}	1.7×10^{-4}	8.5×10^{-5}	–	1.0×10^{-4}
Rat	3.1×10^{-5}	0.000	0.000	0.090	0.910	–	1.6×10^{-4}	8.3×10^{-5}	–	9.8×10^{-5}
Duck	4.6×10^{-5}	0.000	0.000	0.062	0.938	1.9×10^{-4}	–	8.1×10^{-5}	7.3×10^{-5}	1.0×10^{-4}
Deer	1.6×10^{-4}	0.000	0.000	0.018	0.982	–	–	4.7×10^{-5}	–	5.4×10^{-5}
Pine tree (trunk)	1.6×10^{-4}	0.000	0.000	0.018	0.982	–	–	5.9×10^{-5}	–	–
Brown seaweed	2.9×10^{-5}	0.000	0.000	0.096	0.904	2.0×10^{-4}	–	–	–	–
Crab	4.0×10^{-5}	0.000	0.000	0.071	0.929	1.9×10^{-4}	–	–	–	–
Trout	4.2×10^{-5}	0.000	0.000	0.068	0.932	1.9×10^{-4}	–	–	–	–
Flatfish	3.3×10^{-5}	0.000	0.000	0.087	0.913	2.0×10^{-4}	–	–	–	–
^{79}Se (progeny included: none)										
Bee	3.0×10^{-5}	0.000	0.000	0.009	0.991	–	–	0	0	0
Wild grass (spike)	3.0×10^{-5}	0.000	0.000	0.009	0.991	1.4×10^{-7}	–	0	–	0
Earthworm	3.0×10^{-5}	0.000	0.000	0.009	0.991	–	0	0	–	0
Frog	3.0×10^{-5}	0.000	0.000	0.009	0.991	6.7×10^{-8}	0	0	–	0
Rat	3.0×10^{-5}	0.000	0.000	0.009	0.991	–	0	0	–	0
Duck	3.0×10^{-5}	0.000	0.000	0.009	0.991	2.1×10^{-8}	–	0	0	0
Deer	3.0×10^{-5}	0.000	0.000	0.009	0.991	–	–	0	–	0
Pine tree (trunk)	3.0×10^{-5}	0.000	0.000	0.009	0.991	–	–	0	–	–
Brown seaweed	3.0×10^{-5}	0.000	0.000	0.009	0.991	2.6×10^{-8}	–	–	–	–
Crab	3.0×10^{-5}	0.000	0.000	0.009	0.991	2.4×10^{-8}	–	–	–	–
Trout	3.0×10^{-5}	0.000	0.000	0.009	0.991	2.1×10^{-8}	–	–	–	–
Flatfish	3.0×10^{-5}	0.000	0.000	0.009	0.991	2.0×10^{-8}	–	–	–	–

Table B.34. Dose coefficients for non-human biota exposed to radioactive isotopes of Sr (Z = 38).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{89}Sr (progeny included: none)										
Bee	2.6×10^{-4}	0.000	0.000	0.000	1.000	–	–	1.7×10^{-8}	1.6×10^{-8}	2.1×10^{-8}
Wild grass (spike)	2.8×10^{-4}	0.000	0.000	0.000	1.000	5.3×10^{-5}	–	1.7×10^{-8}	–	2.1×10^{-8}
Earthworm	2.9×10^{-4}	0.000	0.000	0.000	1.000	–	4.6×10^{-8}	1.8×10^{-8}	–	2.1×10^{-8}
Frog	3.2×10^{-4}	0.000	0.000	0.000	1.000	2.3×10^{-5}	4.5×10^{-8}	1.8×10^{-8}	–	2.1×10^{-8}
Rat	3.3×10^{-4}	0.000	0.000	0.000	1.000	–	4.3×10^{-8}	1.8×10^{-8}	–	2.1×10^{-8}
Duck	3.3×10^{-4}	0.000	0.000	0.000	1.000	7.2×10^{-6}	–	1.7×10^{-8}	1.5×10^{-8}	2.2×10^{-8}
Deer	3.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	1.1×10^{-8}	–	1.4×10^{-8}
Pine tree (trunk)	3.4×10^{-4}	0.000	0.000	0.000	1.000	–	–	1.4×10^{-8}	–	–
Brown seaweed	3.2×10^{-4}	0.000	0.000	0.000	1.000	1.7×10^{-5}	–	–	–	–
Crab	3.3×10^{-4}	0.000	0.000	0.000	1.000	8.4×10^{-6}	–	–	–	–
Trout	3.3×10^{-4}	0.000	0.000	0.000	1.000	7.8×10^{-6}	–	–	–	–
Flatfish	3.2×10^{-4}	0.000	0.000	0.000	1.000	1.5×10^{-5}	–	–	–	–
^{90}Sr (progeny included: ^{90}Y)										
Bee	4.3×10^{-4}	0.000	0.000	0.000	1.000	–	–	4.9×10^{-11}	3.1×10^{-11}	2.7×10^{-10}
Wild grass (spike)	5.1×10^{-4}	0.000	0.000	0.000	1.000	1.4×10^{-4}	–	9.4×10^{-11}	–	1.7×10^{-10}
Earthworm	5.2×10^{-4}	0.000	0.000	0.000	1.000	–	1.2×10^{-10}	3.9×10^{-11}	–	1.5×10^{-10}
Frog	5.9×10^{-4}	0.000	0.000	0.000	1.000	6.3×10^{-5}	1.2×10^{-10}	2.9×10^{-11}	–	1.1×10^{-10}
Rat	6.2×10^{-4}	0.000	0.000	0.000	1.000	–	1.0×10^{-10}	1.8×10^{-11}	–	6.2×10^{-11}
Duck	6.3×10^{-4}	0.000	0.000	0.000	1.000	2.0×10^{-5}	–	1.4×10^{-11}	6.7×10^{-12}	6.9×10^{-11}
Deer	6.5×10^{-4}	0.000	0.000	0.000	1.000	–	–	5.7×10^{-12}	–	1.3×10^{-11}
Pine tree (trunk)	6.5×10^{-4}	0.000	0.000	0.000	1.000	–	–	8.5×10^{-12}	–	–
Brown seaweed	6.0×10^{-4}	0.000	0.000	0.000	1.000	5.2×10^{-5}	–	–	–	–
Crab	6.3×10^{-4}	0.000	0.000	0.000	1.000	2.3×10^{-5}	–	–	–	–
Trout	6.3×10^{-4}	0.000	0.000	0.000	1.000	2.3×10^{-5}	–	–	–	–
Flatfish	6.0×10^{-4}	0.000	0.000	0.000	1.000	4.9×10^{-5}	–	–	–	–

Table B.35. Dose coefficients for non-human biota exposed to radioactive isotopes of Tc (Z = 43).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{99}Tc (progeny included: none)										
Bee	5.7×10^{-5}	0.000	0.000	0.003	0.997	–	–	8.7×10^{-11}	8.4×10^{-11}	1.5×10^{-10}
Wild grass (spike)	5.8×10^{-5}	0.000	0.000	0.003	0.997	8.2×10^{-7}	–	9.4×10^{-11}	–	1.4×10^{-10}
Earthworm	5.8×10^{-5}	0.000	0.000	0.003	0.997	–	1.7×10^{-10}	8.5×10^{-11}	–	1.4×10^{-10}
Frog	5.8×10^{-5}	0.000	0.000	0.003	0.997	3.8×10^{-7}	1.7×10^{-10}	8.4×10^{-11}	–	1.3×10^{-10}
Rat	5.8×10^{-5}	0.000	0.000	0.003	0.997	–	1.6×10^{-10}	8.1×10^{-11}	–	1.3×10^{-10}
Duck	5.8×10^{-5}	0.000	0.000	0.003	0.997	1.2×10^{-7}	–	7.9×10^{-11}	7.1×10^{-11}	1.4×10^{-10}
Deer	5.8×10^{-5}	0.000	0.000	0.003	0.997	–	–	4.0×10^{-11}	–	5.7×10^{-11}
Pine tree (trunk)	5.8×10^{-5}	0.000	0.000	0.003	0.997	–	–	7.0×10^{-11}	–	–
Brown seaweed	5.8×10^{-5}	0.000	0.000	0.003	0.997	1.5×10^{-7}	–	–	–	–
Crab	5.8×10^{-5}	0.000	0.000	0.003	0.997	1.4×10^{-7}	–	–	–	–
Trout	5.8×10^{-5}	0.000	0.000	0.003	0.997	1.2×10^{-7}	–	–	–	–
Flatfish	5.8×10^{-5}	0.000	0.000	0.003	0.997	1.3×10^{-7}	–	–	–	–

Table B.36. Dose coefficients for non-human biota exposed to radioactive isotopes of Te (Z = 52).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{129m}Te (progeny included: ^{129}Te)										
Bee	2.8×10^{-4}	0.000	0.000	0.010	0.990	–	–	1.4×10^{-5}	1.4×10^{-5}	1.9×10^{-5}
Wild grass (spike)	3.1×10^{-4}	0.000	0.000	0.009	0.991	9.0×10^{-5}	–	1.4×10^{-5}	–	1.9×10^{-5}
Earthworm	3.1×10^{-4}	0.000	0.000	0.009	0.991	–	3.6×10^{-5}	1.5×10^{-5}	–	1.9×10^{-5}
Frog	3.4×10^{-4}	0.000	0.000	0.008	0.992	6.1×10^{-5}	3.6×10^{-5}	1.5×10^{-5}	–	1.8×10^{-5}
Rat	3.5×10^{-4}	0.000	0.000	0.008	0.992	–	3.4×10^{-5}	1.4×10^{-5}	–	1.8×10^{-5}
Duck	3.6×10^{-4}	0.000	0.000	0.008	0.992	4.1×10^{-5}	–	1.4×10^{-5}	1.2×10^{-5}	1.9×10^{-5}
Deer	3.8×10^{-4}	0.000	0.000	0.007	0.993	–	–	8.6×10^{-6}	–	1.0×10^{-5}
Pine tree (trunk)	3.8×10^{-4}	0.000	0.000	0.007	0.993	–	–	1.1×10^{-5}	–	–
Brown seaweed	3.4×10^{-4}	0.000	0.000	0.008	0.992	5.3×10^{-5}	–	–	–	–
Crab	3.6×10^{-4}	0.000	0.000	0.008	0.992	4.4×10^{-5}	–	–	–	–
Trout	3.6×10^{-4}	0.000	0.000	0.008	0.992	4.3×10^{-5}	–	–	–	–
Flatfish	3.5×10^{-4}	0.000	0.000	0.008	0.992	5.1×10^{-5}	–	–	–	–
^{132}Te (progeny included: ^{132}I)										
Bee	3.0×10^{-4}	0.000	0.000	0.009	0.991	–	–	5.0×10^{-4}	4.9×10^{-4}	6.1×10^{-4}
Wild grass (spike)	3.3×10^{-4}	0.000	0.000	0.009	0.991	1.5×10^{-3}	–	4.9×10^{-4}	–	6.2×10^{-4}
Earthworm	3.3×10^{-4}	0.000	0.000	0.008	0.992	–	1.3×10^{-3}	5.1×10^{-4}	–	6.2×10^{-4}
Frog	3.9×10^{-4}	0.000	0.000	0.007	0.993	1.4×10^{-3}	1.3×10^{-3}	5.2×10^{-4}	–	6.2×10^{-4}
Rat	4.6×10^{-4}	0.000	0.000	0.006	0.994	–	1.2×10^{-3}	5.1×10^{-4}	–	6.2×10^{-4}
Duck	5.5×10^{-4}	0.000	0.000	0.005	0.995	1.2×10^{-3}	–	5.0×10^{-4}	4.5×10^{-4}	6.5×10^{-4}
Deer	1.2×10^{-3}	0.000	0.000	0.002	0.998	–	–	3.3×10^{-4}	–	3.9×10^{-4}
Pine tree (trunk)	1.1×10^{-3}	0.000	0.000	0.003	0.997	–	–	3.9×10^{-4}	–	–
Brown seaweed	4.4×10^{-4}	0.000	0.000	0.006	0.994	1.3×10^{-3}	–	–	–	–
Crab	5.2×10^{-4}	0.000	0.000	0.005	0.995	1.3×10^{-3}	–	–	–	–
Trout	5.2×10^{-4}	0.000	0.000	0.005	0.995	1.3×10^{-3}	–	–	–	–
Flatfish	4.6×10^{-4}	0.000	0.000	0.006	0.994	1.3×10^{-3}	–	–	–	–

Table B.37. Dose coefficients for non-human biota exposed to radioactive isotopes of Th (Z = 90).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{227}Th (progeny included: none)										
Bee	3.5×10^{-3}	0.017	0.969	0.002	0.011	–	–	2.5×10^{-5}	2.4×10^{-5}	3.2×10^{-5}
Wild grass (spike)	3.5×10^{-3}	0.017	0.969	0.002	0.012	7.2×10^{-5}	–	2.4×10^{-5}	–	3.1×10^{-5}
Earthworm	3.5×10^{-3}	0.017	0.969	0.002	0.012	–	5.4×10^{-5}	2.5×10^{-5}	–	3.0×10^{-5}
Frog	3.5×10^{-3}	0.017	0.968	0.002	0.013	6.9×10^{-5}	5.4×10^{-5}	2.5×10^{-5}	–	3.0×10^{-5}
Rat	3.5×10^{-3}	0.017	0.967	0.002	0.014	–	5.1×10^{-5}	2.4×10^{-5}	–	2.9×10^{-5}
Duck	3.5×10^{-3}	0.017	0.966	0.002	0.015	6.0×10^{-5}	–	2.3×10^{-5}	2.1×10^{-5}	3.1×10^{-5}
Deer	3.6×10^{-3}	0.017	0.956	0.002	0.025	–	–	1.4×10^{-5}	–	1.6×10^{-5}
Pine tree (trunk)	3.6×10^{-3}	0.017	0.956	0.002	0.025	–	–	1.8×10^{-5}	–	–
Brown seaweed	3.5×10^{-3}	0.017	0.967	0.002	0.014	6.5×10^{-5}	–	–	–	–
Crab	3.5×10^{-3}	0.017	0.966	0.002	0.015	6.2×10^{-5}	–	–	–	–
Trout	3.5×10^{-3}	0.017	0.966	0.002	0.015	6.1×10^{-5}	–	–	–	–
Flatfish	3.5×10^{-3}	0.017	0.967	0.002	0.014	6.4×10^{-5}	–	–	–	–
^{228}Th (progeny included: ^{224}Ra ^{220}Rn ^{216}Po ^{212}Pb ^{212}Bi ^{212}Po ^{208}Tl)										
Bee	1.9×10^{-2}	0.018	0.961	0.000	0.021	–	–	2.2×10^{-4}	2.1×10^{-4}	3.1×10^{-4}
Wild grass (spike)	1.9×10^{-2}	0.018	0.958	0.000	0.024	9.3×10^{-4}	–	2.6×10^{-4}	–	3.4×10^{-4}
Earthworm	1.9×10^{-2}	0.018	0.958	0.000	0.024	–	7.4×10^{-4}	2.6×10^{-4}	–	3.6×10^{-4}
Frog	1.9×10^{-2}	0.018	0.955	0.000	0.027	8.6×10^{-4}	7.3×10^{-4}	2.8×10^{-4}	–	3.8×10^{-4}
Rat	1.9×10^{-2}	0.018	0.953	0.000	0.029	–	7.0×10^{-4}	2.9×10^{-4}	–	3.9×10^{-4}
Duck	1.9×10^{-2}	0.018	0.950	0.000	0.032	7.6×10^{-4}	–	2.9×10^{-4}	2.6×10^{-4}	4.2×10^{-4}
Deer	2.0×10^{-2}	0.017	0.933	0.000	0.049	–	–	2.1×10^{-4}	–	2.8×10^{-4}
Pine tree (trunk)	2.0×10^{-2}	0.017	0.936	0.000	0.046	–	–	2.2×10^{-4}	–	–
Brown seaweed	1.9×10^{-2}	0.018	0.953	0.000	0.029	8.2×10^{-4}	–	–	–	–
Crab	1.9×10^{-2}	0.018	0.951	0.000	0.031	7.8×10^{-4}	–	–	–	–
Trout	1.9×10^{-2}	0.018	0.951	0.000	0.031	7.7×10^{-4}	–	–	–	–
Flatfish	1.9×10^{-2}	0.018	0.953	0.000	0.029	8.1×10^{-4}	–	–	–	–
^{229}Th (progeny included: none)										
Bee	2.9×10^{-3}	0.017	0.958	0.004	0.021	–	–	1.4×10^{-5}	1.3×10^{-5}	2.1×10^{-5}
Wild grass (spike)	2.9×10^{-3}	0.017	0.957	0.004	0.021	5.1×10^{-5}	–	1.4×10^{-5}	–	1.9×10^{-5}
Earthworm	2.9×10^{-3}	0.017	0.957	0.004	0.021	–	2.8×10^{-5}	1.4×10^{-5}	–	1.9×10^{-5}
Frog	2.9×10^{-3}	0.017	0.956	0.004	0.022	4.8×10^{-5}	2.7×10^{-5}	1.4×10^{-5}	–	1.9×10^{-5}
Rat	2.9×10^{-3}	0.017	0.955	0.004	0.023	–	2.6×10^{-5}	1.3×10^{-5}	–	1.8×10^{-5}

Duck	2.9×10^{-3}	0.017	0.954	0.004	0.025	4.1×10^{-5}	–	1.3×10^{-5}	1.2×10^{-5}	1.9×10^{-5}
Deer	3.0×10^{-3}	0.017	0.946	0.004	0.033	–	–	7.0×10^{-6}	–	8.9×10^{-6}
Pine tree (trunk)	3.0×10^{-3}	0.017	0.945	0.004	0.033	–	–	1.1×10^{-5}	–	–
Brown seaweed	2.9×10^{-3}	0.017	0.955	0.004	0.023	4.5×10^{-5}	–	–	–	–
Crab	2.9×10^{-3}	0.017	0.954	0.004	0.024	4.2×10^{-5}	–	–	–	–
Trout	2.9×10^{-3}	0.017	0.954	0.004	0.024	4.2×10^{-5}	–	–	–	–
Flatfish	2.9×10^{-3}	0.017	0.955	0.004	0.024	4.4×10^{-5}	–	–	–	–
^{230}Th (progeny included: none)										
Bee	2.7×10^{-3}	0.017	0.979	0.000	0.003	–	–	9.0×10^{-8}	7.6×10^{-8}	2.7×10^{-7}
Wild grass (spike)	2.7×10^{-3}	0.017	0.979	0.000	0.003	5.7×10^{-7}	–	1.4×10^{-7}	–	2.0×10^{-7}
Earthworm	2.7×10^{-3}	0.017	0.979	0.000	0.003	–	2.1×10^{-7}	8.1×10^{-8}	–	1.9×10^{-7}
Frog	2.7×10^{-3}	0.017	0.979	0.000	0.003	4.1×10^{-7}	2.1×10^{-7}	7.4×10^{-8}	–	1.5×10^{-7}
Rat	2.7×10^{-3}	0.017	0.979	0.000	0.003	–	1.9×10^{-7}	6.5×10^{-8}	–	1.2×10^{-7}
Duck	2.7×10^{-3}	0.017	0.979	0.000	0.003	2.4×10^{-7}	–	6.1×10^{-8}	5.1×10^{-8}	1.3×10^{-7}
Deer	2.7×10^{-3}	0.017	0.979	0.000	0.003	–	–	2.9×10^{-8}	–	4.3×10^{-8}
Pine tree (trunk)	2.7×10^{-3}	0.017	0.979	0.000	0.003	–	–	4.6×10^{-8}	–	–
Brown seaweed	2.7×10^{-3}	0.017	0.979	0.000	0.003	3.1×10^{-7}	–	–	–	–
Crab	2.7×10^{-3}	0.017	0.979	0.000	0.003	2.6×10^{-7}	–	–	–	–
Trout	2.7×10^{-3}	0.017	0.979	0.000	0.003	2.5×10^{-7}	–	–	–	–
Flatfish	2.7×10^{-3}	0.017	0.979	0.000	0.003	2.8×10^{-7}	–	–	–	–
^{231}Th (progeny included: none)										
Bee	9.6×10^{-5}	0.000	0.000	0.117	0.883	–	–	2.4×10^{-6}	2.2×10^{-6}	5.4×10^{-6}
Wild grass (spike)	9.7×10^{-5}	0.000	0.000	0.116	0.884	1.2×10^{-5}	–	2.6×10^{-6}	–	4.6×10^{-6}
Earthworm	9.7×10^{-5}	0.000	0.000	0.116	0.884	–	4.3×10^{-6}	2.2×10^{-6}	–	4.4×10^{-6}
Frog	9.9×10^{-5}	0.000	0.000	0.113	0.887	9.6×10^{-6}	4.2×10^{-6}	2.1×10^{-6}	–	4.0×10^{-6}
Rat	1.0×10^{-4}	0.000	0.000	0.111	0.889	–	3.9×10^{-6}	1.9×10^{-6}	–	3.3×10^{-6}
Duck	1.0×10^{-4}	0.000	0.000	0.110	0.890	6.6×10^{-6}	–	1.8×10^{-6}	1.6×10^{-6}	3.5×10^{-6}
Deer	1.1×10^{-4}	0.000	0.000	0.105	0.895	–	–	8.6×10^{-7}	–	1.2×10^{-6}
Pine tree (trunk)	1.1×10^{-4}	0.000	0.000	0.105	0.895	–	–	1.4×10^{-6}	–	–
Brown seaweed	1.0×10^{-4}	0.000	0.000	0.112	0.888	8.0×10^{-6}	–	–	–	–
Crab	1.0×10^{-4}	0.000	0.000	0.110	0.890	7.0×10^{-6}	–	–	–	–
Trout	1.0×10^{-4}	0.000	0.000	0.110	0.890	6.8×10^{-6}	–	–	–	–
Flatfish	1.0×10^{-4}	0.000	0.000	0.111	0.889	7.6×10^{-6}	–	–	–	–
^{232}Th (progeny included: none)										
Bee	2.4×10^{-3}	0.017	0.980	0.000	0.003	–	–	6.0×10^{-8}	4.8×10^{-8}	2.2×10^{-7}
Wild grass (spike)	2.4×10^{-3}	0.017	0.980	0.000	0.003	4.4×10^{-7}	–	1.1×10^{-7}	–	1.5×10^{-7}

Earthworm	2.4×10^{-3}	0.017	0.980	0.000	0.003	–	1.4×10^{-7}	5.2×10^{-8}	–	1.4×10^{-7}
Frog	2.4×10^{-3}	0.017	0.979	0.000	0.003	2.9×10^{-7}	1.4×10^{-7}	4.5×10^{-8}	–	1.1×10^{-7}
Rat	2.4×10^{-3}	0.017	0.979	0.000	0.003	–	1.2×10^{-7}	3.8×10^{-8}	–	7.9×10^{-8}
Duck	2.4×10^{-3}	0.017	0.979	0.000	0.003	1.5×10^{-7}	–	3.4×10^{-8}	2.7×10^{-8}	8.6×10^{-8}
Deer	2.4×10^{-3}	0.017	0.979	0.000	0.003	–	–	1.4×10^{-8}	–	2.3×10^{-8}
Pine tree (trunk)	2.4×10^{-3}	0.017	0.979	0.000	0.003	–	–	2.2×10^{-8}	–	–
Brown seaweed	2.4×10^{-3}	0.017	0.979	0.000	0.003	2.0×10^{-7}	–	–	–	–
Crab	2.4×10^{-3}	0.017	0.979	0.000	0.003	1.7×10^{-7}	–	–	–	–
Trout	2.4×10^{-3}	0.017	0.979	0.000	0.003	1.6×10^{-7}	–	–	–	–
Flatfish	2.4×10^{-3}	0.017	0.979	0.000	0.003	1.8×10^{-7}	–	–	–	–
^{234}Th (progeny included: ^{234m}Pa ^{234}Pa)										
Bee	3.4×10^{-4}	0.000	0.000	0.005	0.995	–	–	5.0×10^{-6}	4.9×10^{-6}	7.0×10^{-6}
Wild grass (spike)	4.0×10^{-4}	0.000	0.000	0.004	0.996	1.2×10^{-4}	–	4.9×10^{-6}	–	6.9×10^{-6}
Earthworm	4.1×10^{-4}	0.000	0.000	0.004	0.996	–	1.2×10^{-5}	5.2×10^{-6}	–	6.9×10^{-6}
Frog	4.6×10^{-4}	0.000	0.000	0.004	0.996	6.3×10^{-5}	1.2×10^{-5}	5.2×10^{-6}	–	6.9×10^{-6}
Rat	4.9×10^{-4}	0.000	0.000	0.004	0.996	–	1.1×10^{-5}	5.2×10^{-6}	–	6.8×10^{-6}
Duck	5.0×10^{-4}	0.000	0.000	0.003	0.997	2.9×10^{-5}	–	5.1×10^{-6}	4.6×10^{-6}	7.2×10^{-6}
Deer	5.2×10^{-4}	0.000	0.000	0.003	0.997	–	–	3.2×10^{-6}	–	4.0×10^{-6}
Pine tree (trunk)	5.2×10^{-4}	0.000	0.000	0.003	0.997	–	–	3.8×10^{-6}	–	–
Brown seaweed	4.7×10^{-4}	0.000	0.000	0.004	0.996	5.3×10^{-5}	–	–	–	–
Crab	4.9×10^{-4}	0.000	0.000	0.003	0.997	3.1×10^{-5}	–	–	–	–
Trout	4.9×10^{-4}	0.000	0.000	0.003	0.997	3.1×10^{-5}	–	–	–	–
Flatfish	4.7×10^{-4}	0.000	0.000	0.004	0.996	5.1×10^{-5}	–	–	–	–

Table B.38. Dose coefficients for non-human biota exposed to radioactive isotopes of U (Z = 92).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{233}U (progeny included: none)										
Bee	2.8×10^{-3}	0.017	0.982	0.000	0.001	–	–	7.4×10^{-8}	6.4×10^{-8}	2.2×10^{-7}
Wild grass (spike)	2.8×10^{-3}	0.017	0.982	0.000	0.001	4.1×10^{-7}	–	1.1×10^{-7}	–	1.6×10^{-7}
Earthworm	2.8×10^{-3}	0.017	0.982	0.000	0.001	–	1.7×10^{-7}	6.6×10^{-8}	–	1.5×10^{-7}
Frog	2.8×10^{-3}	0.017	0.981	0.000	0.001	2.9×10^{-7}	1.6×10^{-7}	5.9×10^{-8}	–	1.2×10^{-7}
Rat	2.8×10^{-3}	0.017	0.981	0.000	0.001	–	1.4×10^{-7}	5.0×10^{-8}	–	9.1×10^{-8}
Duck	2.8×10^{-3}	0.017	0.981	0.000	0.001	1.7×10^{-7}	–	4.5×10^{-8}	3.8×10^{-8}	9.9×10^{-8}
Deer	2.8×10^{-3}	0.017	0.981	0.000	0.001	–	–	2.3×10^{-8}	–	3.2×10^{-8}
Pine tree (trunk)	2.8×10^{-3}	0.017	0.981	0.000	0.001	–	–	3.5×10^{-8}	–	–
Brown seaweed	2.8×10^{-3}	0.017	0.981	0.000	0.001	2.2×10^{-7}	–	–	–	–
Crab	2.8×10^{-3}	0.017	0.981	0.000	0.001	1.8×10^{-7}	–	–	–	–
Trout	2.8×10^{-3}	0.017	0.981	0.000	0.001	1.7×10^{-7}	–	–	–	–
Flatfish	2.8×10^{-3}	0.017	0.981	0.000	0.001	2.0×10^{-7}	–	–	–	–
^{234}U (progeny included: none)										
Bee	2.8×10^{-3}	0.017	0.980	0.000	0.003	–	–	7.7×10^{-8}	6.0×10^{-8}	3.3×10^{-7}
Wild grass (spike)	2.8×10^{-3}	0.017	0.980	0.000	0.003	5.8×10^{-7}	–	1.4×10^{-7}	–	2.3×10^{-7}
Earthworm	2.8×10^{-3}	0.017	0.980	0.000	0.003	–	1.7×10^{-7}	6.2×10^{-8}	–	2.1×10^{-7}
Frog	2.8×10^{-3}	0.017	0.980	0.000	0.003	3.7×10^{-7}	1.7×10^{-7}	4.8×10^{-8}	–	1.5×10^{-7}
Rat	2.8×10^{-3}	0.017	0.980	0.000	0.003	–	1.5×10^{-7}	3.2×10^{-8}	–	9.5×10^{-8}
Duck	2.8×10^{-3}	0.017	0.980	0.000	0.003	1.5×10^{-7}	–	2.6×10^{-8}	1.7×10^{-8}	1.0×10^{-7}
Deer	2.8×10^{-3}	0.017	0.980	0.000	0.003	–	–	8.7×10^{-9}	–	1.9×10^{-8}
Pine tree (trunk)	2.8×10^{-3}	0.017	0.980	0.000	0.003	–	–	1.8×10^{-8}	–	–
Brown seaweed	2.8×10^{-3}	0.017	0.980	0.000	0.003	2.3×10^{-7}	–	–	–	–
Crab	2.8×10^{-3}	0.017	0.980	0.000	0.003	1.7×10^{-7}	–	–	–	–
Trout	2.8×10^{-3}	0.017	0.980	0.000	0.003	1.6×10^{-7}	–	–	–	–
Flatfish	2.8×10^{-3}	0.017	0.980	0.000	0.003	2.0×10^{-7}	–	–	–	–
^{235}U (progeny included: ^{231}Th)										
Bee	2.7×10^{-3}	0.016	0.936	0.006	0.042	–	–	3.2×10^{-5}	3.1×10^{-5}	4.4×10^{-5}
Wild grass (spike)	2.7×10^{-3}	0.016	0.935	0.006	0.042	1.1×10^{-4}	–	3.2×10^{-5}	–	4.1×10^{-5}
Earthworm	2.7×10^{-3}	0.016	0.935	0.006	0.043	–	7.1×10^{-5}	3.2×10^{-5}	–	4.1×10^{-5}
Frog	2.7×10^{-3}	0.016	0.934	0.006	0.044	1.0×10^{-4}	7.0×10^{-5}	3.1×10^{-5}	–	4.0×10^{-5}

Rat	2.7×10^{-3}	0.016	0.931	0.006	0.047	–	6.6×10^{-5}	3.1×10^{-5}	–	3.9×10^{-5}
Duck	2.7×10^{-3}	0.016	0.929	0.006	0.049	8.6×10^{-5}	–	3.0×10^{-5}	2.7×10^{-5}	4.1×10^{-5}
Deer	2.8×10^{-3}	0.016	0.911	0.006	0.067	–	–	1.7×10^{-5}	–	2.0×10^{-5}
Pine tree (trunk)	2.8×10^{-3}	0.016	0.911	0.006	0.068	–	–	2.5×10^{-5}	–	–
Brown seaweed	2.7×10^{-3}	0.016	0.932	0.006	0.046	9.4×10^{-5}	–	–	–	–
Crab	2.7×10^{-3}	0.016	0.930	0.006	0.048	8.8×10^{-5}	–	–	–	–
Trout	2.7×10^{-3}	0.016	0.929	0.006	0.049	8.7×10^{-5}	–	–	–	–
Flatfish	2.7×10^{-3}	0.016	0.931	0.006	0.047	9.2×10^{-5}	–	–	–	–
^{238}U (progeny included: none)										
Bee	2.5×10^{-3}	0.017	0.981	0.000	0.002	–	–	5.1×10^{-8}	3.8×10^{-8}	2.3×10^{-7}
Wild grass (spike)	2.5×10^{-3}	0.017	0.981	0.000	0.002	4.0×10^{-7}	–	9.5×10^{-8}	–	1.6×10^{-7}
Earthworm	2.5×10^{-3}	0.017	0.981	0.000	0.002	–	1.2×10^{-7}	4.0×10^{-8}	–	1.4×10^{-7}
Frog	2.5×10^{-3}	0.017	0.981	0.000	0.002	2.5×10^{-7}	1.1×10^{-7}	3.0×10^{-8}	–	1.1×10^{-7}
Rat	2.5×10^{-3}	0.017	0.981	0.000	0.002	–	9.8×10^{-8}	1.9×10^{-8}	–	6.2×10^{-8}
Duck	2.5×10^{-3}	0.017	0.981	0.000	0.002	9.5×10^{-8}	–	1.4×10^{-8}	7.7×10^{-9}	6.7×10^{-8}
Deer	2.5×10^{-3}	0.017	0.981	0.000	0.002	–	–	4.4×10^{-9}	–	1.1×10^{-8}
Pine tree (trunk)	2.5×10^{-3}	0.017	0.981	0.000	0.002	–	–	9.1×10^{-9}	–	–
Brown seaweed	2.5×10^{-3}	0.017	0.981	0.000	0.002	1.5×10^{-7}	–	–	–	–
Crab	2.5×10^{-3}	0.017	0.981	0.000	0.002	1.1×10^{-7}	–	–	–	–
Trout	2.5×10^{-3}	0.017	0.981	0.000	0.002	1.0×10^{-7}	–	–	–	–
Flatfish	2.5×10^{-3}	0.017	0.981	0.000	0.002	1.3×10^{-7}	–	–	–	–

Table B.39. Dose coefficients for non-human biota exposed to radioactive isotopes of Zn (Z = 30).

RAPs	Internal exposure					External exposure				
	(µGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (µGy h^{-1} Bq^{-1} L)	In-soil (µGy h^{-1} Bq^{-1} kg)	On-ground (µGy h^{-1} Bq^{-1} kg)	Above-ground (µGy h^{-1} Bq^{-1} kg)	Immersion in air (µGy h^{-1} Bq^{-1} m^3)
^{65}Zn (progeny included: none)										
Bee	8.0×10^{-6}	0.000	0.000	0.511	0.489	–	–	1.1×10^{-4}	1.1×10^{-4}	1.4×10^{-4}
Wild grass (spike)	1.0×10^{-5}	0.000	0.000	0.420	0.580	3.3×10^{-4}	–	1.1×10^{-4}	–	1.5×10^{-4}
Earthworm	1.1×10^{-5}	0.000	0.000	0.396	0.604	–	3.0×10^{-4}	1.2×10^{-4}	–	1.5×10^{-4}
Frog	1.8×10^{-5}	0.000	0.000	0.243	0.757	3.2×10^{-4}	3.0×10^{-4}	1.2×10^{-4}	–	1.5×10^{-4}
Rat	3.2×10^{-5}	0.000	0.000	0.141	0.859	–	2.8×10^{-4}	1.2×10^{-4}	–	1.5×10^{-4}
Duck	4.9×10^{-5}	0.000	0.000	0.092	0.908	2.9×10^{-4}	–	1.2×10^{-4}	1.1×10^{-4}	1.6×10^{-4}
Deer	1.9×10^{-4}	0.000	0.000	0.023	0.977	–	–	8.1×10^{-5}	–	9.9×10^{-5}
Pine tree (trunk)	1.7×10^{-4}	0.000	0.000	0.027	0.973	–	–	9.1×10^{-5}	–	–
Brown seaweed	2.9×10^{-5}	0.000	0.000	0.157	0.843	3.1×10^{-4}	–	–	–	–
Crab	4.3×10^{-5}	0.000	0.000	0.106	0.894	3.0×10^{-4}	–	–	–	–
Trout	4.4×10^{-5}	0.000	0.000	0.103	0.897	3.0×10^{-4}	–	–	–	–
Flatfish	3.2×10^{-5}	0.000	0.000	0.141	0.859	3.1×10^{-4}	–	–	–	–

Table B.40. Dose coefficients for non-human biota exposed to radioactive isotopes of Zr ($Z = 40$).

RAPs	Internal exposure					External exposure				
	(μGy h^{-1} Bq^{-1} kg)	f_0	f_1	f_2	f_3	Aquatic (μGy h^{-1} Bq^{-1} L)	In-soil (μGy h^{-1} Bq^{-1} kg)	On-ground (μGy h^{-1} Bq^{-1} kg)	Above-ground (μGy h^{-1} Bq^{-1} kg)	Immersion in air (μGy h^{-1} Bq^{-1} m^3)
^{95}Zr (progeny included: ^{95m}Nb)										
Bee	7.1×10^{-5}	0.000	0.000	0.002	0.998	–	–	1.4×10^{-4}	1.4×10^{-4}	1.7×10^{-4}
Wild grass (spike)	7.5×10^{-5}	0.000	0.000	0.002	0.998	4.2×10^{-4}	–	1.5×10^{-4}	–	1.7×10^{-4}
Earthworm	7.6×10^{-5}	0.000	0.000	0.002	0.998	–	3.9×10^{-4}	1.4×10^{-4}	–	1.7×10^{-4}
Frog	8.6×10^{-5}	0.000	0.000	0.002	0.998	4.1×10^{-4}	3.9×10^{-4}	1.4×10^{-4}	–	1.7×10^{-4}
Rat	1.1×10^{-4}	0.000	0.000	0.002	0.998	–	3.7×10^{-4}	1.4×10^{-4}	–	1.7×10^{-4}
Duck	1.3×10^{-4}	0.000	0.000	0.001	0.999	3.6×10^{-4}	–	1.4×10^{-4}	1.3×10^{-4}	1.8×10^{-4}
Deer	3.2×10^{-4}	0.000	0.000	0.001	0.999	–	–	9.0×10^{-5}	–	1.1×10^{-4}
Pine tree (trunk)	3.0×10^{-4}	0.000	0.000	0.001	0.999	–	–	1.2×10^{-4}	–	–
Brown seaweed	1.0×10^{-4}	0.000	0.000	0.002	0.998	3.9×10^{-4}	–	–	–	–
Crab	1.2×10^{-4}	0.000	0.000	0.001	0.999	3.7×10^{-4}	–	–	–	–
Trout	1.2×10^{-4}	0.000	0.000	0.001	0.999	3.7×10^{-4}	–	–	–	–
Flatfish	1.1×10^{-4}	0.000	0.000	0.002	0.998	3.9×10^{-4}	–	–	–	–

ANNEX C. PROGRAMME BIOTADC – DOSE COEFFICIENTS FOR ENVIRONMENTAL EXPOSURE OF NON-HUMAN BIOTA

C.1. Introduction

(C 1) The programme BiotaDC[1] is an open-access web-based application performing DC calculations for animals and plants. The programme utilises the current dosimetric approach recommended by ICRP for non-human biota and serves as a complement to this report. This Annex provides a description of the programme's input parameters and explains modes of operations and output results.

(C 2) The programme originates from the dosimetric database developed in the FASSET and ERICA projects (Larsson, 2004, 2008) for terrestrial animals and plants. For aquatic organisms, the programme implements a technique based on an original set of computed doses for spherical shapes in aquatic medium and an analytical method to scale these to non-spherical and ellipsoidal shapes (Ulanovsky and Pröhl, 2006). The detailed overview of the methodology adopted by *Publication 108* (ICRP, 2008b) can be found elsewhere (Ulanovsky et al., 2008; Ulanovsky and Pröhl, 2008). In the following years, more changes and improvements have been added to the tool resulting in extension of the methodology used to assess external exposures of terrestrial animals to environmental sources of radiation (Ulanovsky, 2014).

(C 3) The programme uses binary data files derived from *Publication 107* (ICRP, 2008a), which contain data on radionuclide emissions, including discrete energy photon, electron, and α-particles, continuous energy β-spectra, spontaneous fission energy yield and energy of α-recoil nuclei.

(C 4) The programme queries the database to construct a decay chain for the given parent nuclide and to include radiations emitted both by the parent nuclide and its progeny into DC computation. The system of ordinary differential equations, describing the constructed decay chain, is solved (Strenge, 1997) to determine the activity of decay chain members either as transient values at a specified time after the beginning of the parent decay or as integral values for a specified time interval. The decay chain can be truncated based on dosimetric criteria, i.e. removing daughters that contribute less than 10^{-9} to the total energy emitted by the full decay chain members. Alternatively, the decay chain can be truncated at the first daughter nuclide with physical half-life of >10 d or longer than that of the parent nuclide. In the latter case, parent and residual daughters are assumed to be in secular equilibrium. This is the so-called "*Publication 108* compatible" approach that was originally implemented in the ERICA tool (Brown, 2008) and later used to calculate DCs in *Publication 108* (ICRP, 2008b). This method is a simplified way to account for contribution of radioactive progeny, and it should be noted that the method may result in implausible results for some exposure scenarios.

C.2. Operation

(C 5) The programme BiotaDC can be found at http://biotadc.icrp.org. After connection to this website, a user sees the following introductory screen (Fig. C.1). At this point, the user should select the ecosystem of interest: aquatic or terrestrial.

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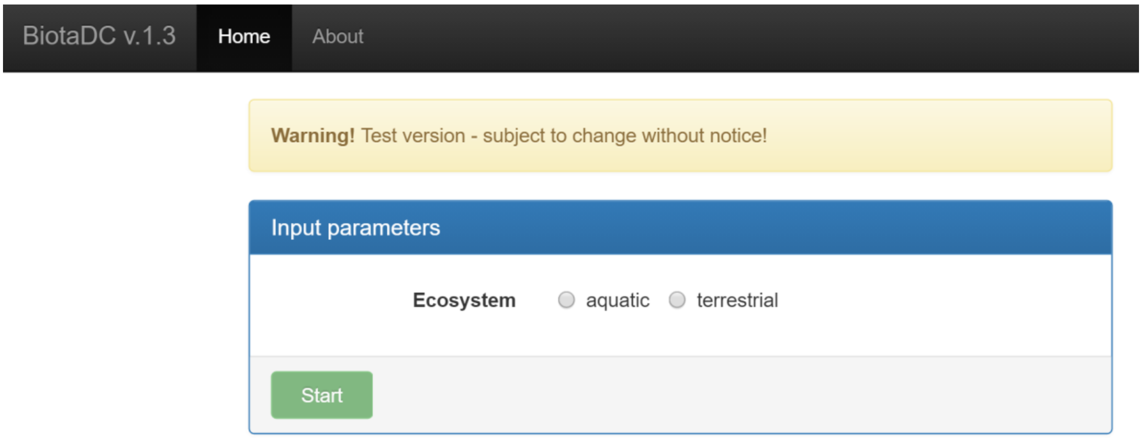
[1] Copyright © ICRP, 2016. Developed on behalf of ICRP by A. Ulanovsky and A. Ulanowski



Warning! Test version - subject to change without notice!

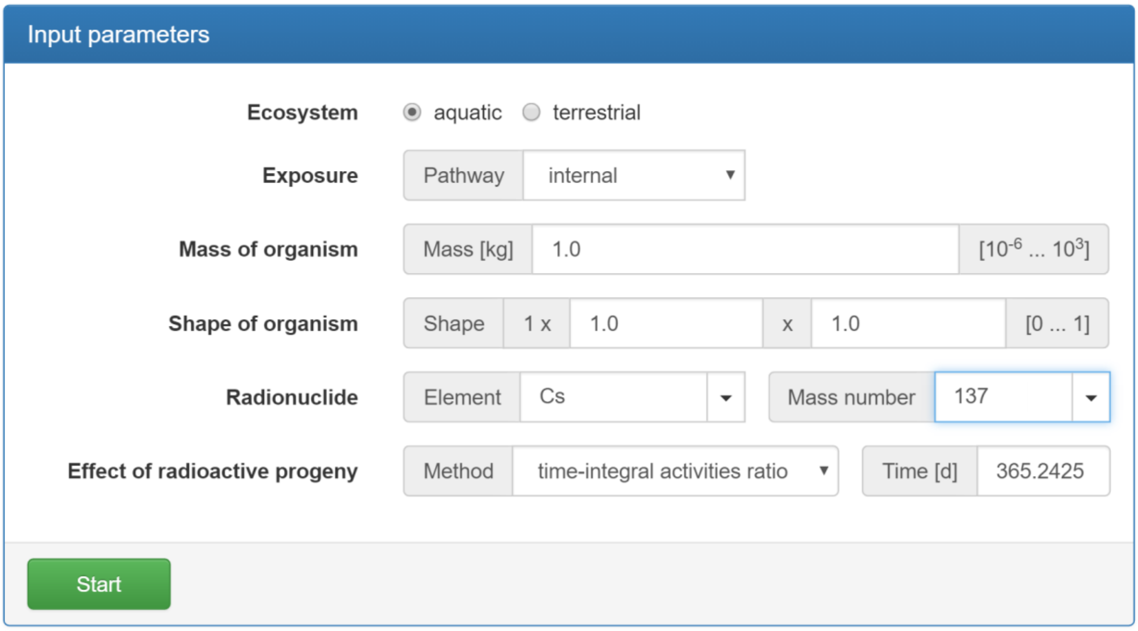
Input parameters

Ecosystem ○ aquatic ○ terrestrial

Fig. C.1. Initial screen of the programme after connecting to the website.

(C 6) If aquatic ecosystem is selected, then the user is provided with the choice of the following parameters of the organism, for which DC will be calculated (Fig. C.2):

- exposure pathway: internal or external;
- the body mass within the range from 10^{-6} to 10^{3} kg;
- proportions of the body in the form of relative lengths of axes of an ellipsoid, which most reasonably approximates the body shape, assuming the longest axis to be of unit length and lengths of the shorter axes to be in range from 0 to 1; and
- element and mass number of the radionuclide of interest.



Input parameters

Ecosystem ● aquatic ○ terrestrial

Exposure Pathway: internal

Mass of organism Mass [kg]: 1.0 [10^{-6} ... 10^{3}]

Shape of organism Shape: 1 x 1.0 x 1.0 [0 ... 1]

Radionuclide Element: Cs Mass number: 137

Effect of radioactive progeny Method: time-integral activities ratio Time [d]: 365.2425

Fig. C. 2. Parameter selection screen for aquatic organism.

(C 7) Input of body mass and proportions is fully flexible and any value within the allowed ranges can be given by the user. For convenience and as a reference, the body masses and proportions of RAPs (ICRP, 2008b) are shown in Table C.1, as required for input in the programme. Shown in Table C.1 are RAPs' lifetimes, which can be found helpful for selection of appropriate time constants while considering the effect of radioactive progeny in decay chains.

Table C.1. Lifetime, body mass and shape parameters for Reference Animals and Plants (RAPs) (ICRP, 2008b).

RAP	Lifetime (y)	Body mass (kg)	Body proportions		
Bee	0.274	5.89×10^{-4}	1	× 0.375	× 0.375
Grass spike	1	2.62×10^{-3}	1	× 0.2	× 0.2
Earthworm	5	5.24×10^{-3}	1	× 0.1	× 0.1
Frog	10	0.0314	1	× 0.375	× 0.313
Rat	2	0.314	1	× 0.3	× 0.25
Brown seaweed	5	0.654	1	× 1.0	× 0.01
Crab	15	0.754	1	× 0.6	× 0.3
Duck	11	1.26	1	× 0.333	× 0.267
Trout	6	1.26	1	× 0.16	× 0.12
Flatfish	10	1.31	1	× 0.625	× 0.063
Deer	15	245	1	× 0.462	× 0.462
Pine tree trunk	200	471	1	× 0.03	× 0.03

(C 8) The methods of accounting for radioactive progeny are illustrated in Figs. C.3 and C.4 using the simplest 'parent + daughter' decay chain of ^{140}Ba ($T_{1/2} = 12.75\,\mathrm{d}$) with daughter ^{140}La ($T_{1/2} = 1.68\,\mathrm{d}$) and are the following:

- 'Time-integral activities ratio' (default) indicates a recommended method to account for the contribution of radioactive progeny to the DC. Energy emitted by the daughter nuclides is added to the parent contribution using relative weights based on time-integrated activities of the parent and the daughters, assuming no daughters at the beginning of the parent decay. The time-integral activities of the parent and the daughter nuclides are shown as shaded areas $\tilde{A}_0$ and $\tilde{A}_1$ in Fig. C.3, and their ratio is shown in Fig. C.4 by the solid line. For this method, the input parameter 'Time' denotes time of integration of activities of the decay chain members and it can be selected to be relevant for the specific assessment task, e.g. 1 h, 10 d, 1 y, 100 y, etc.
- The 'Transient activities ratio' method can be used to choose an alternative method of accounting for daughters' contributions, when transient activities of the decay chain members at time, defined by the input parameter 'Time', after the beginning of the parent decay are used to calculate relative weights of the decay chain members. The transient activities are shown as curves and points $A_0(T)$ and $A_1(T)$ in Fig. C.3, and their ratio is indicated by the dashed line in Fig. C.4.
- 'Publication 108 compatible' denotes the method compatible to that used in *Publication 108* and the ERICA tool (Brown et al., 2008). Namely, DCs include contributions from the parent radionuclide and from the daughters in the truncated decay chain under the assumption of equilibrium activity ratios (shown by the dotted curve in Fig. C.4). The decay chain is truncated at the first daughter nuclide for which the physical half-life is >10 d or longer than the physical half-life of the parent. For this method, the truncation time is a fixed parameter, thus input of the parameter 'Time' is not allowed.

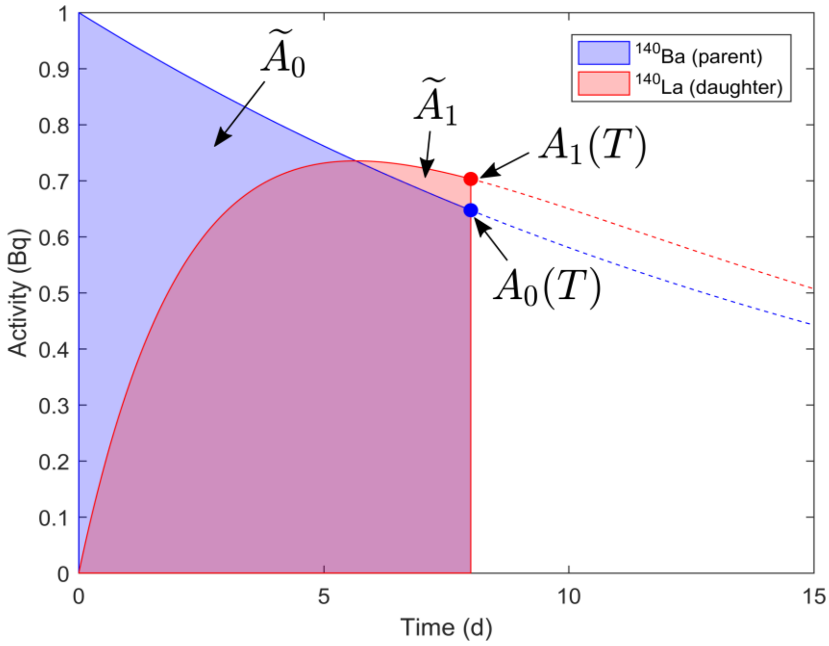


Fig. C.3. Time-dependent activity of ^{140}Ba (parent) and ^{140}La (daughter) following radioactive decay of 1 Bq of ^{140}Ba.

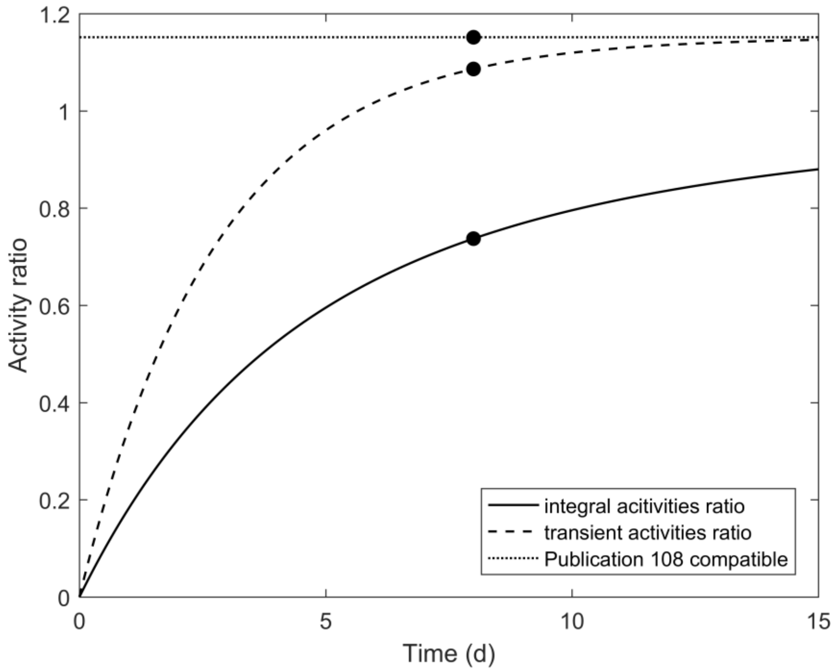
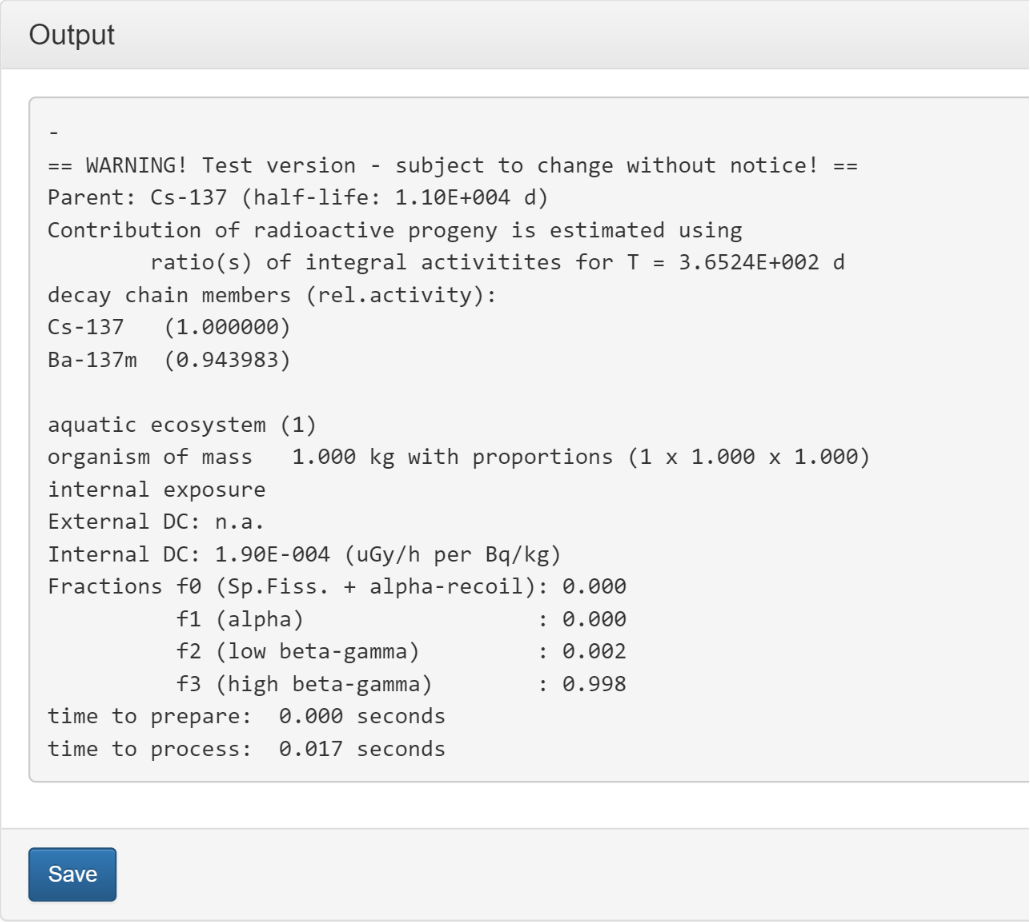


Fig. C.4. Time-dependent ratios of integral (solid line) and transient (dashed line) activities of ^{140}La (daughter) and ^{140}Ba (parent) in comparison to equilibrium activity ratio (dotted line) implied in the dose coefficients of *Publication 108* (ICRP, 2008b).

(C 9) When all parameters have been specified (Fig. C.2), pressing the button ‘Start’ results in output as shown in Fig. C.5. The output listing shows the parent radionuclide, information on the option used to calculate contributions from the decay chain members, list of the radionuclides in the decay chain along with their relative activities used for DC calculation, ecosystem, organism properties (body mass and proportions), type of exposure (internal), DCs for external (not calculated) and internal (calculated always), relative fractions of DC due to various types of radiation, and run times.

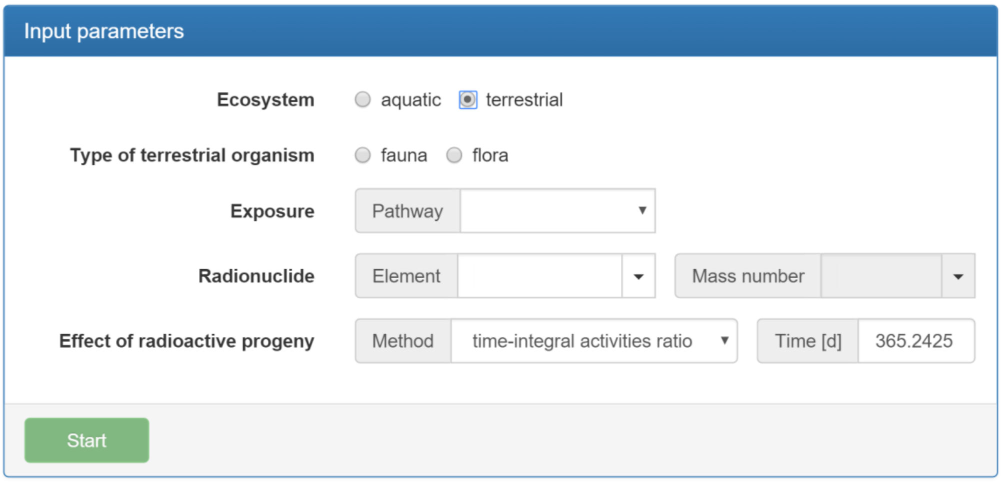


```
-
== WARNING! Test version - subject to change without notice! ==
Parent: Cs-137 (half-life: 1.10E+004 d)
Contribution of radioactive progeny is estimated using
        ratio(s) of integral activitites for T = 3.6524E+002 d
decay chain members (rel.activity):
Cs-137   (1.000000)
Ba-137m  (0.943983)

aquatic ecosystem (1)
organism of mass   1.000 kg with proportions (1 x 1.000 x 1.000)
internal exposure
External DC: n.a.
Internal DC: 1.90E-004 (uGy/h per Bq/kg)
Fractions f0 (Sp.Fiss. + alpha-recoil): 0.000
          f1 (alpha)                  : 0.000
          f2 (low beta-gamma)         : 0.002
          f3 (high beta-gamma)        : 0.998
time to prepare:  0.000 seconds
time to process:  0.017 seconds
```

Fig. C.5. Output after specifying input parameters as shown in Fig. C.2.

(C 10) Alternatively, selection of the terrestrial ecosystem will result in the following screen (Fig. C.6), where the type of the terrestrial organism needs to be specified to show other elements of the input interface.



Input parameters

Ecosystem ○ aquatic ● terrestrial

Type of terrestrial organism ○ fauna ○ flora

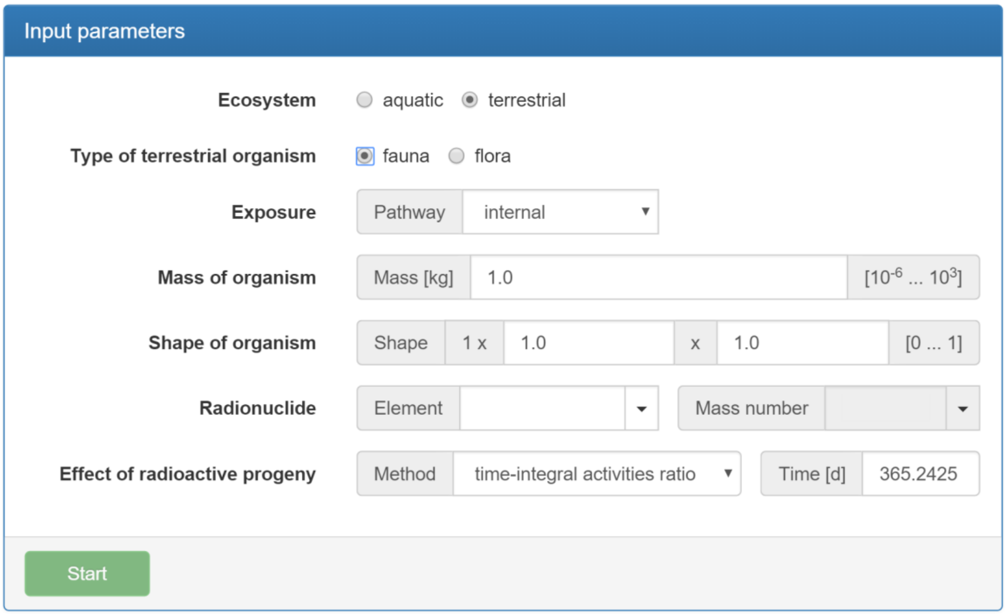
Exposure Pathway

Radionuclide Element | Mass number

Effect of radioactive progeny Method: time-integral activities ratio | Time [d]: 365.2425

Fig. C.6. Parameter selection screen for terrestrial organisms. Type of the organism is not specified.

(C 11) So, selection of ‘fauna’ and ‘internal’ exposure pathway results in the input form (Fig. C.7) similar to that for aquatic organisms with the input fields fully similar to those.



Input parameters

Ecosystem ○ aquatic ● terrestrial

Type of terrestrial organism ● fauna ○ flora

Exposure Pathway: internal

Mass of organism Mass [kg]: 1.0 [10^{-6} ... 10^3]

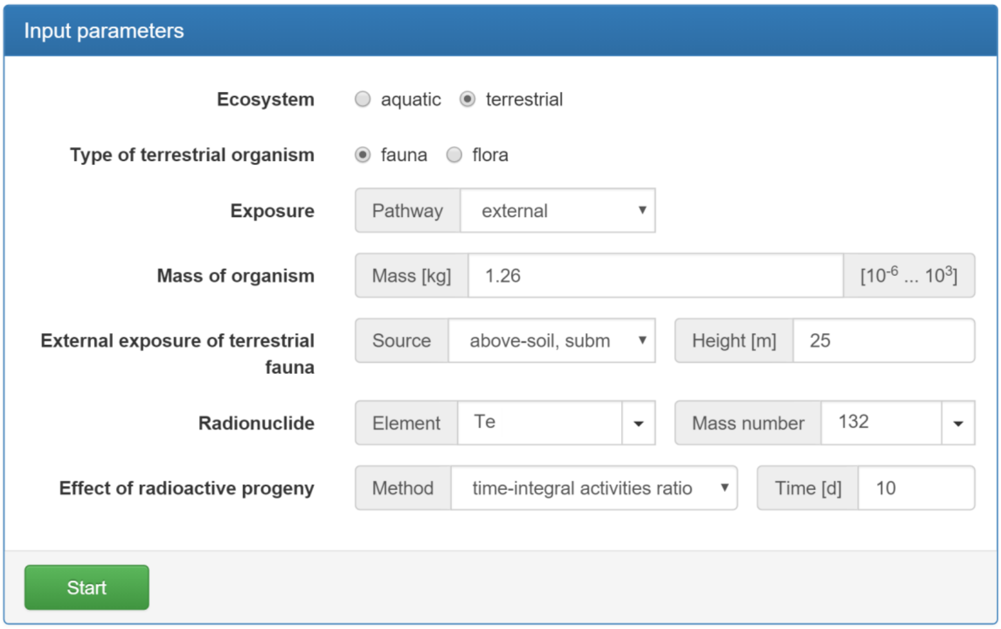
Shape of organism Shape: 1 x 1.0 x 1.0 [0 ... 1]

Radionuclide Element | Mass number

Effect of radioactive progeny Method: time-integral activities ratio | Time [d]: 365.2425

Fig. C.7. Parameter selection screen for terrestrial organism. Fauna has been selected.

(C 12) If, however, for the terrestrial organism, selections are made for ‘fauna’ and ‘external’ exposure, then the input form changes (Fig. C.8) and does not show any means to specify proportions of the organism’s body. This is due to the current model for external exposure of terrestrial organisms that provides dosimetric response for spherical bodies. Additional parameters shown in the input form in this case are type of the source and organism’s height above the ground surface.



Input parameters

Ecosystem ○ aquatic ● terrestrial

Type of terrestrial organism ● fauna ○ flora

Exposure: Pathway external

Mass of organism: Mass [kg] 1.26 [10^{-6} ... 10^{3}]

External exposure of terrestrial fauna: Source above-soil, subm; Height [m] 25

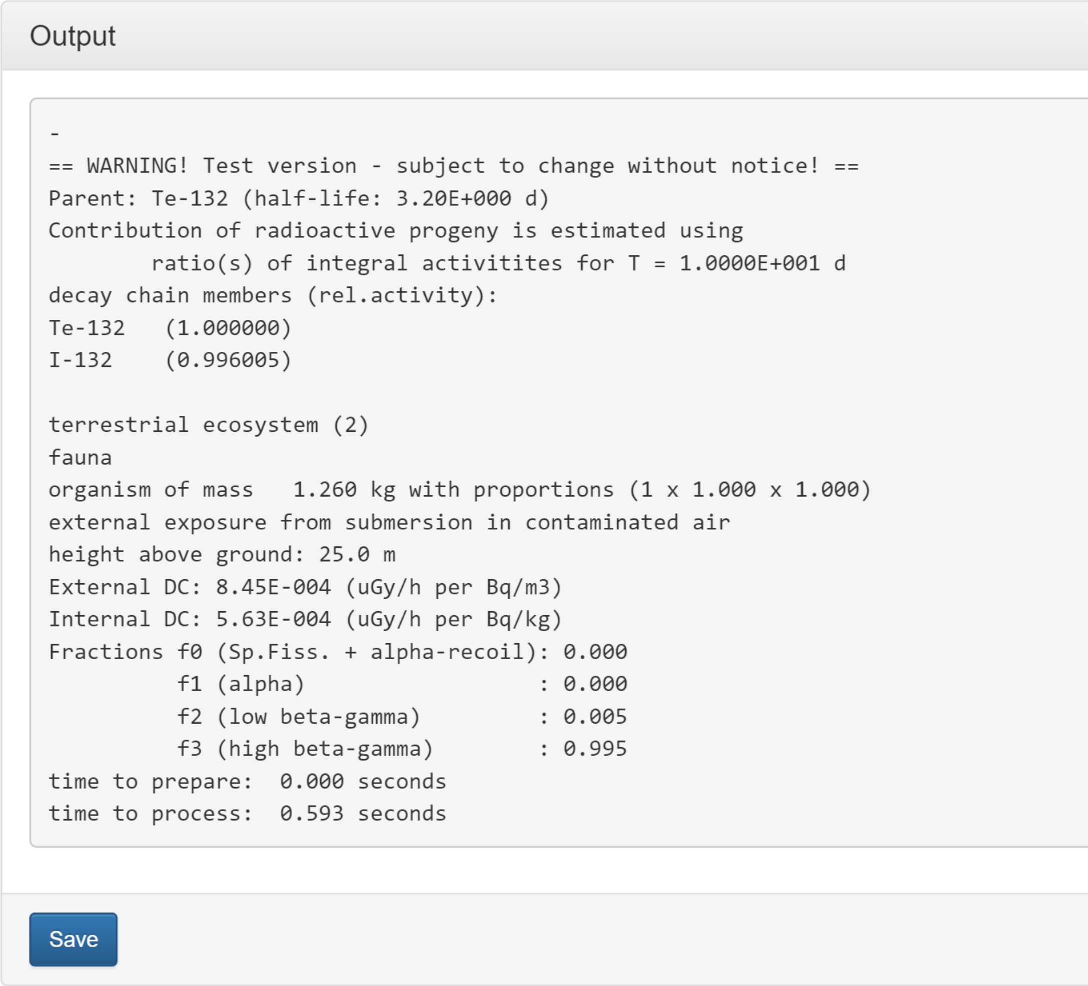
Radionuclide: Element Te; Mass number 132

Effect of radioactive progeny: Method time-integral activities ratio; Time [d] 10

Fig. C.8. Parameter selection screen for terrestrial animals. External exposure above soil to radioactively contaminated air has been selected.

(C 13) An example of results of DC calculations after selecting external exposure for terrestrial organisms is shown in Fig. C.9. Here, external DCs have been calculated for a bird with body mass 1.26 kg (e.g. ICRP duck) at height 25 m above the ground flying through air contaminated by ^{132}Te. The contribution of the short-lived daughter ^{132}I is accounted for using relative weights calculated from activities integrated within a 15-d period. DCs for internal exposure shown in this case are calculated for a spherical body shape, because the spherical model is used in this case for the external DC calculation. If the user wishes to get internal DCs accounting for non-spherical body shapes, then the user should explicitly select ‘internal’ exposure and corresponding input fields for body proportions will then became assessable.

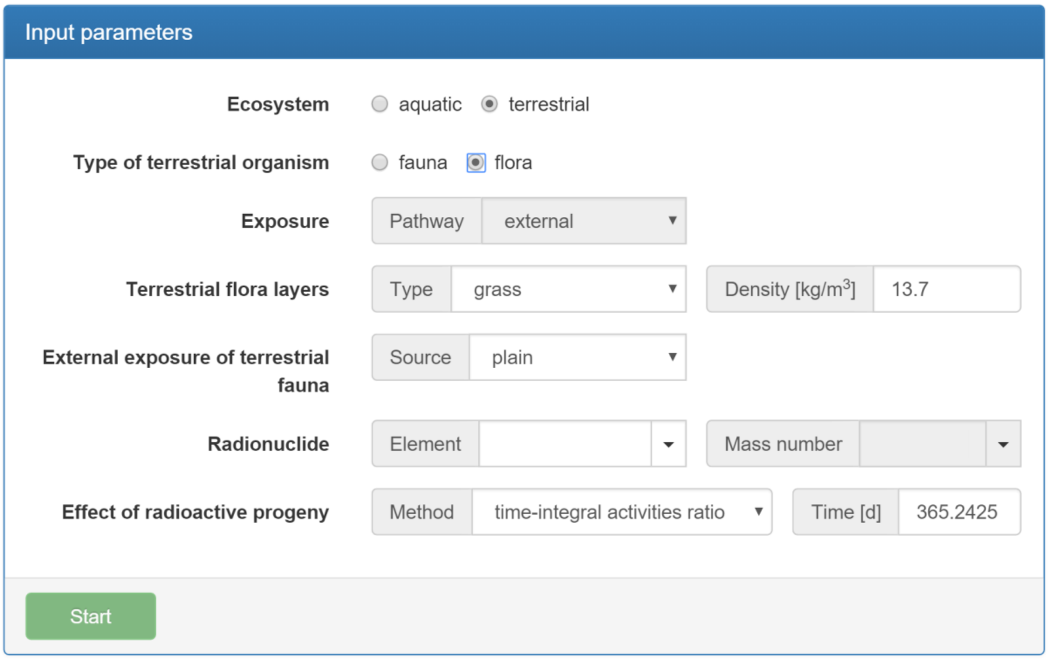
(C 14) Finally, Fig. C.10 shows the parameter input form if external exposure of terrestrial flora has to be calculated using the simple model of homogeneous vegetation layers.



```
-
== WARNING! Test version - subject to change without notice! ==
Parent: Te-132 (half-life: 3.20E+000 d)
Contribution of radioactive progeny is estimated using
        ratio(s) of integral activitites for T = 1.0000E+001 d
decay chain members (rel.activity):
Te-132   (1.000000)
I-132    (0.996005)

terrestrial ecosystem (2)
fauna
organism of mass   1.260 kg with proportions (1 x 1.000 x 1.000)
external exposure from submersion in contaminated air
height above ground: 25.0 m
External DC: 8.45E-004 (uGy/h per Bq/m3)
Internal DC: 5.63E-004 (uGy/h per Bq/kg)
Fractions f0 (Sp.Fiss. + alpha-recoil): 0.000
          f1 (alpha)                  : 0.000
          f2 (low beta-gamma)         : 0.005
          f3 (high beta-gamma)        : 0.995
time to prepare:  0.000 seconds
time to process:  0.593 seconds
```

Fig. C.9. Results of calculation for the case shown in Fig. C.8.



Input parameters

Ecosystem: ○ aquatic ● terrestrial

Type of terrestrial organism: ○ fauna ● flora

Exposure: Pathway external

Terrestrial flora layers: Type grass; Density [kg/m^3] 13.7

External exposure of terrestrial fauna: Source plain

Radionuclide: Element; Mass number

Effect of radioactive progeny: Method time-integral activities ratio; Time [d] 365.2425

Fig. C.10. Parameter selection screen for terrestrial organisms. Flora has been selected.

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