FASSET

Framework for Assessment of Environmental Impact

Deliverable 3

Dosimetric models and data for assessing radiation exposures to biota

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Edited by

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FASSET will bring to radiation protection a framework for the assessment of environmental impact of ionising radiation. The framework will link together current knowledge about sources, exposure, dosimetry and environmental effects/consequences for reference organisms and ecosystems. Relevant components of the framework will be identified on an ecosystem basis through systematic consideration of the available data. The application of the framework in assessment situations will be described in an overall report from the project. The project started in November 2000 and is to end by October 2003.

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Executive summary

Radiation protection has traditionallyfocused in the last decades on the protection of man. However, the limitation to the consideration of the radiation exposure to humans is being increasingly questioned and the need for a sound scientific basis to assess and evaluate radiation exposures to flora and fauna, from both natural and artificial radionuclides is now recognised:

The main objective of the FASSET project is to develop a framework for the assessment of the impact of ionising radiation on flora and fauna. For this purpose, within the FASSET project, 4 work packages were defined:

- In work package 1, dosimetric models are developed that enable the assessment of internal and external exposures for both, terrestrial and aquatic biota.
- In work package 2, reference organisms are defined and models are developed to enable the estimation of radioactivity levels in environmental media and in biota subsequent to releases of radionuclides into a wide range of ecosystems.
- Work package 3 investigates the relationship between exposure to biota and possible effects. The activities are focused on four effect categories as morbidity, mortality, reduced reproductive success and mutation.
- Work package 4 sets up a framework that integrates assessment and evaluation of exposures to biota.

This deliverable describes the dosimetric models that enable the assessment of exposures to a broad range of target organisms due to both, internal and external exposure. Input quantities for the assessment are measured or calculated activity concentrations in biota or in environmental media such as soil, water or sediments. Nuclide-specific dose conversion coefficients (DCCs) are derived taking into account habitat, target size and exposure route (internal and external exposure). The following points were considered:

- *Selection of radionuclides.* The DCC were derived for a number of selected radionuclides that are considered to be most relevant in case of radioactive releases from nuclear installations and for the natural radiation background.
- *Selection of reference organisms.* Due to the enormous variabilities of species and habitats, it is impossible to consider all species explicitly. Therefore, for both, the terrestrial and the aquatic environment, a set of reference organisms differing in size and habitat were defined for further detailed considerations that allow the assessment of exposures to a wide range of possible species.
- *Definition of geometries.* For the reference organisms, the shape was approximated by spheres, cylinders, and, in most cases, ellipsoids. For biota in the terrestrial environment, specific exposure conditions are defined for biota that live in and those that live on soil.

- *Calculations of DCC for monoenergetic sources.* For the biota in the terrestrial environment, DCCs were calculated by means of Monte Carlo calculations for monoenergetic radiation sources. Such techniques are required for terrestrial habitats with their pronounced inhomogeneities in materials and densities to simulate radiation transport. For aquatic biota, analytical approximations were applied which are sufficiently accurate since the densities of the materials and tissues involved vary only slightly.
- *Calculations of nuclide-specific dose conversion coefficients.* From the DCCs for monoenergetic radiation sources, nuclide-specific DCCs were derived for external and internal exposure, taking into account the type of radiation as well as energy and intensity of the emission.

  The DCCs for external exposure in the terrestrial environment are given for organisms living on the soil, for planar radiation sources with a surface roughness of 3 mm, a volume source due to the homogeneous contamination of the upper 10 cm of soil. For organisms living in the soil, that the organisms live in the centre of a homogeneously contaminated layer of a thickness of 50 cm.

  The DCCs for internal exposure were derived, assuming a homogeneous distribution of the radionuclide in the organism. Unweighted DCCs for internal exposures are given. To illustrate the possible impact of the weighting factors of different kinds of radiation, weighted DCC for internal exposure are given assuming weighting factors of 10 for α-radiation, 3 for low-β radiation (E < 10 keV), and 1 for β-radiation with energies above 10 keV and γ-radiation.
- *General dependencies of the DCCs.* The dose conversion coefficients for external exposure decrease with the size of the animal due to the increasing self-shielding effect.

  The differences in DCCs for external exposure among organisms are more pronounced for low energy γ-emitters, since for such photons the effect of self-shielding is more important.

  The exposure to small organisms (e.g. mouse) from high-energy photon emitters is higher for underground organisms, compared to aboveground organisms, whereas it is vice versa for larger organisms (e.g. fox).

  The external exposure to low-energy photon emitters is in general higher for aboveground organisms, since then the shielding effect of the soil is less pronounced.

  For internal exposure to γ-emitters, DCCs increase in proportion to the mass of the organism due to the higher absorbed fractions. This dependence is more pronounced for high-energy photon emitters (e.g. ^{137}Cs/^{137m}Ba)

  For α- and β-emitters, the DCCs for internal exposure are nearly size-independent.

  For internal exposure, the impact of the radiation quality is especially important for tritium and the α-emitters.

- *Compilation of background radioactivity levels.* In order to enable a comparison of exposures to biota from radioactivity released from nuclear installations with the natural background, data on the levels of natural radionuclides in different environmental compartments such as marine waters, freshwaters and soils were collected. Special emphasis is given to the radionuclides ^{238}U, ^{232}Th, ^{230}Th, ^{228}Ra, ^{226}Ra, ^{222}Rn, ^{210}Po and ^{40}K. These data are used to estimate natural background exposures to biota.
- *Background exposures in the terrestrial environment.* For terrestrial organisms, the external exposure is in the order of 0.1–0.4 mGy/a, depending on size and habitat. The main contributor is ^{40}K. Internal background exposures for terrestrial organisms are more variable. Again, an important contributor is ^{40}K that causes exposures in the order of 0.3 mGy/a. The exposures to muscles and plant tissues caused by uranium, thorium, and radium, lead and polonium are low; however, liver, bone and kidney may be exposed at levels of 0.1 to 1 mGy/a unweighted absorbed dose. Weighted absorbed doses due to α-emitters are higher in proportion to the weighting factor assumed.

  Under specific environmental conditions, much higher internal exposures may be estimated. Burrowing mammals receive relatively high lung doses due to the inhalation of radon and its daughter nuclides.

  Animals that graze in Arctic regions may be exposed by ^{210}Pb and ^{210}Po that may be found in high levels in lichens.
- *Background exposures in the aquatic environment.* For aquatic organisms, the majority of the calculated absorbed dose arises from internally incorporated α-emitters, with ^{210}Po and ^{226}Ra being the major contributors. The dose attributed is therefore closely proportional to the weighting factor assumed for α-radiation. Calculated doses for freshwater organisms are somewhat higher than for marine organisms, and the range of doses is also much greater, reflecting the much greater variability of radionuclide concentrations in freshwater as compared to seawater.

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1. Introduction

During decades, scientific and administrative activities of radiation protection focused on the radiation exposure of man due to both, artificial and natural sources. However, in the last years, the limitation to human health protection is being increasingly questioned and the possible impact of ionizing radiation on non-human biota attracted more and more attention by politic, the public and science. The requirement for an internationally agreed rationale to the protection of the environment to ionizing radiation has been recognized.

It is the aim of the FASSET project to develop a scientifically well founded framework for the assessment of the impact of ionising radiationon on flora and fauna. For this purpose, 4 work packages were set up:

- In work package 1, dosimetric models are developed that enable the assessment of internal and external exposures for both, terrestrial and aquatic biota.
- In work package 2, reference organisms are defined and models are developed to enable the estimation of activity levels in environmental media and in biota subsequent to releases of radionuclides into a wide range of ecosystems.
- Work package 3 investigates the relationship between exposure to biota and possible effects. The activities are focused on four potential endpoints as morbidity, mortality, reduced reproductive success and cytogenetic effects.
- Work package 4 sets up a framework that integrates assessment and evaluation of exposures to biota.

The emphasis of this deliverable is the development of dosimetric models that enable the assessment of exposures to a broad range of target organisms due to both, internal and external exposure. Input quantities for the assessment are measured or calculated activity concentrations in biota or in environmental media as soil, water or sediments. Nuclide-specific dose conversion coefficients are derived as function on habitat, target size and exposure route (internal and external exposure).

This report has the following structure: in Chapter 2, the assessment context for the dosimetry of biota is defined. This includes the radionuclides that are involved, the definition of size, shape and mass of the target organisms considered. The applied dose concept is discussed. In Chapter 3, the dosimetric models to derive dose conversion coefficients for terrestrial biota are described that allow the estimation of exposures dependent on radionuclide, organism geometry and habitat for both internal and external exposure. The derivation of dose conversion coefficients for aquatic organisms is outlined in Chapter 4. Chapters 5 and 6 summarize levels of natural radioactivity in terrestrial, aquatic and marine environments and gives estimates of background exposures to biota.

2. Assessment context

2.1 Dose concept

The basic quantity for assessing exposures to ionizing radiation is the absorbed dose, which is defined as the amount of energy that is absorbed by a unit mass of tissue of an organ or organism; it is given in units of Gray [Gy].

There are different types of radiation e.g. α-, β-, and γ-radiation with differing ability to interact with biological material. To account for this different biological effectiveness, the International Commission of Radiological Protection (ICRP) has introduced a quality factor that compares the effectiveness of the different types of to the effectiveness of irradiation with 300 keV photons.

The product of the radiation quality factor and the absorbed dose results in the equivalent dose, which has the advantage to integrate exposures from different radiation types on the basis of the biological effect and not simply on the energy absorbed. The unit of the equivalent dose is Sievert [Sv].

The aim of radiation protection is to limit the overall risk to humans that may arise from ionizing radiation; an emphasis is on the limitation of stochastic effects. However, similar exposures to different human organ or tissues may cause quite different stochastic effects. Therefore, ICRP has introduced the tissue weighting factor that accounts for different sensitivity in respect to stochastic effects of different organs. Thus, the effective dose is the central concept in the modern human radiation protection; it is also given in units of Sievert. The main advantage is that it represents a risk-related quantity that integrates over all pathways (internal and external exposure), all types of radiation and the organ-specific exposures.

The effective dose is clearly dedicated to the consideration of exposures to humans, since it aims at the quantification of stochastic effects and risks.

The application of the concept of equivalent dose may be applied to biota only with limitations. The radiation quality factors were derived for the application in dose assessments for humans, for which stochastic effects are primarily important. However, in the assessment of exposures to biota, due to the different endpoints, the emphasis is on the consideration of higher dose levels that may even cause deterministic effects.

Therefore, the radiation quality factors used for the dose assessment to humans may not be applicable to dose assessment for biota. Before the concept of equivalent dose is applied to biota, quality factors have to be derived for the relevant endpoints.

According to these considerations, the absorbed dose will be the key quantity for the exposure assessment of biota. The estimations made in the framework of this project are made on the base of absorbed dose. To account for the radiation quality, the possible impact of the radiation weighting factor on the exposures to biota is illustrated.

2.2 Reference organisms

Clearly, it would be nearly impossible to consider all species of flora and fauna during the course of an environmental impact assessment even within limited geographical boundaries. Instead, reference organism types could be selected, to be representative of large components of common ecosystems and for which models (examples include transfer-uptake and dosimetric) could be adopted for the purpose of deriving organism, tissue, or organ, dose rates. Knowledge of the absorbed dose (rate) for such reference organisms in terms of several broadly defined end-points, would then allow a basic assessment to be made concerning possible biological effects. The reference organism approach provides a means of reducing the assessment to manageable proportions and may allow logical links/associations between sets of data attributed to different organism types to be established. In this way some insight into the potential environmental impacts of ionising radiation may be derived for components of the environment for which data are poor or absent.

The reference organism approach has been advocated in a number of earlier publications [Pentreath, 1999; Pentreath & Woodhead, 2000; Strand et al. 2000] where it has been argued that [Pentreath, 1999] an attempt should not be made to model everything but that models should be selected based on an appreciation of the actual and potential data that are likely to become available, and pre-existing information concerning the effects of geometry, the behaviour of radionuclides in the environment and the behaviour of the organisms.

Within the FASSET project the term "reference organism" has been defined as: "a series of entities that provides a basis for the estimation of the radiation dose rate to a range of organisms that are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects" [Larsson et al., 2002].

Pentreath & Woodhead (2001) suggested that a pragmatic selection of reference organisms should consider the following criteria:

- The extent to which they are considered to be typical representative fauna or flora of a particular ecosystem.
- The extent to which they are likely to be exposed to radiation from a range of radionuclides in a given situation, both as a result of bioaccumulation and the nature of their surroundings, and because of their overall lifespan, life-cycle and general biology.
- The stage or stages in their life-cycle likely to be of most relevance for evaluating total dose or dose-rate, and of producing different types of dose-effect responses.
- The extent to which their exposure to radiation can be modelled using relatively simple geometries.
- The chances of being able to identify any effects at the level of the individual organism that could be related to radiation exposure.

- The amount of radiobiological information that is already available on them, including data on probable radiation effects.
- Their amenability to future research in order to obtain the necessary data on radiation effects.
- The extent to which they have some form of public or political resonance, so that both decision makers and the general public at large are likely to know what these organisms actually are, in common language.

Within FASSET the number of selection criteria has been reduced and includes:

- Ecological sensitivity, i.e., the potential of the organism, through feeding habits and habitat occupancy, to be exposed to significant dose rates from radionuclides in their environment that derive from a variety of release scenarios.
- Intrinsic sensitivity of the organism to chronic low-level irradiation for the biological endpoints of significance at the relevant level of biological organisation.
- Ecological significance, i.e., the organism's importance to the maintenance of the community or ecosystem. The potential requirement for generic representatives of each trophic level in the marine, freshwater and terrestrial environments will need to be considered.

However, only criterion on ecological sensitivity and to a limited extent[1] the ecological significance have been applied in the selection of a "candidate" set of reference organisms. This selection process, from an exposure pathways perspective, is documented in a Deliverable Report (D1) for the FASSET Project [Strand et al., 2001]. Analyses were based on a consideration of the biogeochemical behaviour (primarily transfer and biological uptake) of 20 radionuclides (see below) within 4 terrestrial (i.e. forest, semi-natural, agricultural and wetlands) and 3 aquatic (i.e. marine, freshwater and brackish) ecosystems. The component ecosystems were selected to be typical for Europe. Lists of candidate reference organisms derived from the study are presented in Tables 2-1 and 2-2.

[1] Simplified ecological niches/organism grouping were used to attain representative(s) from different ecological compartments. Importance in terms of maintenance of a healthy ecosystem was not considered.

Table 2-1 Candidate reference organisms for aquatic ecosystems.

Organism	Habitat		
	Marine	Brackish water	Freshwater
Bacteria	x	x	x
Worm	x	x	
Insect larvae		x	x
Bivalve mollusc	x	x	x
Macroalgae	x	x	
Crustacean	x	x	x
Amphibian			x
Benthic fish	x	x	x
Vascular plant	x	x	x
Pelagic fish	x	x	x
Mammal	x	x	x
Wading bird	x	x	x
Phytoplankton	x	x	x
Zooplankton	x	x	x

Table 2-2 Candidate reference organisms for terrestrial ecosystems.

Organism	Habitat			
	Forest	Semi-natural	Agricultural	Wetlands
Microorganism	x	x		x
Fungi	x	x		
Grass/herb/crop	x	x	x	x
Herbivorous mammal	x	x	x	x
Tree	x		x	
Burrowing mammal	x	x		
Shrub		x		
Carnivorous mammal	x	x		x
Canopy invertebrate	x			
Plant	x	x	x	x
Lichen/bryophyte	x	x		x
Detritivorous insect	x	x		
Bird egg	x	x		

It should be stressed that this is not a definitive set, as the qualifying word “candidate” implies, and will be modified as more information is collated and synthesised. The organism list has been used as a basis for selecting suitable target geometries/phantoms. It became apparent that the identification of actual species (or in some cases families or classes of organism) representing each of the broadly defined groups would be helpful in the process of generating the quantitative information on size, shape and density required in geometry construction. “Representative” reference organisms were selected through a consideration of their ubiquity, geographical spread (is the organism present in many parts of Europe?) and available data. The dimensions and shape were derived from the adult form of the biota in most cases. In order to provide a guide as to the variation in sizes within each of the reference groups, large and small members of each biota type were also listed with concomitant attributes of size and shape. By way of illustration, the marine benthic fish category can be represented by Plaice (family *Pleuronectidae*). Typical dimensions of the adult fish, simplified to the form of a flat ellipsoid in the process of geometry construction, are 0.4 x 0.2 x 0.03 m. Similarly, small and large members of the benthic fish group can be represented by the Norwegian Topknot (*Phrynorhombus norvegicus*) of dimensions 0.07 x 0.07 x 0.01 m and the Common skate (*Raja batis*) of dimensions 1 x 1 x 0.085 m. Again a flat ellipsoid geometry is adopted in both cases. A full overview of the large, small and representative biota used for each of the reference organism types is presented in Tables 2-3 to 2-6.

Table 2-3 Selected reference organism geometries for the marine environment[1].

Organism type (habitat)	Example biota type	wt (kg) f.w.	Body length (m)	Body width (m)	Body depth (m)	Suggested shape	Reference
Bacteria (Benthic)	Escherichia[2]	3.9E–16	2.0E–6	5.0E–7	5.0E–7	Cylinder	"Bacteria" Encyclopædia Britannica http://www.britannica.com
Worm (Benthic)	Lugworm (*genus Arenicola, Phylum Annelida*)	0.24	0.23	0.012	0.012	Cylinder	"Polychaete" Encyclopædia Britannica
Bivalve mollusc	Blue mussel (*Mytelis edulis*)	0.016	0.05	0.025	0.025	Ellipsoid	"Bivalve" Encyclopædia Britannica
Crustacean (Benthic)	Lobster (*Homarus gammarus*)	1.5	0.3	0.1	0.1	Ellipsoid	British Marine Life Study Society www.ourworld.compuserve.com/homepages/bmlss/Index.html
Fish (Benthic)	Plaice (family *Pleuronectidae*, e.g. *Pleuronectes platessa*)	1.25	0.4	0.2	0.03	Flat ellipsoid	"Plaice" Encyclopædia Britannica; The Aquarium Project: web.ukonline.co.uk/aquarium/
Vascular plants	Sea grass (division *Anthophyta*, class *Monocotyledoneae*)	0.015	0.2	0.05	0.05	Cylinder	http://www.botany.hawaii.edu/
Mammals	Harp Seal (*Pagophilus groenlandicus*)	180	1.8	0.44	0.44	Ellipsoid	"Harp seal" Encyclopædia Britannica
Wading birds	Duck e.g.Eider (*Somateria spp.*)	0.6	0.15	0.11	0.076	Ellipsoid	Copplestone et al. (2001)
Phytoplankton (pelagic)		6.5E–11	5.0E–5	5.0E–5	5.0E–5	Sphere	Copplestone et al. (2001)
Zooplankton (pelagic)		1.6E–5	6.2E–3	3.1E–3	6.1E–3	Ellipsoid	IAEA [1988]
Macroalgae (benthic)	*Fucus spp.*, single blade	6.3E–3	0.3	0.02	0.002	Flat ellipsoid	"Seaweed" Encyclopædia Britannica
	Fucus spp., macroalgae cluster	0.82	0.25	0.25	0.025	Flat ellipsoid	"Seaweed" Encyclopædia Britannica
Fish (pelagic)	Mackerel (*Scomber scombrus*)	0.5	0.3	0.06	0.06	Ellipsoid	"Mackerel" Encyclopædia Britannica

[1] The biota sizes relate to the adult form for each of the organisms considered

[2] These bacteria are not specifically marine benthic bacteria but are selected to give a size range for this organism type

Table 2-4 Selected reference organism geometries for the freshwater environment.

Organism type	Example animal/plant species	wt (kg) f.w.	Body length (m)	Body width (m)	Body depth (m)	Suggested shape
Phytoplankton	Blue-green algae (*Aphanizomenon*)	1.9E–9	8.0E–5	7.0E–6	7.0E–6	Cylinder
Zooplankton	Water fleas (*Daphnia spp.*)		2.5E–3	5.3E–4	1.6E–3	Ellipsoid
Vascular plants	Water milfoil (*Myriophyllum spicatum*)		1	2.0E–3	2.0E–3	Ellipsoid
Gastropoda	Gastropods (*Lymnaea spp.*)		0.05	0.025	0.025	Ellipsoid
Bivalve molluscs	Freshwater clam (*Anodonta spp.*)		0.1	0.025	0.05	Ellipsoid
Crustacea	Water slater (*Asellus aquaticus*)	1.5E–5	0.02	0.007	0.001	Ellipsoid
Insect larvae	Chironomids (Chironomus plumosus)	2.0E–5	0.02	0.0015	0.0015	Cylinder
Benthic fish	Burbot (*Lota lota*)	1.5	0.5	0.08	0.07	Ellipsoid
Pelagic fish	Perch (*Perca fluviatilis*)	0.35	0.3	0.035	0.06	Ellipsoid
Amphibians	Frog (*Rana temporaria*)		0.08	0.03	0.02	Ellipsoid
Birds	Common Gull (*Larus canus*)	0.4	0.4	0.13	0.13	Ellipsoid
Mammals	Muskrat (*Ondatra zibethicus*)	1.3	0.33	0.15	0.15	Ellipsoid

Table 2-5 Selected reference organism geometries for the brackish (Baltic Sea) environment.

Organism type	Example animal/plant species	wt (kg) f.w.	Body length (m)	Body width (m)	Body depth (m)	Suggested shape
Phytoplankton	Blue-green algae (*Aphanizomenon*)	1.9E–9	8.0E–5	7.0E–6	7.0E–6	Cylinder
Zooplankton	Water fleas (*Bosmina coregoni*)		1.0E–3	2.5E–4	8.0E–4	Ellipsoid
Macroalgae	Bladder-wrack (*Fucus vesiculosus*)	1.0E–2	0.6	0.01	0.0015	Ellipsoid/flat
Vascular plants	Water milfoil (*Myriophyllum spicatum*)	1.0E–2	1	2.0E–3	2.0E–3	Ellipsoid
Bivalve molluscs	Common mussel (*Mytilus edulis*)	3.2E–3	0.035	0.015	0.020	Ellipsoid
Worms	Polychaete (*Marenzelleria viridis*)	1.2E–4	0.03	0.04	0.002	Cylinder
Crustacea	Isopod (*Saduria entomon*)	1.6E–3	0.055	0.018	0.008	Ellipsoid
Insect larvae	Chironomids (*Chironomus plumosus*)	2.0E–5	0.02	0.0015	0.0015	Cylinder
Benthic fish	Cod (*Gadus morhua*)	3	0.6	0.12	0.06	Ellipsoid
Pelagic fish	Baltic herring (*Clupea harengus*)	0.3	0.19	0.033	0.012	Ellipsoid
Birds	Common Gull (*Larus canus*)	0.4	0.4	0.13	0.13	Ellipsoid
Mammals	Ringed seal (*Phoca hispida*)	80	1.5	0.5	0.5	Ellipsoid

Table 2-6 Selected reference organism geometries for the terrestrial environment.

Organism type	Example animal type	Length (cm)	Width (cm)	Height (cm)	Shape	Volume (cm³)	Mass[1] (g)	Shielding layer (mm)	Position (cm)	Air around target (mm)	Refer-ence
Soil invertebrate	Earthworm (*Lumbricus terrestris*)	12	0.8	0.8	Cylinder	6	6	0	0, –5, –25, –50	0	1, 2, 3, 4, 5
Soil invertebrate	Woodlouse / Pillbug (*Armadillidium vulgare*)	1.7	0.6	0.3	Ellipsoid	0.16	0.17	0	0, –5, –25, –50	0	6, 7
Burrowing mammal	Mole (*Talpa europaea*)	11	4	4	Ellipsoid	92	97	1	0, –25, –50	5	8, 2, 9, 10, 11
Herbivorous mammal (also burrowing)	Mouse (*Mus Musculus*)	7	3	3	Ellipsoid	33	35	1	0, –25, –50	5	
Herbivorous mammal (also burrowing)	Rabbit (*Oryctolagus cuniculus*)	30	11	11	Ellipsoid	1.9E3	2.0E3	1	0, –25, –50	5	7, 2, 12, 13, 14
Herbivorous mammal	Domestic cow/ Moose (*Alces alces*)	160	70	90	Ellipsoid	5.3E5	5.5E5	3	0, 50		
Herbivorous mammal	Row Deer	60	27	27	Ellipsoid	2.3E4	2.4E4	1	0, 50		
Carnivorous mammal	Weasel (*Mustela nivalis*)	15	3	4	Ellipsoid	94	99	1	0	5	7, 2, 14, 17
Carnivorous mammal (also burrowing)	Red fox (*Vulpes vulpes*)	40	15	20	Ellipsoid	6.3E3	6.6E3	1	0, –25, –50	5	7, 2, 14, 18, 19
Reptile	Snake	100	3	3	Cylinder	7.1E2	7.4E2	0	0, –25, –50	0	
(Ground nesting) Large Bird egg	Red Grouse (*Lagopus lagopus scoticus*)	4.5	3	3	Ellipsoid	21	22	1	0		20, 21
(Ground nesting) Small Bird egg	Sky-lark (*Alauda arvensis*)	2.4	1.7	1.7	Ellipsoid	4	4	1	0		22
Herbivorous Bird	like “mouse”	7	3	3	Ellipsoid	33	35	1	300		
Carnivorous Bird	like “mole”	30	11	11	Ellipsoid	1901	1996	1	10000		

Referencies:

1. Lee 1985

[1] Assuming mass density $\rho = 1.05$ g/cm³

2. Britannica 2002
3. http://edis.ifas.ufl.edu/IN047
4. University of California Sustainable Agriculture Research & Education Program
5. http://www.sarep.ucdavis.edu
6. Copplestone et al. 2001
7. http://ohioline.osu.edu/hyg-fact/2000/2072.html
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19. http://animaldiversity.ummz.umich.edu/accounts/vulpes/v._vulpes$narrative.html
20. Witherby et al. 1949
21. http://www.asken.co.uk/Practical/4_shooting_management.htm
22. Witherby et al. 1950

2.3 Radionuclides considered

There is a large range of anthropogenic and natural radionuclides, which may need to be considered within environmental impact assessments and in this initial consideration of a framework it is not possible to consider them all. Therefore, a sub-set of radionuclides of twenty elements have been selected. They are summarized in Table 2-7.

Table 2-7 Radionuclides selected for consideration within FASSET [Strand et al., 2001].

Principal radioisotopes	Half–life (a)	Radiation type	Sources
^{3}H	12	β^-	Cosmic, fission, activation
^{14}C	5600	β^-	Cosmic, activation
^{40}K	1.3E9	β^-, γ	Primordial
^{36}Cl	3E5	ε, e^-	Neutron activation
^{63}Ni ^{59}Ni	96 75000	β^- β^+, ε	Neutron activation
^{89}Sr ^{90}Sr	0.0138 28.5	β^-, γ	Fission
^{94}Nb	20300	β^-, γ, e^-	Fission
^{99}Tc	213000	β^-, γ, e^-	Fission
^{106}Ru	1.01	β^-	Fission
^{129}I ^{131}I	1.57E7 0.022	β^-, γ, e^- β^-, γ	Fission
^{134}Cs ^{137}Cs ^{135}Cs	2.06 30 200000	β^-, β^+, γ β^- β^-	Fission
^{210}Po	0.378	α, γ	^{238}U decay series
^{210}Pb	22	β^-, γ	^{238}U decay series
^{226}Ra	1600	α, γ	^{238}U decay series
^{227}Th ^{228}Th ^{230}Th ^{231}Th ^{232}Th ^{234}Th	0.021 1.9 77000 2.9E–3 1.4E10 0.066	α, γ, e^- α, γ α, γ, e^- β^-, γ, e^- α, γ β^-, γ, e^-	Natural U & Th series decay chains
^{234}U ^{235}U ^{238}U	2.45E5 7.04E8 4.47E9	α, γ α α, e^-	Natural
^{238}Pu ^{239}Pu ^{240}Pu ^{241}Pu	88 24000 6500 14.4	α, β^-, γ α, γ α, e^- α, β^-, γ	Activation-neutron capture
^{241}Am	432	α, γ	Activation-neutron capture decay of ^{241}Pu
^{237}Np	2.1E6	α, γ, e^-	Activation-neutron capture
^{242}Cm ^{243}Cm ^{244}Cm	0.447 28.5 18.1	α, γ α, γ, ε, e^-	Activation-neutron capture

The selection of radionuclides includes:

- Radionuclides routinely considered in both regulatory assessments of waste disposal and releases from different facility types, and emergency planning for accidental releases.
- A range of environmental mobilities and biological uptake rates.
- Both anthropogenic and natural radionuclides.
- Representatives of α-, β^- and γ-emitters; radionuclides for which sufficient data is likely to be available.

Subsequently, a framework designed to assess these radionuclides should be sufficiently robust to be readily applicable to the consideration of others.

2.4 Relative biological effectiveness

Radiations of different qualities have different degrees of effectiveness in producing effects in biological systems. When radiation is absorbed in biological material, the energy is deposited along the tracks of charged particles in a pattern that is characteristic of the type of radiation involved. After exposure to γ-radiation, the ionisation density would be quite low. After exposure to neutrons, protons, or α-particles, the ionisation along the tracks occur much more frequently, producing a much denser pattern of ionisations.

These differences in density of ionisations are a major reason that α-particles produce more biological damage effects per unit of absorbed radiation dose than low-LET radiation as γ-radiation or electrons [Hall 1988].

Other factors that contribute to these differences include the energy of radiation used, the dose received, the temporal pattern in which it was received, and the particular biological endpoint being studied. Many scientific investigations have been conducted to study the differing effectiveness of radiations under different experimental conditions. The higher effectiveness in producing biological damage is quantified by the Relative Biological Effectiveness, RBE. It is calculated for a given test radiation, as the dose of a reference radiation, γ-radiation, required to produce the same biological effect as was seen with a test dose of another radiation.

For the calculation of the equivalent dose, ICRP recommends an RBE factor for α-radiation of 20. However, for humans, stochastic radiation effects are the major concern, whereas for biota deterministic effects as morbidity, mortality, reduced reproductive success, and mutations are of primary interest. Therefore, the RBE of 20 as used for humans might not be appropriate for biota.

The problem in deriving appropriate values for RBE is that any value obtained in experiments is specific to the endpoint studied and the exposure conditions as dose, dose rate, and chronic and acute exposure regime. Furthermore, it is specific to the biological and environmental conditions. Therefore it is very difficult to derive general valid RBE values for use in environmental impact assessment of ionising radiation.

UNSCEAR [1996] suggests a value for RBE of α-radiation of 5 for the use in impact assessment to biota, since a RBE of 20 as used for the assessment of stochastic effects in humans would overestimate the deterministic effects that are of primary concern in this area.

Kocher and Trabalka [2000] suggest a RBE factor of 5–10 for biota. This range has been derived on the analysis given in ICRP [1989] for deterministic effects.

However, there is a number of experiments which suggest also higher values for RBE. In some of the experiments, endpoints are investigated that are especially important for the consideration of doses to biota. Howell et al. [1994] investigated oncogenic transformation of cells cultures exposed to charged particles of defined LET. A maximum RBE of 20 was found for LET around 125 keV/µm. Rao et al. [1991] found RBE values around 7 for spermatogonial cell killing after exposures to 5.3 MeV α-particles emitted by ^{210}Po in the cells. However, RBE values that were a factor of 8 higher were found for sperm head abnormalities.

NCRP [1991] summarises RBE values for internal α-emitters of 15–50 for the induction of bone sarcomas, lung cancer and liver chromosome aberrations. Especially the last endpoint is relevant for the considerations of biota. It is interesting to note that in this analysis, RBE increased with decreasing dose. The lower doses covered in this study are more relevant to environmental exposures.

These examples highlight the large variability of RBE values and the uncertainty that is associated with the application of RBE values. The investigations cover a range of about 5–50, however, in some cases even higher values are reported. However, due to the complex interaction of RBE on dosimetric and environmental factors as well as on the endpoint considered, the derivation of a general applicable RBE value for internal α-emitters appears currently not possible.

In order to illustrate the impact of the RBE of internal α-emitters, for the calculation of the nuclide-specific dose conversion coefficients for α-emitters, a RBE value for α-radiation of 10 is applied.

A number of investigations suggest that low-energy β-radiation with energies below 10 keV have a higher biological effectiveness than electrons with energies above 10 keV [Moiseenko et al., 2000; Straume et al., 1993]. Moiseenko et al. (2000) considers a RBE value for tritium (mean β-energy < 10 keV) between 2 and 3 as appropriate.

In order to illustrate the impact of the RBE of internal emitters for the calculation of the nuclide-specific dose conversion coefficients, RBE values of 10 and 3 are applied for α-radiations and for low-energy β-radiation respectively. Due to the pronounced variability these values should be considered as examples.

3. Dosimetric models for estimation of radiation exposures to terrestrial biota

3.1 Derivation of dose conversion coefficients

Plants and animals may be exposed to ionising radiation from radionuclides in the environment by both external and internal exposure.

Recent approaches to estimate exposures of biota from radionuclides in the environment are based on a number of simplifying assumptions that potentially lead to more or less pronounced overestimations of the exposures. The most important of theses assumptions are:

- The environmental medium surrounding the biota exposed is infinitely large.
- The density of the surrounding medium is homogeneous.
- The contamination level of the surrounding medium is homogeneous.

Those conditions are in general adequate for aquatic ecosystems, where the differences in density of water and the biota exposed are very little. However, in terrestrial habitats with pronounced heterogeneities in materials and densities, analytical approaches are associated with considerable uncertainties.

In case of internal exposure, it is additionally assumed that the whole energy of γ-radiation is absorbed within organisms, although the range of γ-radiation is in general much longer than the organism size. This causes considerable overestimations especially for small biota.

3.1.1 External exposure

Radionuclides distributed in the environment lead to an external radiation exposure of the organism living in or close to a contaminated medium. The external exposures of biota are the result of a complex and non-linear interactions of various factors:

- The geometrical relation between the source of the radiation and the target.
- The contamination levels in the environment.
- The materials and their shielding properties in the environment.
- The radionuclide-specific decay properties characterised by the radiation type, the energies emitted and the yield.
- The size of the organism.

The geometric relationship between radiation source and the exposed organism is a very important factor. The intensity of the radiation field around a source decreases with distance and it is influenced by the material between the radiation source and the target. The number of situations is enormous; therefore a number of limited and representative situation have been selected for detailed calculations. The exposure conditions were selected so that they allow the determination of exposures also for those conditions for which explicit calculations were not made.

Table 3-1 summarises the different source-target combinations, in which the habitat of the exposure target is listed against the location of the radiation source. All combinations with the radiation source in the aquatic environment and the target in the terrestrial environment and vice versa can be excluded from further consideration.

In the aquatic environment, the source-target combinations with the activity in water or sediment or at the interface water-sediment are potentially relevant. However, in the aquatic environment, the difference in densities is very low, so the conditions for radiation transport are relatively homogeneous. Under those circumstances, the application of analytical approaches allows estimates with sufficient accuracy. The derivation of dose conversion coefficients for marine and freshwater biota is described in Chapter 4.

Table 3-1 Source-target combinations to derive dose conversion coefficients for external exposure.

Exposure target	Radiation source			
	Air	Soil	Water	Sediment
Air	x[1]	x		
Soil surface	x	x		
Soil	(x)[2]	x		
Water			x	(x)
Sediment surface			x	x
Sediment			x	x

Geometries

In the terrestrial environment, the radiation source may be in air or in soil and the exposure targets live in the soil (e.g. mouse, earthworm), on the soil (e.g. rabbit, deer, cow) or in the air (birds). However, the air as a relevant source of radiation is in general a temporary and local phenomenon, since processes as fallout, rainout and washout cause an effective deposition to soil. The most relevant radiation source subsequent to a release in the environment is therefore due the contamination of the soil, which causes—in dependence on the half-life—a persistent radiation source for all terrestrial biota.

The estimation of external exposures in the terrestrial environment is more complex than in the aquatic environment. Soil, air and organic matter differ considerably in composition and density, which cannot, in general, be adequately taken into account by analytical solutions. Therefore, the radiation transport is simulated by means of Monte Carlo techniques, which provides several advantages:

- Materials differing in composition and density can be considered,
- complex geometries of sources and targets can be simulated,
- all relevant physical processes that control radiation transport are precisely treated,
- the self-shielding is implicitly considered, and,
- the uncertainty of the simulation of a specified situation is very low.

Due to the complexity of the processes and the enormous variability of organisms and their natural habitats, it is impossible to cover any exposure conditions. Therefore, typical energies,

---

[1] Source—target combinations that need detailed considerations

[2] Probably not relevant

contaminated media, and organism sizes were selected for detailed considerations. Exposure conditions for which detailed calculations are not available are then determined by interpolation between those cases. The exposure conditions for this purpose were defined taking into account the following criteria:

- Dose conversion coefficients (DCC) are calculated for β-and γ-emitters. Due to the short range of α-radiation, the external exposure from α-particles is not relevant.
- According to the selection of the reference species, distinction has to be made between species that live in soil (e.g. earthworm, burrowing mammal), on the soil (e.g. herbivorous mammal) or above the soil (birds).
- For the calculations of dose conversion coefficients for species living in the soil, a uniformly contaminated volume source was assumed.
- For the derivation of DCC for species living on the ground, a planar radiation source on top of the soil with a surface roughness of 3 mm and a volume source with a depth of 10 cm were assumed.

For a given reference organism placed at some depth into the soil, the important factors to determine the external dose are the distribution of radionuclide concentration in the soil and the energy of the emitted radiations. In order to consider the effect of depth distribution, the absorbed dose were calculated using Monte Carlo techniques assuming monoenergetic γ-emitters uniformly distributed on a plane at different depths over the first 50 cm layer. The details are summarised in Table 3-2.

Table 3-2 Exposure conditions considered for the calculation of dose conversion coefficients for external exposure of reference organisms (animals).

Radiation source	Habitat of exposure target	Radiation type	Target location relative to soil surface (cm)	Source depth (cm)	Energy range (keV)	Target size (m)	Geometry
Soil	Soil	β^-		50	10–2000	10^{-4}–10^{-1}	Ellipsoid
		γ	0, –5, –25, –50	0, 5, 10, 20, 30, 40, 50	50–3000		
	Interface soil/air, air	β^-	10^{-2}–1	50	10–2000	10^{-2}–1	
		γ	10^{-2}–10	0, 5, 20	50–2000		

For the reference plants defined as herbaceous vegetation, shrub and tree, the exposure conditions are specified in Table 3-3. The exposure will be calculated for the meristem and the buds. These organs are characterised by very intensive cell division, which may cause high radiosensitivity.

Table 3-3 Exposure conditions considered for the calculation of dose conversion coefficients for external exposure of reference organisms (plants).

Plant type	Height (m)	Target organ	Height of plant part considered
Herb	0–0.1	Meristem	At the ground (0 m)
Shrub	0.1–1	Bud, meristem	In middle of canopy (0.55 m)
Tree	1–10	Bud, meristem	In middle of canopy (5.5 m)

For the distribution of the radionuclides in the canopy, a distinction is made between α-, β-, and γ-radiation due to their different ranges. For γ-radiation, the whole canopy is considered to be a homogeneously contaminated source of radiation. For high energy β-radiation, the irradiation of the target is also assumed to occur from a homogeneously contaminated canopy. However, due to the much shorter range of α- and low energy β-radiation, the irradiation from the external or internal contamination of the target organ has to be considered explicitly. For α-radiation, due to the very short range of a few centimetres in air, only the exposure from the external or internal contamination of the target has to be taken into account. These assumptions are summarised below (Table 3-4).

Table 3-4 Radiation sources and quantities assessed for the calculations of dose conversion coefficients for reference plants.

Radiation type	Source	Quantity assessed
α	Activity on/in the target organ	Average dose rate in the target
β	Homogeneously distributed in the canopy, activity on/in the target organ	Average dose rate in the target
γ	Homogeneously distributed in the canopy	Average dose rate in the canopy

Composition of materials

The density of the materials involved and their elemental composition have an important impact on the radiation transport. Details are summarised in Table 3-5.

Table 3-5 Composition of material assumed for the calculation of dose conversion coefficients.

Element	Material			
	Organism tissue[1]	Shielding layer[2]	Soil[3]	Air
H	10.2	7	2.1	0.064
C	14.3	50	1.6	0.014
N	3.4	16		75.09
O	71.0	24	57.7	23.56
Na	0.1			
Al			5.0	
Si			27.1	
P	0.2			
S	0.3	3		
Cl	0.1			
Ar				1.28
K	0.4		1.3	
Ca			4.1	
Fe			1.1	
Density (g/cm^3)	1.05	1.0	1.6	0.0012

[1] Muscle skeletal tissue [ICRU-46]

[2] Fur, approximate composition

[3] Typical silty soil [K. Eckerman and J. Ryman, Federal Guidance Report No. 12, 1993]

Monte Carlo method

The Monte Carlo calculations are made for monoenergetic photons and electrons for the energy range as specified in Table 3-2. Radionuclide-specific dose conversion coefficients are determined by interpolation, taking into account the nuclide-specific energies emitted and their emission probabilities.

The values of the absorbed dose rate normalized per starting photon and surface unit give a dose conversion coefficient which can be defined as:

$$C_{\mathrm{surf}}(z_{\mathrm{t}},z^{*},E_0)=\frac{\dot{D}(z_{\mathrm{t}},z^{*},E_0)}{j(z^{*},E_0)}=\frac{\dot{D}(z_{\mathrm{t}},z^{*},E_0)}{n(z^{*},E_0)}\times A_{\mathrm{surf}}=\mathsf{D}(z_{\mathrm{t}},z^{*},E_0)\times A_{\mathrm{surf}},$$

where:

$C_{\mathrm{surf}}(z_{\mathrm{t}},z^{*},E_0)$	dose rate conversion coefficient, (Gy s^{-1})/(photon s^{-1} m^{-2}) = Gy/(photon m^{-2});
z_{t}	depth where the organism (target) is located, m;
z^{*}	depth of the plane source, m;
E_0	energy of source photons, MeV;
$\dot{D}(\mathrm{z}_{\mathrm{t}},z^{*},E_0)$	absorbed dose rate in the target, Gy s^{-1};
$j(z^{*},E_0)$	flow rate of source photons, photon m^{-2} s^{-1};
$n(z^{*},E_0)$	number of source photons emitted per unit time, photon s^{-1};
A_{surf}	surface area of the source, m^2;
$\mathsf{D}(z_{\mathrm{t}},z^{*},E_0)$	absorbed dose normalized per starting photon, Gy.

Therefore, the dose rate conversion coefficient $C_{\mathrm{surf}}(z_{\mathrm{t}},z^{*},E_0)$ relates the activity distribution on a plane at a depth z^{*} and the dose absorbed rate on a specific organism placed at a depth z_{t}, for monoenergetic photon with the energy E_0. The absorbed dose rate is the product of the dose rate conversion coefficient and the source flow rate (the latter have to be derived from the activity concentration):

$$\dot{D}\left(z_{\mathrm{t}},z^{*},E_0\right)=C_{\mathrm{surf}}\left(z_{\mathrm{t}},z^{*},E_0\right)\times j(z^{*},E_0).$$

For monoenergetic photons emitted from planar source, the unit for the absorbed dose rate conversion coefficient is [Gy s^{-1} per photon s^{-1} m^{-2}] = [Gy m^{-2}].

The simulations of the photon transport were performed with the MCNP code in the mode with detailed interaction treatment. All relevant processes quantifying the radiation transport are taken into account as coherent and incoherent scattering, photoelectric absorption and production of fluorescent photons after photoeffect. As pointed out in the MCNP manual, the detailed photon physics treatment is especially appropriate for deep penetration problems. For electrons, a thick-target bremsstrahlung[1] model was used instead of an electron transport simulation.

Despite the availability of modern devices, Monte Carlo calculations are very time-consuming especially for the reference organisms that live on soil. Due to the long range of high energy photons in air, a large area around the organism has to be considered. Therefore a large contaminated area has to be taken into account as radiation source. However, especially small target get only relatively few hits from the photon emitted in the surrounding area, because the probability that a target is hit by a photon emitted decreases in proportion to the square of the distance source-target. The tracks of a very big number of photons have to be simulated to achieve results with an acceptable statistical error.

Therefore, a two-step method has been developed: In a first step, the KERMA (Kinetic Energy Released in Material) is calculated in air from different sources on or in soil. In a second step, the ratio of the dose in an organism and the dose in air is calculated for the different organisms and energies.

3.1.2 Internal exposure

The exposure due to radioactivity incorporated into an organism is determined by the activity concentration in the organism, the size of the organisms, the radionuclide distribution and the kind of radiation and the energy.

Geometries

In analogy as it was done for external exposure, dose conversion coefficients are defined as the ratio between of the the absorbed dose in the target (the whole body or some specific organ) and the mass activity concentration (in the contaminated tissues). For estimating internal exposures to biota, a set of cases were defined that allow the assessment of exposures to a wide range of possible species that are not explicitly considered by interpolation between size of the target and energy (Table 3-6).

Table 3-6 Energy and geometry specifications for calculations of internal exposures in animals.

Radiation type	Energy range (MeV)	Target size range (m)	Geometry
α	3–10	10^{-5}–10^{-3}	Spheres
β	0.005–4	10^{-5}–0.03	Ellipsoids
γ	0.02–3	0.01–1	Ellipsoids

Mathematical approach

The simplest case of an homogeneous distribution of the radionuclide in the reference organism is illustrated by:

$$C_{\text{int},t}(E_0) = \frac{\dot{D}_t(E_0)}{S_\text{m}(E_0)} = \frac{\dot{D}_t(E_0)}{n(E_0)} \times m_t = \mathsf{D}_t(E_0) \times m_t,$$

where:

[1] Takes into account the production of photons due to decellaration of electrons

$C_{\text{int},t}$ dose rate conversion coefficient for organism (target) *t*, (Gy s^{-1})/(photon s^{-1} kg) = Gy/(photon kg^{-1});

E_0 energy of source photons, MeV;

$\dot{D}_t(E_0)$ absorbed dose rate in the target *t*, Gy s^{-1};

$S_{\text{m}}(E_0)$ number of source photons emitted per unit mass per unit time, photon kg^{-1} s^{-1};

$n(E_0)$ number of source photons emitted per unit time, photon s^{-1};

m_t target mass, kg;

$\mathsf{D}_t(E_0)$ absorbed dose normalized per starting photon, Gy.

The absorbed dose rate due to internal exposure will be:

$$\dot{D}_t\left(E_0\right)=C_{\text{int},t}\left(E_0\right)\times S_{\text{m}}\left(E_0\right).$$

It is also possible to calculate the absorbed fraction of energy, $\Phi_t\left(E_0\right)$, defined as the fraction of energy emitted by the source that is absorbed by the organism (or in a specific target organ). In the case considered above, the absorbed fraction in the whole organism is:

$$\Phi_t\left(E_0\right)=\frac{E_{\text{absorbed},t}}{E_{\text{emitted},t}}=\frac{\mathsf{D}_t\left(E_0\right)\times m_t}{E_0}.$$

Therefore, both quantities are related:

$$C_{\text{int},t}\left(E_0\right)=\Phi_t\left(E_0\right)\times E_0.$$

3.2 Results

3.2.1 External exposure for organisms living in the soil

Figure 3-1 shows the DCC for several soil organisms in dependence of the photon energy. For its derivation, a volumetric 50 cm thick contaminated source has been assumed. It is assumed that the organisms live at a depth of 25 cm, so they are exposed by a 4π-geometry. The dose conversion coefficient increases in proportion with the photon energy. Whereas the dose conversion coefficient varies by a factor of 200 between the photon energies of 50 keV to 3 MeV, the variations of DCC for the organisms do not exceed a factor of 2 even for low energies. For high energy photons, the difference is only a factor of 1.5.

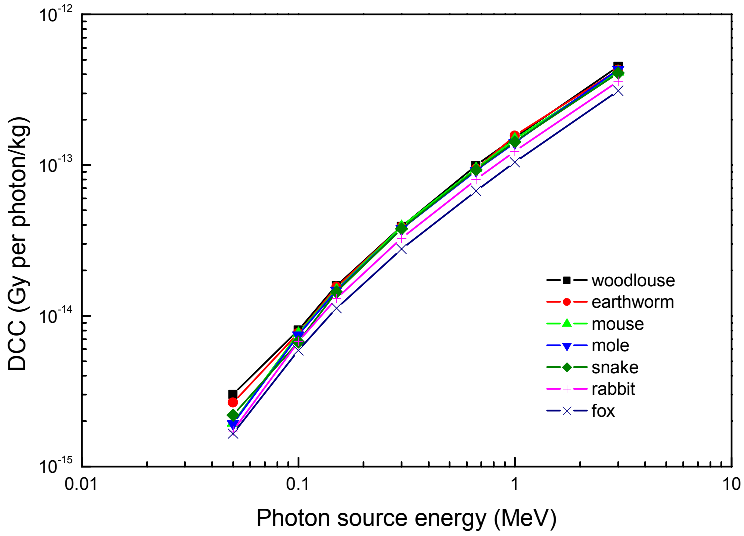


Figure 3-1 Dose conversion coefficients for various soil organisms at a depth of 25 cm in soil for monoenergetic photons for a uniformly contaminated source in the upper 50 cm of soil (soil density: 1600 kg/m³).

Figure 3-2 shows the dose conversion coefficient for an earthworm as function of soil depth and photon energy. The upper 50 cm of the soil are homogeneously contaminated. The highest DCC is for an organism at depth 25 cm, the lowest is derived for organisms on the interface of contaminated to uncontaminated layer (depth: 0 and 50 cm). At these locations, the DCC is a factor of 2 lower compared to the centre of the contaminated layer. The organisms are exposed to a 2π-geometry compared to a 4π-geometry.

The difference of the DCC at depth 25 cm to depths 5 cm is only about 20 %. The low difference is due to the relatively short mean free path of photons in soil. In Figure 3-3, the mean free path of photons is plotted for air, water, tissue and soil (ρ = 1.6 g/cm³) as function of the energy. The mean free path of 20-keV, 100-keV and 3-MeV photons is about 0.2, 2 and 10 cm. This means, an organism in soil is exposed from the photons in a shell of 10 cm thickness.

Detailed results for the DCCs for external exposure for in-soil reference organisms due to a mono-energetic isotropic volume source as a function of the energy of the source and the position of the organism are summarised in Table A-1 (Appendix). Numerical values of the dose conversion coefficients for in-soil reference organism and external exposure due to a monoenergetic isotropic planar sources as a function of the energy and depth of the source are summarised in Table A-2 (Appendix).

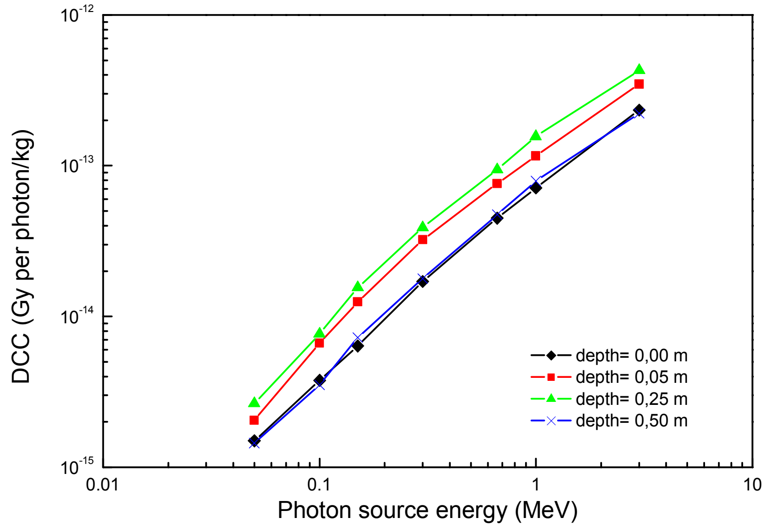


Figure 3-2 Dose conversion coefficients for an earthworm for various depths in soil for monoenergetic photons for a uniformly contaminated source in the upper 50 cm of soil (soil density of 1600 kg/m³).

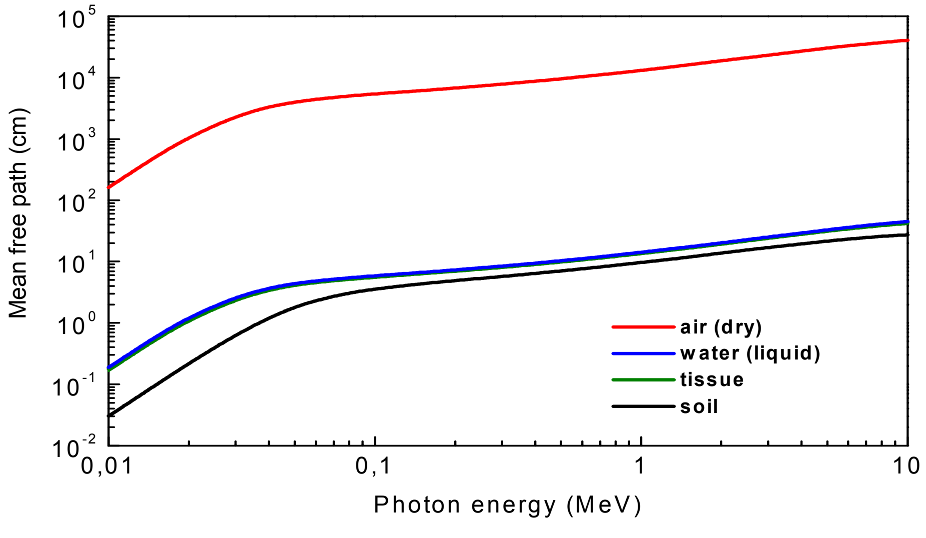


Figure 3-3 Mean free path of photons in air, water, tissue and soil.

3.2.2 External exposure for organisms living on soil

The external exposures per photon/m² for reference organisms living on soil are given in dependence on the photon source energy in Figure 3-4. Within the energy range from 10 keV to 3 MeV, the DCC decreases from 10 to 100 keV by a factor of about 5 for small animals and by a factor of 2 for big animals. In this energy range, the mean free path of photons is much shorter, and once an interaction with matter occurs, the energy is transferred more or less completely. Beyond 100 keV, the absorbed dose per photon increases by approximately 2 orders of magnitude. The exposure of smaller animals is higher than for big ones due to the more effective self-shielding of big organisms, such differences are more pronounced for low energies. The difference between mouse and cattle is a factor of about 6 for 50 keV photons, whereas it is a factor of 3 for 3 MeV photons. The DCC given in Figure 3-4 are for a zero source depth. This is an idealised case of a completely plane source, from which the photon are emitted.

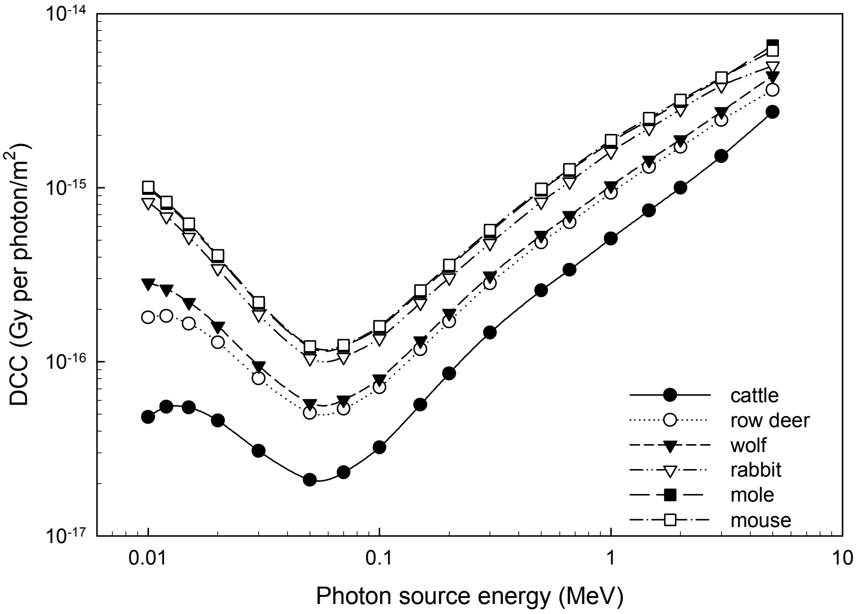
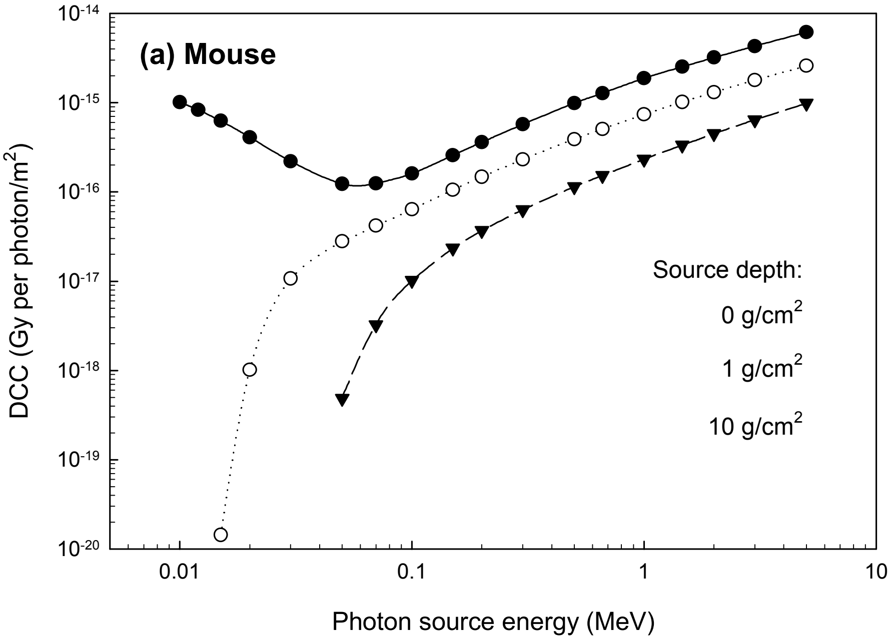


Figure 3-4 External dose per photon as function of the source energy and the reference organism for a planar source on top of the soil.

In Figure 3-5 the DCC are given for different depth of the source in soil. Under those conditions, the DCC for low-energy photons to animals living on soil are very low, since already small soil layers are sufficient to attenuate the photons completely.



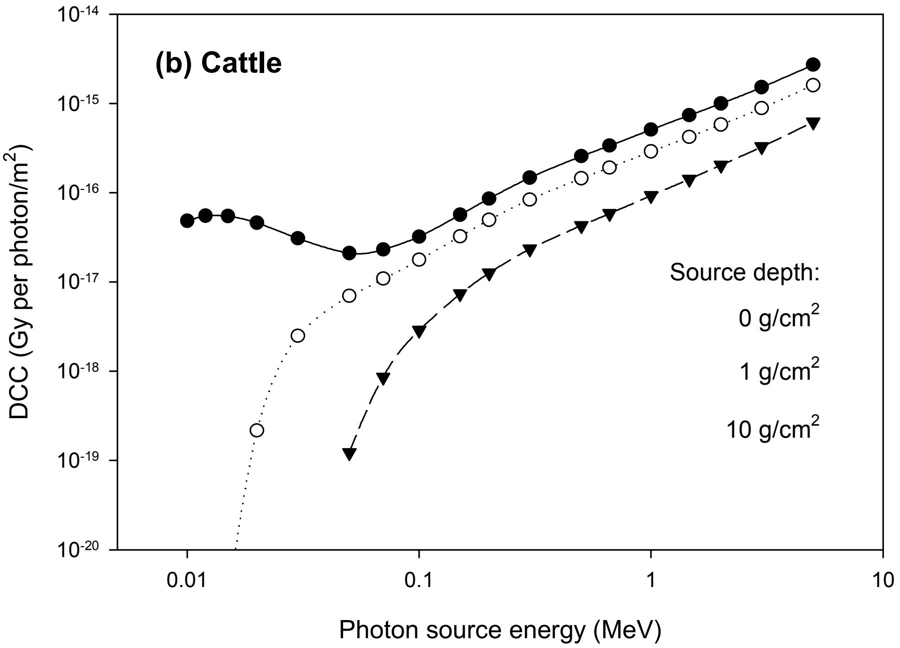


Figure 3-5 External dose per photon as function of the source energy and depth of the source in the soil for a mouse (a) and a cattle (b) living on the soil, the source depth quantifies by how much soil the photon source is covered (e.g. the source depth of 10 g/cm² for soil densities of 1.0 and 1.6 g/cm³ are equivalent to a depth of the source in the soil of 10 and 6.25 cm respectively).

Detailed numerical values of DCCs for monoenergetic photons for a planar source on top of the soil are given in Table A-3 for the reference organisms living on soil. Respective values are summarised for a planar source at a depth of 3 mm in Table A-4 and for a volume source at a depth of 10 cm are given in Table A-5 (Appendix).

3.2.3 Internal exposure

Monoenergetic α-radiation

For the calculations of absorbed fraction, the assumption has been made that the α-emitters are homogeneously distributed with the target. The range of α-particles in living tissue is very small, within the energy range from 3–10 MeV, the range increases from 16 to 130 µm. Therefore, with the exception of bacteria, it is assumed for all organisms that all energy absorbed is emitted. Since the dimensions of bacteria are well below the range of α-particles, the absorbed fraction is assumed to be zero.

Monoenergetic β-radiation

The absorbed fractions of electrons are summarised in Figure 3-6 in dependence on the initial electron energy for a number of organisms. The organisms considered cover a wide range of sizes. For electron energies below 100 keV, the absorbed fraction is nearly 1 even for very small organisms. The mean free path of electrons in living tissue increases from 160 µm for 100 keV electrons to 5 mm for 1 MeV electrons. The absorbed fraction is close to unity if the diameter of the target is well above the range of the electron. Only for very small targets and high energies, the absorbed fraction of electrons is considerably smaller than 0.5.

Monoenergetic γ-radiation

The absorbed fractions of photons are shown in Figure 3-7 in dependence on the initial photon energy for a number of organisms. The mean free path of photons is considerably longer than the range of electrons. Therefore, the absorbed fractions cover a wide range of several orders of magnitude from nearly 1 for low energy γ-radiation and large organisms to 0.001 for small organisms and high photon energies.

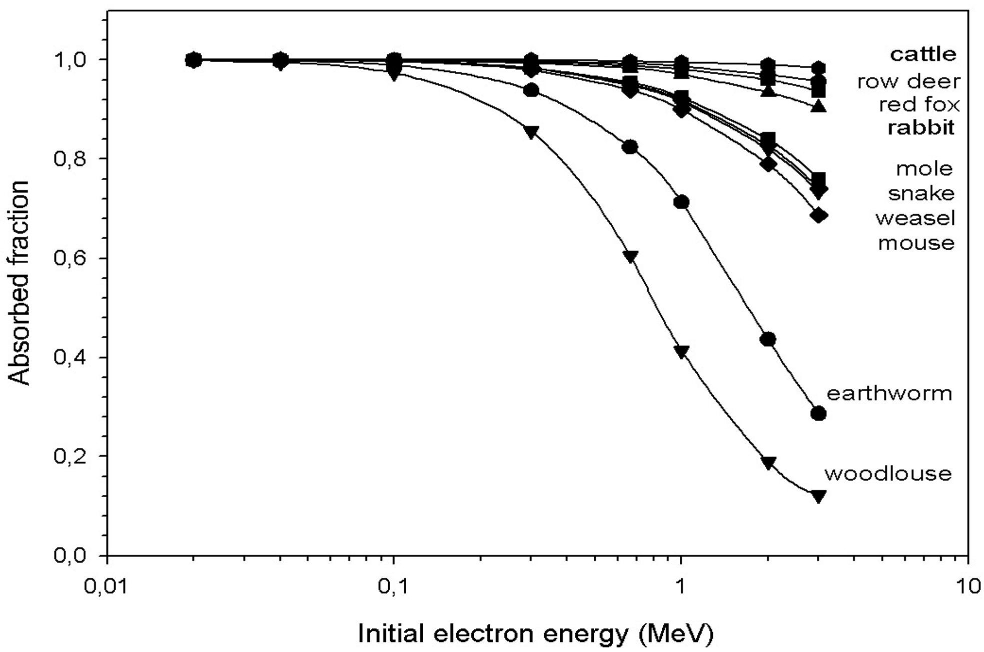


Figure 3-6 Absorbed fractions for electrons in dependence of initial electron energy and organism.

The absorption is a non-linear function of target size and energy. The main processes causing absorption of photon energy are the Compton effect, the photo effect and pair production; their contributions to absorption depends on the energy of the photon emitted. As a result, the absorbed fraction decreases in the energy range from 20 to 100 keV by a factor of 10–15 for small organisms, whereas it is relatively constant between 100 keV and 1 MeV. Beyond energies of 1 MeV, the decrease of the absorbed fractions with energy is steeper.

Detailed results for the absorbed fractions for photons and electrons are given in Table A-6 (Appendix).

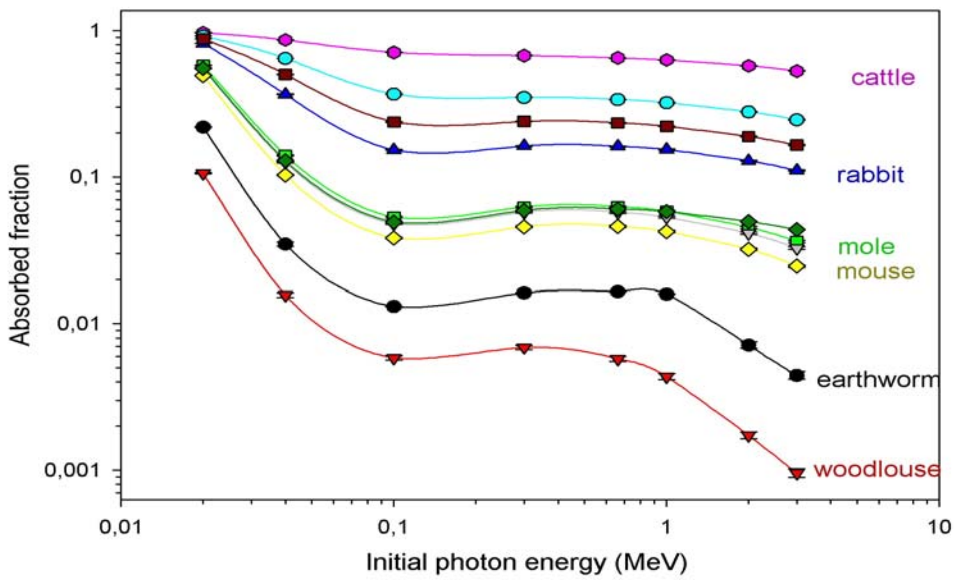


Figure 3-7 Absorbed fractions for electrons in dependence of initial electron energy and organism.

Figure 3-8 summarizes the dose conversion coefficients for photons for the soil organisms considered. The DCC increases in proportion to energy and to animal size.

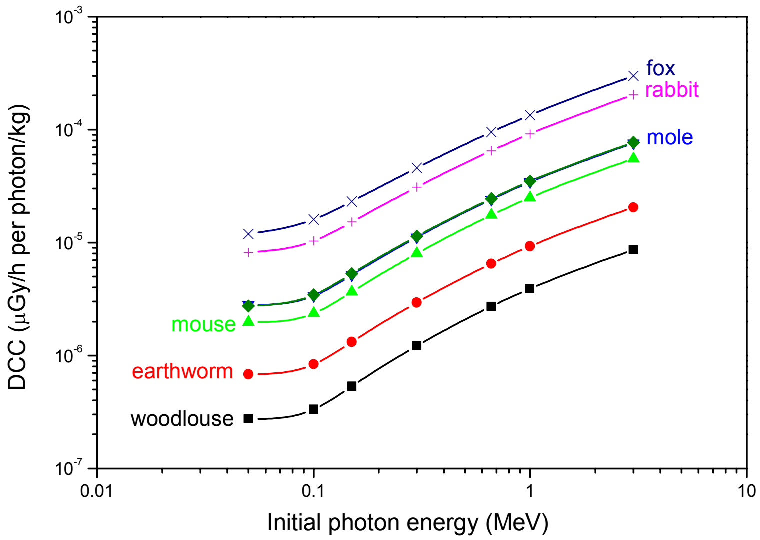


Figure 3-8 Dose conversion coefficient for monoenergetic photons for soil organisms as function of photon energy.

3.3 Radionuclide-dependent dose conversion coefficients

The dose conversion coefficients are calculated for mono-energetic electrons and photons. The figures indicate that the application of a linear interpolation scheme will provide results for intermediate source energies.

The dose conversion coefficient $C_{N,O,S}$ for the radionuclide *N*, the organism *O* and the exposure situation *S* is obtained from the energy-dependent $C_{E,O,S}$ by multiplication with the yields and summing of the energies of the emission spectrum of the radionuclide *N*:

$$C_{N,O,S} = \sum_j \sum_i y_{N,i} \times C_{E_i,O,S},$$

where *j* is the index for the radiation type (α-, β-, γ-radiation) and *i* is the index for the energy.

The radionuclide transformation data are taken from ICRP-38. Radioactive daughter nuclides are included in the calculation of the DCCs, if their half-lives are shorter than 10 days. The daughter nuclides included are summarised in Table 3-7.

Table 3-7 Daughter nuclides considered for the calculation of dose conversion coefficients.

Mother nuclide	Daughter nuclides considered to be in equilibrium with mother nuclide						
Sr-90	Y-90						
Ru-106	Rh-106						
Cs-137	Ba-137m						
Pb-210	Bi-210						
Ra-226	At-218	Po-218	Bi-214	Pb-214	Rn-222	Po-214	
Th-228	Po-216	Tl-208	Bi-212	Pb-212	Rn-220	Po-212	Ra-224
Th-234	Pa-234m	Pa-234					
U-235	Th-231						
Pu-241	U-237						

In the Table 3-8 to 3-12 the radionuclide-specific DCC are given for the following exposure situations:

- *External exposure for organisms on soil* (Table 3-8). The values are given for *a planar source for organisms that live on soil*. A surface roughness of 3 mm is assumed, this means, the radionuclides are effectively mixed in the upper 3 mm. The values are given in units of [μGy/h per Bq/m² soil].
- *External exposure for organisms on soil* (Table 3-9). The values are given for a homogeneously contaminated *volume source with a thickness of 10 cm* and a soil density of 1.6 g/cm³. The values are given in units of [μGy/h per Bq/m² soil].
- *External exposure for soil organisms* (Table 3-10). The values are given for organisms at a *depth of 25 cm* of *50 cm thick* homogeneously contaminated *soil layer* in units of [μGy/h per Bq/kg soil].

- *External exposure for critical organs of plants* (Table 3-11). The values are given for meristem of grass and for buds of a shrub and a tree. The values are given for a planar source with a surface roughness of 3 mm [µGy/h per Bq/m²] and volume source with a depth of 10 cm [µGy/h per Bq/kg soil].
- *Internal exposure of organisms* (Table 3-12). The values are given for *radionuclides that are homogeneously distributed* in the organism. The values are given in units of [µGy/h per Bq/kg].
- Weighted internal dose conversion coefficients are summarised in Table 3-13. As outlined in chapter 2.4, weighting factors of 10, 3, 1 and 1 are assumed for α-radiation, low-energy β-radiation (E<10 keV), β-radiation (E>10 keV) and γ-radiation respectively.

Radionuclide-specific DCCs for internal exposure for the contributions of the types of radiation are given in Table A-7 (α-radiation), A-8 (low-energy-β-radiation), A-9 (β-radiation) and A-10 (γ-radiation).

Table 3-8 Unweighted dose conversion coefficients for *external exposure* for organisms that live *on soil* for *a planar source* with a surface roughness of 3 mm.

Radio-nuclide	Unweighted external dose conversion coefficients (µGy/h per Bq/m²)													
	wood-louse	earth-worm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle	small egg	big egg	herbi-vorous bird	carni-vorous bird
H-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K-40	4.8E-7	4.8E-7	4.8E-7	4.7E-7	4.7E-7	4.6E-7	4.3E-7	4.1E-7	3.2E-7	1.5E-7	4.8E-7	4.8E-7	4.2E-7	3.0E-7
Cl-36	5.3E-10	5.3E-10	5.2E-10	5.2E-10	5.2E-10	5.0E-10	4.6E-10	4.3E-10	3.3E-10	1.3E-10	5.3E-10	5.2E-10	4.5E-10	3.2E-10
Ni-59	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ni-63	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sr-89	2.8E-10	2.8E-10	2.8E-10	2.8E-10	2.8E-10	2.7E-10	2.5E-10	2.3E-10	1.8E-10	7.5E-11	2.8E-10	2.8E-10	2.4E-10	1.7E-10
Sr-90	1.8E-12	1.8E-12	1.8E-12	1.7E-12	1.7E-12	1.7E-12	1.6E-12	1.4E-12	8.8E-13	1.6E-13	1.8E-12	1.8E-12	1.2E-12	4.3E-13
Nb-94	5.3E-6	5.3E-6	5.3E-6	5.2E-6	5.2E-6	5.0E-6	4.7E-6	4.4E-6	3.4E-6	1.4E-6	5.3E-6	5.3E-6	4.5E-6	3.2E-6
Tc-99	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ru-106	7.0E-7	7.0E-7	6.9E-7	6.9E-7	6.9E-7	6.6E-7	6.1E-7	5.7E-7	4.5E-7	1.8E-7	7.0E-7	6.9E-7	6.0E-7	4.2E-7
I-129	9.4E-8	9.4E-8	9.4E-8	9.3E-8	9.3E-8	9.0E-8	8.4E-8	7.6E-8	5.0E-8	1.0E-8	9.4E-8	9.4E-8	8.2E-8	5.2E-8
I-131	1.3E-6	1.3E-6	1.3E-6	1.3E-6	1.3E-6	1.2E-6	1.2E-6	1.1E-6	8.3E-7	3.2E-7	1.3E-6	1.3E-6	1.1E-6	8.0E-7
Cs-134	5.3E-6	5.3E-6	5.2E-6	5.2E-6	5.2E-6	5.0E-6	4.6E-6	4.3E-6	3.4E-6	1.4E-6	5.3E-6	5.2E-6	4.5E-6	3.2E-6
Cs-135	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cs-137	1.9E-6	1.9E-6	1.9E-6	1.9E-6	1.9E-6	1.8E-6	1.7E-6	1.6E-6	1.2E-6	5.0E-7	1.9E-6	1.9E-6	1.7E-6	1.2E-6
Po-210	2.9E-11	2.9E-11	2.8E-11	2.8E-11	2.8E-11	2.7E-11	2.5E-11	2.4E-11	1.8E-11	7.5E-12	2.9E-11	2.8E-11	2.4E-11	1.7E-11
Pb-210	7.1E-9	7.0E-9	7.0E-9	7.0E-9	7.0E-9	6.7E-9	6.3E-9	5.7E-9	3.8E-9	8.1E-10	7.0E-9	7.0E-9	6.1E-9	4.2E-9
Ra-226	5.6E-6	5.6E-6	5.6E-6	5.5E-6	5.5E-6	5.3E-6	5.0E-6	4.7E-6	3.7E-6	1.6E-6	5.6E-6	5.6E-6	4.8E-6	3.5E-6
Th-227	3.6E-7	3.6E-7	3.5E-7	3.5E-7	3.5E-7	3.3E-7	3.1E-7	2.9E-7	2.2E-7	7.5E-8	3.6E-7	3.5E-7	3.1E-7	2.2E-7
Th-228	4.6E-6	4.6E-6	4.6E-6	4.6E-6	4.6E-6	4.4E-6	4.2E-6	3.9E-6	3.1E-6	1.4E-6	4.6E-6	4.6E-6	4.0E-6	2.9E-6
Th-230	1.9E-9	1.9E-9	1.9E-9	1.9E-9	1.9E-9	1.8E-9	1.7E-9	1.6E-9	1.0E-9	2.4E-10	1.9E-9	1.9E-9	1.5E-9	9.4E-10
Th-231	5.7E-8	5.7E-8	5.7E-8	5.6E-8	5.6E-8	5.4E-8	5.0E-8	4.6E-8	3.1E-8	6.9E-9	5.7E-8	5.7E-8	4.8E-8	3.1E-8
Th-232	1.3E-9	1.3E-9	1.3E-9	1.3E-9	1.3E-9	1.3E-9	1.2E-9	1.1E-9	6.8E-10	1.4E-10	1.3E-9	1.3E-9	9.8E-10	5.3E-10
Th-234	8.4E-8	8.4E-8	8.3E-8	8.2E-8	8.2E-8	7.9E-8	7.4E-8	6.9E-8	5.2E-8	1.9E-8	8.4E-8	8.3E-8	7.3E-8	5.2E-8
U-234	2.0E-9	2.0E-9	1.9E-9	1.9E-9	1.9E-9	1.9E-9	1.7E-9	1.6E-9	1.0E-9	2.0E-10	2.0E-9	1.9E-9	1.4E-9	6.5E-10
U-235	5.6E-7	5.6E-7	5.5E-7	5.5E-7	5.5E-7	5.3E-7	4.9E-7	4.5E-7	3.2E-7	9.7E-8	5.6E-7	5.5E-7	4.8E-7	3.5E-7
U-238	1.4E-9	1.4E-9	1.4E-9	1.4E-9	1.4E-9	1.3E-9	1.2E-9	1.1E-9	7.1E-10	1.3E-10	1.4E-9	1.4E-9	9.7E-10	4.0E-10
Pu-238	2.3E-9	2.3E-9	2.3E-9	2.3E-9	2.3E-9	2.2E-9	2.1E-9	1.9E-9	1.2E-9	2.2E-10	2.3E-9	2.3E-9	1.6E-9	6.9E-10
Pu-239	1.1E-9	1.1E-9	1.1E-9	1.0E-9	1.0E-9	1.0E-9	9.3E-10	8.4E-10	5.5E-10	1.2E-10	1.1E-9	1.1E-9	7.7E-10	3.7E-10
Pu-240	2.3E-9	2.3E-9	2.2E-9	2.2E-9	2.2E-9	2.1E-9	2.0E-9	1.8E-9	1.1E-9	2.1E-10	2.2E-9	2.2E-9	1.6E-9	6.6E-10
Pu-241	1.7E-11	1.7E-11	1.7E-11	1.6E-11	1.6E-11	1.6E-11	1.5E-11	1.3E-11	9.4E-12	2.6E-12	1.7E-11	1.7E-11	1.4E-11	1.0E-11
Am-241	8.4E-8	8.4E-8	8.3E-8	8.3E-8	8.3E-8	8.0E-8	7.4E-8	6.7E-8	4.5E-8	9.9E-9	8.4E-8	8.3E-8	7.2E-8	5.1E-8
Np-237	9.1E-8	9.1E-8	9.1E-8	9.0E-8	9.0E-8	8.7E-8	8.1E-8	7.3E-8	5.0E-8	1.2E-8	9.1E-8	9.1E-8	7.9E-8	5.5E-8
Cm-242	2.8E-9	2.8E-9	2.8E-9	2.8E-9	2.8E-9	2.7E-9	2.5E-9	2.2E-9	1.4E-9	2.7E-10	2.8E-9	2.8E-9	2.0E-9	8.7E-10
Cm-243	4.2E-7	4.2E-7	4.2E-7	4.1E-7	4.1E-7	4.0E-7	3.7E-7	3.4E-7	2.5E-7	7.9E-8	4.2E-7	4.2E-7	3.6E-7	2.6E-7
Cm-244	2.6E-9	2.6E-9	2.5E-9	2.5E-9	2.5E-9	2.4E-9	2.3E-9	2.0E-9	1.3E-9	2.4E-10	2.6E-9	2.5E-9	1.8E-9	7.9E-10

Table 3-9 Unweighted dose conversion coefficients for *external exposure* of organisms that live *on soil* for a homogeneously contaminated *volume source*; the thickness of the contaminated soil layer is 10 cm, the soil density is 1.6 g/cm³.

Radio-nuclide	Unweighted external dose conversion coefficients (µGy/h per Bq/kg)													
	wood-louse	earth-worm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle	small egg	big egg	herbi-vorous bird	carni-vorous bird
H-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K-40	3.0E-5	3.0E-5	3.0E-5	3.0E-5	3.0E-5	2.9E-5	2.7E-5	2.6E-5	2.1E-5	9.4E-6	3.0E-5	3.0E-5	2.9E-5	2.3E-5
Cl-36	3.1E-8	3.1E-8	3.1E-8	3.1E-8	3.1E-8	3.0E-8	2.7E-8	2.6E-8	2.0E-8	8.1E-9	3.1E-8	3.1E-8	2.9E-8	2.3E-8
Ni-59	1.4E-7	1.3E-7	1.4E-7	1.3E-7	1.3E-7	1.3E-7	1.1E-7	8.6E-8	3.6E-9	8.7E-11	1.3E-7	1.4E-7	0	0
Ni-63	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sr-89	1.7E-8	1.7E-8	1.7E-8	1.7E-8	1.7E-8	1.6E-8	1.5E-8	1.4E-8	1.1E-8	4.7E-9	1.7E-8	1.7E-8	1.6E-8	1.3E-8
Sr-90	1.1E-10	1.1E-10	1.0E-10	1.0E-10	1.0E-10	9.9E-11	9.0E-11	8.0E-11	4.3E-11	7.5E-12	1.1E-10	1.0E-10	4.1E-11	1.0E-11
Nb-94	3.2E-4	3.2E-4	3.2E-4	3.2E-4	3.2E-4	3.0E-4	2.8E-4	2.7E-4	2.1E-4	8.7E-5	3.2E-4	3.2E-4	3.0E-4	2.4E-4
Tc-99	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ru-106	4.2E-5	4.2E-5	4.2E-5	4.1E-5	4.1E-5	4.0E-5	3.7E-5	3.4E-5	2.7E-5	1.1E-5	4.2E-5	4.2E-5	3.9E-5	3.1E-5
I-129	1.7E-6	1.7E-6	1.7E-6	1.7E-6	1.7E-6	1.6E-6	1.5E-6	1.3E-6	8.7E-7	1.7E-7	1.7E-6	1.7E-6	1.4E-6	8.8E-7
I-131	7.7E-5	7.7E-5	7.7E-5	7.6E-5	7.6E-5	7.3E-5	6.7E-5	6.3E-5	5.0E-5	1.9E-5	7.7E-5	7.7E-5	7.2E-5	5.7E-5
Cs-134	3.2E-4	3.2E-4	3.2E-4	3.1E-4	3.1E-4	3.0E-4	2.8E-4	2.6E-4	2.1E-4	8.5E-5	3.2E-4	3.2E-4	3.0E-4	2.4E-4
Cs-135	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cs-137	1.2E-4	1.2E-4	1.2E-4	1.1E-4	1.1E-4	1.1E-4	1.0E-4	9.5E-5	7.6E-5	3.1E-5	1.2E-4	1.2E-4	1.1E-4	8.6E-5
Po-210	1.7E-9	1.7E-9	1.7E-9	1.7E-9	1.7E-9	1.6E-9	1.5E-9	1.4E-9	1.1E-9	4.7E-10	1.7E-9	1.7E-9	1.6E-9	1.3E-9
Pb-210	3.5E-7	3.5E-7	3.4E-7	3.4E-7	3.4E-7	3.3E-7	3.0E-7	2.6E-7	1.5E-7	2.8E-8	3.5E-7	3.4E-7	1.8E-7	1.2E-7
Ra-226	3.4E-4	3.4E-4	3.4E-4	3.4E-4	3.4E-4	3.3E-4	3.1E-4	2.9E-4	2.3E-4	1.0E-4	3.4E-4	3.4E-4	3.2E-4	2.6E-4
Th-227	2.0E-5	2.0E-5	2.0E-5	1.9E-5	1.9E-5	1.9E-5	1.7E-5	1.6E-5	1.2E-5	4.3E-6	2.0E-5	2.0E-5	1.8E-5	1.4E-5
Th-228	2.9E-4	2.9E-4	2.9E-4	2.9E-4	2.9E-4	2.8E-4	2.6E-4	2.5E-4	2.0E-4	9.5E-5	2.9E-4	2.9E-4	2.7E-4	2.2E-4
Th-230	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.1E-7	9.5E-8	5.6E-8	1.2E-8	1.2E-7	1.2E-7	7.0E-8	4.2E-8
Th-231	2.4E-6	2.4E-6	2.4E-6	2.3E-6	2.3E-6	2.3E-6	2.1E-6	1.9E-6	1.2E-6	2.8E-7	2.4E-6	2.4E-6	1.8E-6	1.3E-6
Th-232	9.5E-8	9.5E-8	9.3E-8	9.2E-8	9.2E-8	8.9E-8	8.1E-8	7.2E-8	4.0E-8	7.7E-9	9.5E-8	9.3E-8	4.3E-8	2.1E-8
Th-234	4.7E-6	4.6E-6	4.6E-6	4.6E-6	4.6E-6	4.4E-6	4.1E-6	3.8E-6	2.9E-6	1.1E-6	4.6E-6	4.6E-6	4.3E-6	3.4E-6
U-234	1.2E-7	1.2E-7	1.1E-7	1.1E-7	1.1E-7	1.1E-7	9.9E-8	8.8E-8	4.8E-8	9.0E-9	1.2E-7	1.1E-7	5.0E-8	2.0E-8
U-235	3.0E-5	3.0E-5	3.0E-5	2.9E-5	2.9E-5	2.8E-5	2.6E-5	2.4E-5	1.8E-5	5.4E-6	3.0E-5	3.0E-5	2.7E-5	2.2E-5
U-238	8.7E-8	8.6E-8	8.5E-8	8.4E-8	8.3E-8	8.1E-8	7.3E-8	6.5E-8	3.5E-8	6.0E-9	8.6E-8	8.5E-8	3.2E-8	9.4E-9
Pu-238	1.2E-7	1.2E-7	1.1E-7	1.1E-7	1.1E-7	1.1E-7	9.8E-8	8.7E-8	4.8E-8	8.4E-9	1.1E-7	1.1E-7	4.7E-8	1.5E-8
Pu-239	5.2E-8	5.2E-8	5.1E-8	5.1E-8	5.1E-8	4.9E-8	4.5E-8	4.0E-8	2.3E-8	5.1E-9	5.2E-8	5.1E-8	2.6E-8	1.2E-8
Pu-240	1.1E-7	1.1E-7	1.1E-7	1.1E-7	1.1E-7	1.0E-7	9.4E-8	8.3E-8	4.6E-8	8.1E-9	1.1E-7	1.1E-7	4.5E-8	1.4E-8
Pu-241	8.2E-10	8.2E-10	8.2E-10	8.1E-10	8.1E-10	7.8E-10	7.2E-10	6.6E-10	4.6E-10	1.3E-10	8.2E-10	8.2E-10	7.3E-10	5.7E-10
Am-241	2.9E-6	2.9E-6	2.9E-6	2.9E-6	2.9E-6	2.8E-6	2.5E-6	2.3E-6	1.5E-6	3.3E-7	2.9E-6	2.9E-6	2.3E-6	1.7E-6
Np-237	3.9E-6	3.9E-6	3.9E-6	3.8E-6	3.8E-6	3.7E-6	3.4E-6	3.1E-6	2.1E-6	5.3E-7	3.9E-6	3.9E-6	3.3E-6	2.5E-6
Cm-242	1.2E-7	1.2E-7	1.1E-7	1.1E-7	1.1E-7	1.1E-7	9.9E-8	8.8E-8	4.9E-8	8.9E-9	1.2E-7	1.1E-7	5.2E-8	1.7E-8
Cm-243	2.3E-5	2.3E-5	2.2E-5	2.2E-5	2.2E-5	2.1E-5	2.0E-5	1.8E-5	1.4E-5	4.4E-6	2.3E-5	2.2E-5	2.1E-5	1.7E-5
Cm-244	1.1E-7	1.1E-7	1.0E-7	1.0E-7	1.0E-7	1.0E-7	9.1E-8	8.1E-8	4.5E-8	8.0E-9	1.1E-7	1.0E-7	4.7E-8	1.5E-8

Table 3-10 Unweighted dose conversion coefficients for *external exposure* of organisms that live *in soil* for a homogeneously *volume source*; the thickness of the contaminated soil layer is 50 cm, the soil density is 1.6 g/cm³, the organisms live at a depth of 25 cm.

Radio-	Unweighted external dose conversion coefficients (µGy/h per Bq/kg)						
nuclide	woodlouse	earthworm	mouse	mole	snake	rabbit	red fox
H-3	0	0	0	0	0	0	0
C-14	0	0	0	0	0	0	0
K-40	4.2E-5	4.3E-5	3.4E-5	3.4E-5	3.8E-5	2.6E-5	1.9E-5
Cl-36	3.8E-8	3.8E-8	3.1E-8	2.9E-8	3.2E-8	2.0E-8	1.4E-8
Ni-59	0	0	0	0	0	0	0
Ni-63	0	0	0	0	0	0	0
Sr-89	2.1E-8	2.4E-8	1.8E-8	1.7E-8	1.9E-8	1.3E-8	8.8E-9
Sr-90	4.5E-11	1.1E-11	0	0	0	0	0
Nb-94	4.0E-4	4.3E-4	3.4E-4	3.2E-4	3.6E-4	2.3E-4	1.6E-4
Tc-99	0	0	0	0	0	0	0
Ru-106	5.2E-5	5.2E-5	4.3E-5	4.0E-5	4.5E-5	2.9E-5	1.9E-5
I-129	2.3E-6	1.9E-6	5.5E-7	4.6E-7	1.0E-6	7.3E-8	3.5E-8
I-131	9.0E-5	8.8E-5	7.3E-5	6.9E-5	7.6E-5	4.7E-5	3.1E-5
Cs-134	4.0E-4	4.1E-4	3.3E-4	3.1E-4	3.5E-4	2.2E-4	1.5E-4
Cs-135	0	0	0	0	0	0	0
Cs-137	1.5E-4	1.5E-4	1.2E-4	1.1E-4	1.2E-4	7.9E-5	5.3E-5
Po-210	2.2E-9	2.3E-9	1.8E-9	1.7E-9	1.9E-9	1.3E-9	8.6E-10
Pb-210	2.3E-7	1.9E-7	1.1E-7	1.1E-7	1.3E-7	5.7E-8	3.5E-8
Ra-226	4.6E-4	4.6E-4	3.7E-4	3.6E-4	4.0E-4	2.7E-4	1.9E-4
Th-227	2.1E-5	2.1E-5	1.7E-5	1.6E-5	1.7E-5	1.1E-5	6.8E-6
Th-228	4.2E-4	4.0E-4	3.3E-4	3.3E-4	3.6E-4	2.5E-4	1.8E-4
Th-230	7.4E-8	5.5E-8	3.8E-8	3.6E-8	4.0E-8	2.4E-8	1.5E-8
Th-231	2.0E-6	1.7E-6	1.1E-6	1.0E-6	1.1E-6	6.7E-7	4.4E-7
Th-232	4.3E-8	2.6E-8	1.6E-8	1.5E-8	1.7E-8	9.9E-9	6.4E-9
Th-234	5.5E-6	5.8E-6	4.5E-6	4.3E-6	4.7E-6	3.1E-6	2.1E-6
U-234	5.2E-8	2.9E-8	1.1E-8	1.0E-8	1.2E-8	6.7E-9	4.4E-9
U-235	2.9E-5	2.9E-5	2.3E-5	2.2E-5	2.4E-5	1.4E-5	9.4E-6
U-238	3.3E-8	1.5E-8	2.3E-9	2.1E-9	2.5E-9	1.2E-9	7.4E-10
Pu-238	5.3E-8	2.7E-8	2.0E-9	1.9E-9	2.2E-9	1.1E-9	7.3E-10
Pu-239	3.0E-8	2.0E-8	8.6E-9	8.1E-9	8.9E-9	5.4E-9	3.5E-9
Pu-240	5.1E-8	2.6E-8	2.1E-9	2.0E-9	2.3E-9	1.2E-9	7.4E-10
Pu-241	7.9E-10	7.4E-10	5.7E-10	5.4E-10	5.7E-10	3.6E-10	2.3E-10
Am-241	3.1E-6	2.6E-6	1.7E-6	1.6E-6	1.8E-6	9.6E-7	6.2E-7
Np-237	3.7E-6	3.3E-6	2.3E-6	2.2E-6	2.4E-6	1.4E-6	9.4E-7
Cm-242	6.5E-8	3.5E-8	1.8E-9	1.7E-9	3.1E-9	1.0E-9	6.5E-10
Cm-243	2.3E-5	2.2E-5	1.8E-5	1.7E-5	1.8E-5	1.1E-5	7.3E-6
Cm-244	5.8E-8	3.1E-8	6.0E-10	5.5E-10	1.8E-9	2.7E-10	1.6E-10

Table 3-11 ***External exposure for critical organs of plants.*** **The values are given for meristem of grass and for buds of a shrub and a tree for a planar source with a surface roughness of 3 mm and volume source with a depth of 10 cm.**

Radio-nuclide	Dose conversion coefficient					
	planar source, depth = 3mm (µGy/h per Bq/m²)			volume source, depth = 10 cm, (µGy/h per Bq/kg)		
	herb	shrub	tree	herb	shrub	tree
H-3	0	0	0	0	0	0
C-14	0	0	0	0	0	0
K-40	4.5E-7	4.0E-7	3.0E-7	2.9E-5	2.7E-5	2.4E-5
Cl-36	5.0E-10	4.4E-10	3.2E-10	3.0E-8	2.9E-8	2.4E-8
Ni-59	0	0	0	3.6E-8	0	0
Ni-63	0	0	0	0	0	0
Sr-89	2.7E-10	2.4E-10	1.7E-10	1.7E-8	1.6E-8	1.3E-8
Sr-90	3.8E-12	2.1E-12	3.6E-14	1.1E-10	4.6E-11	2.5E-14
Nb-94	5.0E-6	4.4E-6	3.2E-6	3.1E-4	2.9E-4	2.5E-4
Tc-99	0	0	0	0	0	0
Ru-106	6.6E-7	5.8E-7	4.2E-7	4.1E-5	3.9E-5	3.3E-5
I-129	9.6E-8	8.0E-8	4.9E-8	2.1E-6	1.7E-6	1.1E-6
I-131	1.3E-6	1.1E-6	8.2E-7	7.6E-5	7.2E-5	6.1E-5
Cs-134	5.0E-6	4.4E-6	3.2E-6	3.1E-4	2.9E-4	2.5E-4
Cs-135	0	0	0	0	0	0
Cs-137	1.8E-6	1.6E-6	1.2E-6	1.1E-4	1.1E-4	9.0E-5
Po-210	2.7E-11	2.4E-11	1.7E-11	1.7E-9	1.6E-9	1.4E-9
Pb-210	1.1E-8	7.5E-9	4.6E-9	3.6E-7	2.0E-7	1.4E-7
Ra-226	5.3E-6	4.7E-6	3.5E-6	3.3E-4	3.2E-4	2.7E-4
Th-227	3.6E-7	3.1E-7	2.3E-7	2.0E-5	1.9E-5	1.6E-5
Th-228	4.4E-6	3.9E-6	2.9E-6	2.8E-4	2.7E-4	2.3E-4
Th-230	3.5E-9	2.1E-9	8.7E-10	1.3E-7	7.4E-8	4.4E-8
Th-231	7.2E-8	5.4E-8	3.0E-8	2.6E-6	2.0E-6	1.4E-6
Th-232	2.8E-9	1.5E-9	4.4E-10	9.6E-8	4.5E-8	1.9E-8
Th-234	8.5E-8	7.4E-8	5.3E-8	4.7E-6	4.3E-6	3.7E-6
U-234	3.7E-9	2.1E-9	3.8E-10	1.2E-7	5.4E-8	1.5E-8
U-235	5.8E-7	5.0E-7	3.6E-7	3.1E-5	2.8E-5	2.4E-5
U-238	2.9E-9	1.5E-9	1.7E-10	8.9E-8	3.5E-8	4.0E-9
Pu-238	4.1E-9	2.4E-9	2.4E-10	1.2E-7	5.3E-8	5.5E-9
Pu-239	1.7E-9	1.1E-9	2.1E-10	5.5E-8	2.9E-8	9.5E-9
Pu-240	3.9E-9	2.3E-9	2.4E-10	1.2E-7	5.1E-8	5.5E-9
Pu-241	1.8E-11	1.5E-11	1.1E-11	8.7E-10	7.7E-10	6.3E-10
Am-241	1.1E-7	8.5E-8	5.3E-8	3.4E-6	2.8E-6	2.1E-6
Np-237	1.0E-7	8.5E-8	5.5E-8	4.3E-6	3.6E-6	2.8E-6
Cm-242	4.4E-9	2.7E-9	4.7E-10	1.3E-7	6.0E-8	8.1E-9
Cm-243	4.3E-7	3.7E-7	2.7E-7	2.3E-5	2.1E-5	1.8E-5
Cm-244	4.1E-9	2.5E-9	4.2E-10	1.2E-7	5.4E-8	6.4E-9

Table 3-12 *Unweighted* dose conversion coefficients for *internal exposure*, the activity is homogeneously distributed in the organisms. They are the sum of the contributions of α-, low-β, β- and γ-radiation.

Radio-nuclide	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg)									
	wood-louse	earth-worm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H-3	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
C-14	2.8E-5	2.8E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5
K-40	2.0E-4	2.6E-4	2.9E-4	2.9E-4	2.9E-4	2.9E-4	3.1E-4	3.2E-4	3.3E-4	3.6E-4
Cl-36	1.4E-4	1.5E-4	1.5E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4
Ni-59	2.9E-6	3.1E-6	3.7E-6	3.8E-6	3.8E-6	3.8E-6	4.0E-6	4.0E-6	4.0E-6	4.0E-6
Ni-63	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6
Sr-89	2.2E-4	2.9E-4	3.2E-4	3.2E-4	3.2E-4	3.2E-4	3.3E-4	3.3E-4	3.3E-4	3.4E-4
Sr-90	3.5E-4	5.1E-4	6.0E-4	6.1E-4	6.1E-4	6.1E-4	6.4E-4	6.4E-4	6.5E-4	6.5E-4
Nb-94	9.5E-5	1.1E-4	1.4E-4	1.5E-4	1.5E-4	1.5E-4	2.4E-4	3.0E-4	4.0E-4	6.8E-4
Tc-99	5.7E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5
Ru-106	2.6E-4	4.9E-4	7.1E-4	7.4E-4	7.2E-4	7.3E-4	8.0E-4	8.3E-4	8.4E-4	8.9E-4
I-129	3.7E-5	3.8E-5	4.1E-5	4.2E-5	4.1E-5	4.1E-5	4.5E-5	4.6E-5	4.8E-5	5.0E-5
I-131	1.0E-4	1.1E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.5E-4	1.6E-4	1.9E-4	2.6E-4
Cs-134	9.0E-5	1.1E-4	1.3E-4	1.5E-4	1.4E-4	1.5E-4	2.4E-4	3.0E-4	3.9E-4	6.8E-4
Cs-135	3.8E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5
Cs-137	1.2E-4	1.4E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	2.0E-4	2.2E-4	2.5E-4	3.6E-4
Po-210	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3
Pb-210	2.0E-4	2.3E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.5E-4	2.5E-4	2.5E-4	2.5E-4
Ra-226	1.4E-2	1.4E-2	1.4E-2	1.4E-2	1.4E-2	1.4E-2	1.5E-2	1.5E-2	1.5E-2	1.5E-2
Th-227	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.5E-3	3.5E-3
Th-228	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2
Th-230	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
Th-231	9.5E-5	9.7E-5	1.0E-4	1.0E-4	1.0E-4	1.0E-4	1.0E-4	1.0E-4	1.1E-4	1.1E-4
Th-232	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3
Th-234	2.8E-4	4.0E-4	4.7E-4	4.8E-4	4.8E-4	4.8E-4	5.0E-4	5.1E-4	5.1E-4	5.2E-4
U-234	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3
U-235	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
U-238	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3	2.4E-3
Pu-238	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
Pu-239	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
Pu-240	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
Pu-241	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6
Am-241	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
Np-237	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3
Cm-242	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3
Cm-243	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.5E-3	3.5E-3
Cm-244	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3

Table 3-13 *Weighted* dose conversion coefficients for internal exposure. They are the weighted sum of the contributions of α-, low-β, β- and γ-radiation.

Radio-	Weighted internal dose conversion coefficients (µGy/h per Bq/kg) Weighting factors: α = 10, low-energy β (E < 10kev) = 3, β (E≥ 10 keV) = 1, γ = 1									
nuclide	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H-3	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6
C-14	2.8E-5	2.8E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5
K-40	2.0E-4	2.6E-4	2.9E-4	2.9E-4	2.9E-4	2.9E-4	3.1E-4	3.2E-4	3.3E-4	3.6E-4
Cl-36	1.4E-4	1.5E-4	1.5E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4
Ni-59	8.1E-6	8.3E-6	8.9E-6	9.1E-6	9.0E-6	9.0E-6	9.3E-6	9.3E-6	9.3E-6	9.3E-6
Ni-63	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6
Sr-89	2.2E-4	2.9E-4	3.2E-4	3.2E-4	3.2E-4	3.2E-4	3.3E-4	3.3E-4	3.3E-4	3.4E-4
Sr-90	3.5E-4	5.1E-4	6.0E-4	6.1E-4	6.1E-4	6.1E-4	6.4E-4	6.4E-4	6.5E-4	6.5E-4
Nb-94	9.5E-5	1.1E-4	1.4E-4	1.5E-4	1.5E-4	1.5E-4	2.4E-4	3.0E-4	4.0E-4	6.8E-4
Tc-99	5.7E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5
Ru-106	2.6E-4	4.9E-4	7.1E-4	7.4E-4	7.2E-4	7.3E-4	8.0E-4	8.3E-4	8.4E-4	8.9E-4
I-129	4.6E-5	4.7E-5	5.0E-5	5.1E-5	5.0E-5	5.0E-5	5.4E-5	5.5E-5	5.7E-5	5.9E-5
I-131	1.0E-4	1.1E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.5E-4	1.6E-4	1.9E-4	2.6E-4
Cs-134	9.0E-5	1.1E-4	1.3E-4	1.5E-4	1.4E-4	1.5E-4	2.4E-4	3.0E-4	3.9E-4	6.8E-4
Cs-135	3.8E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5
Cs-137	1.2E-4	1.4E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	2.0E-4	2.2E-4	2.5E-4	3.6E-4
Po-210	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2	3.1E-2
Pb-210	2.1E-4	2.4E-4	2.5E-4	2.5E-4	2.5E-4	2.5E-4	2.5E-4	2.6E-4	2.6E-4	2.6E-4
Ra-226	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1	1.4E-1
Th-227	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2
Th-228	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.9E-1
Th-230	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2
Th-231	1.1E-4	1.1E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.3E-4
Th-232	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2	2.3E-2
Th-234	2.8E-4	4.0E-4	4.7E-4	4.8E-4	4.8E-4	4.8E-4	5.0E-4	5.1E-4	5.1E-4	5.2E-4
U-234	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2	2.7E-2
U-235	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2	2.6E-2
U-238	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2	2.4E-2
Pu-238	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2
Pu-239	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2
Pu-240	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2	3.0E-2
Pu-241	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6	9.8E-6
Am-241	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2	3.2E-2
Np-237	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2	2.8E-2
Cm-242	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2	3.5E-2
Cm-243	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2	3.4E-2
Cm-244	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2	3.3E-2

4. Dose conversion coefficients for aquatic biota

4.1 Physical assumptions

Analytical calculations to dose conversion coefficients for aquatic biota derive were based on the semi-empirical theory by Berger on absorption of photons and electrons [Berger, 1968; 1971], involving the deduction of simple mathematical functions for energy deposition in water by photons and electrons from point isotropic sources, in terms of the "point isotropic specific absorbed fractions".

Absorbed dose fractions were calculated for each individual ellipsoid using a Monte Carlo calculation, based on Berger's point specific absorbed fractions, that was repeated for different energies ranging 0.005–1.5 MeV for electrons and 0.015–3 MeV for photons to yield the fraction of energy absorbed within each ellipsoid. The following assumptions were made in the Monte Carlo calculations:

- Organisms are represented as ellipsoids. The dimensions of the abstracted ellipsoid representations for all the reference organisms are given in Table 4-1.
- Density differences between the organism and the surrounding media are ignored.
- Radionuclides are distributed uniformly through all tissues of the animal or plant.
- Resulting absorbed doses, both internal and external, are calculated as an average throughout the volume of the organism. This makes most difference in the case of radionuclides in which the external β-component predominates over the γ component, and (progressively) as the organism becomes larger.
- In calculating the external DCC, it is assumed that the organism is immersed in an infinite absorbing medium with the stated concentration.

Table 4-1 Dimensions of reference organisms.

Ecosystem	Organism	Mass (kg)	Length (cm)	Width (cm)	Depth (cm)	Volume (m^3)	Area (m^2)	Area/Vol. (m^{-1})
Marine	Benthic bacteria	3.9E–16	2.0 E–4	5.0 E–5	5.0 E–5	2.6E–19	2.5E–12	9.7E+6
	Pelagic phytoplankton	6.5E–11	5.0E–3	5.0E–3	5.0E–3	6.5E–14	7.9E–9	1.2E+5
	Pelagic zooplankton	1.6E–5	6.2E–1	3.1E–1	6.1E–1	6.1E–8	8.2E–5	1.3E+3
	Benthic mollusc	1.6E–2	5.0E+0	2.5 E+0	2.5E+0	1.6E–5	3.4E–3	2.1E+2
	Benthic worm	2.4E–1	2.3E+1	1.2 E+0	1.2 E+0	1.7E–5	6.8E–3	3.9E+2
	Vascular plant	1.5E–2	2.0E+1	5.0 E+0	5.0 E+0	2.6E–4	2.5E–2	9.7E+1
	Pelagic fish	5.0E–1	3.0E+1	6.0 E+0	6.0 E+0	5.7E–4	4.5E–2	8.0E+1
	Marine bird	6.0E–1	1.5E+1	1.1E+1	7.6 E+0	6.6E–4	3.9E–2	5.9E+1
	Benthic macroalgae cluster	8.2E–1	2.5E+1	2.5E+1	2.5 E+0	8.2E–4	9.4E–2	1.1E+2
	Benthic fish	1.3 E+0	4.0E+1	2.0E+1	3.0 E+0	1.3E–3	1.2E–1	9.3E+1
	Benthic crustacean	1.5 E+0	3.0E+1	1.0E+1	1.0E+1	1.6E–3	7.7E–2	4.9E+1
	Marine mammal	1.8E+2	1.8E+2	4.4E+1	4.4E+1	1.8E–1	2.0 E+0	1.1E+1
Freshwater	Phytoplankton	0.0 E+0	8.0E–3	7.0E–4	7.0E–4	2.1E–15	1.4E–9	6.8E+5
	Zooplankton	0.0 E+0	2.0E–1	1.4E–1	1.6E–1	2.3E–9	8.7E–6	3.7E+3
	Crustacean	0.0 E+0	1.0 E+0	3.0E–1	1.0E–1	1.6E–8	5.0E–5	3.2E+3
	Insect larvae	0.0 E+0	1.5 E+0	1.5E–1	1.5E–1	1.8E–8	5.6E–5	3.2E+3
	Vascular plant	0.0 E+0	1.0E+2	1.0E–1	2.0E–2	1.0E–7	1.5E–3	1.4E+4
	Gastropod	0.0 E+0	3.0 E+0	1.5 E+0	1.5E+0	3.5E–6	1.2E–3	3.4E+2
	Amphibian	0.0 E+0	7.0 E+0	3.0 E+0	2.0 E+0	2.2E–5	4.5E–3	2.1E+2
	Bivalve mollusc	0.0 E+0	1.0E+1	4.5 E+0	3.0 E+0	7.1E–5	9.7E–3	1.4E+2
	Pelagic fish	3.5E–1	3.0E+1	6.0 E+0	3.5 E+0	3.3E–4	3.6E–2	1.1E+2
	Benthic fish	1.5 E+0	5.0E+1	8.0 E+0	7.0 E+0	1.5E–3	9.3E–2	6.4E+1
	Mammal	1.3 E+0	3.3E+1	1.5E+1	1.5E+1	3.9E–3	1.3E–1	3.4E+1
	Bird	0.0 E+0	4.0E+1	2.0E+1	1.8E+1	7.5E–3	2.0E–1	2.7E+1

4.2 Energy absorbed fraction functions

Energy absorbed fraction functions (EAFF's) where then fitted separately for photons and electrons, the key issue being to avoid using unstable polynomial fittings. The β EAFF is of the form $AF_\beta = 1/(1+aE^n)$, where *a* and *n* are fitting constants. The γ EAFF is of the form $AF_\gamma = \exp[-(E/2\sigma)^n] \times a \exp[-\lambda E^m]$, where a, m, n, λ and σ are fitting constants. Fitting constants were optimised using a non-linear least squares fit to the Monte Carlo calculated data, implemented through the Microsoft Excel solver model. For α radiation it is considered that the absorbed fraction is 1 for all organisms with sizeable dimensions and 0 for bacteria.

The EAFF's thus produced were used, in combination with radionuclide decay data, in order to produce the absorbed fractions for the different radionuclides. This task, which was carried out on an Excel spreadsheet, required preliminary tabulation of all the decay energies and branching ratios for each radionuclide. A simple macro was used to calculate, for each radionuclide, the EAFF's for all the decay modes, then summing (categorised into low-energy β, $\beta+\gamma$ and α) to produce both internal and external DCC's.

A number of radionuclides (^{90}Sr, ^{95}Zr, ^{106}Ru, ^{131}I, ^{144}Ce, ^{210}Pb, ^{226}Ra, ^{227}Th, ^{228}Th, ^{234}Th, ^{235}U, ^{237}Np, ^{238}U, ^{238}Pu and ^{241}Pu) have one or more radioactive decay products. The dose from some of these is included by specifically merging the decay modes and branching ratios, if the half-life of the relevant daughters was found to be very small compared with that of the parent, meaning that they should rapidly reach secular equilibrium. Table 4-2 details what radionuclides were merged with their progeny, in whole or in part.

Table 4-2 Details of radionuclides that were merged with their progeny, in whole or in part.

Radionuclide	Observations
^{90}Sr	^{90}Sr including ^{90}Y in equilibrium
^{95}Zr	^{95}Zr including ^{95m}Nb (but not ^{95}Nb) in equilibrium
^{106}Ru	^{106}Ru including ^{106}Rh in equilibrium
^{131}I	^{131}I including ^{131m}Xe in equilibrium
^{144}Ce	^{144}Ce including ^{144m}Pr and ^{144}Pr in equilibrium
^{210}Pb	^{210}Pb including ^{210}Bi in equilibrium but not ^{210}Po
^{226}Ra	^{226}Ra including all daughter products.
^{227}Th	^{227}Th in equilibrium with ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, etc.
^{228}Th	^{228}Th in equilibrium with ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, etc.
^{234}Th	^{234}Th including ^{234m}Pa and ^{234}Pa in equilibrium
^{235}U	^{235}U with ^{231}Th daughter
^{237}Np	^{237}Np with ^{233}Pa
^{238}U	^{238}U including ^{234}Th, ^{234m}Pa, ^{234}Pa and ^{234}U in equilibrium
^{238}Pu	^{238}Pu
^{241}Pu	^{241}Pu including ^{237}Pu in equilibrium

Note: Some radionuclides undergo spontaneous fission. The dose from the fission fragments or their decay products was not included.

4.3 Results

Calculated absorbed fraction functions for β and γ radiation of the form $AF_\beta = 1/(1+aE^n)$ and $AF_\gamma = \exp[-(E/2\sigma)^n] \times a \exp[-\lambda E^m]$, represented by the fitting constants a, m, n, λ and σ, are given in Tables 4-3 (marine ecosystem) and 4-4 (freshwater ecosystem).

Table 4-3 Calculated absorbed fraction functions for β and γ radiation—marine ecosystem.

Phyto-plankton	Zoo-plankton	Mollusc	Worm	Vascular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crusta-cean	Mammal
Coefficients for $AF_\beta = 1/(1+aE^n)$										
5.9E+2	2.1E+0	2.0E-1	4.2E-1	8.7E-2	7.4E-2	4.8E-2	8.5E-2	7.4E-2	4.2E-2	9.2E-3
1.9E+0	1.5E+0	1.6E+0	1.5E+0	1.4E+0	1.6E+0	1.5E+0	1.5E+0	1.5E+0	1.5E+0	1.3E+0
Coefficients for $AF_\gamma = \exp[-(E/2\sigma)^n] \times a \exp[-\lambda E^m]$										
5.0E-4	9.6E-3	2.0E-2	1.5E-2	2.3E-2	2.3E-2	2.6E-2	2.2E-2	2.2E-2	2.3E-2	1.6E-2
5.2E-1	1.2E+0	1.7E+0	1.4E+0	1.5E+0	1.4E+0	1.5E+0	1.5E+0	1.3E+0	1.2E+0	8.2E-1
5.8E-5	1.4E+0	2.9E+0	2.6E-2	1.1E-1	1.4E-1	2.2E-1	1.7E-1	1.8E-1	2.7E-1	6.1E-1
7.4E-2	5.7E+0	4.6E+0	3.1E-1	4.6E-1	4.6E-1	7.5E-1	8.1E-1	7.7E-1	7.5E-1	2.6E-1
1.6E+0	1.8E-2	3.1E-2	6.4E-1	4.7E-1	4.7E-1	2.5E-1	2.2E-1	2.3E-1	2.8E-1	8.0E-1

Table 4-4 Calculated absorbed fraction functions for β and γ radiation—freshwater ecosystem.

Phyto-plankton	Zooplankton	Crus-tacean	Insect larvae	Vascularplant	Gastro-pod	Amphi-bian	Bivalve mollusc	Pelagic fish	Benthic fish	Mammal	Bird
Coefficients for $AF_\beta = 1/(1+aE^n)$											
3.8E+3	7.9E+0	4.6E+0	5.9E+0	2.5E+1	3.6E-1	1.9E-1	1.2E-1	9.1E-2	5.7E-2	2.8E-2	2.3E-2
1.9E+0	1.7E+0	1.5E+0	1.6E+0	1.6E+0	1.6E+0	1.6E+0	1.6E+0	1.5E+0	1.6E+0	1.5E+0	1.5E+0
Coefficients for $AF_\gamma = \exp[-(E/2\sigma)^n] \times a \exp[-\lambda E^m]$											
7.8E-3	5.5E-3	6.3E-3	6.2E-3	2.4E-3	1.7E-2	2.0E-2	2.2E-2	2.2E-2	2.2E-2	2.4E-2	2.0E-2
3.1E+0	9.5E-1	9.8E-1	9.8E-1	7.1E-1	1.6E+0	1.7E+0	1.6E+0	1.4E+0	1.2E+0	1.1E+0	9.2E-1
2.8E-5	4.5E-1	2.8E-3	2.9E-1	5.1E-4	1.9E+0	9.7E-2	7.2E-2	1.0E-1	2.2E-1	3.8E-1	5.4E-1
1.0E+0	5.6E+0	1.7E-1	4.9E+	5.2E-1	4.6E+0	1.1E+0	4.0E-1	4.4E-1	7.1E-1	7.5E-1	9.0E-1
1.6E-1	1.5E-2	9.1E-1	2.0E-2	5.7E-1	2.7E-2	1.4E-1	4.9E-1	4.7E-1	2.9E-1	2.7E-1	2.3E-1

The final product of using the above absorbed fraction functions to calculate DCC's for different radionuclides is a comprehensive set of dose coefficients reported for both internal and external irradiation. In each case DCC's are given for low energy β (< 10 keV), other β plus γ and α radiation. Separation of the DCC values in this way facilitates the application of variable radiation weighting factors during the calculation of doses.

DCC's for coastal ecosystems (marine) are calculated for the following FASSET reference organisms: benthic bacteria, pelagic phytoplankton and zooplankton, benthic mollusc, benthic worm, vascular plant, pelagic and benthic fish, marine bird, benthic macroalgae cluster, benthic crustacean and marine mammal. In the case of the freshwater ecosystem the organisms are phytoplankton, zooplankton, crustacean, insect larvae, vascular plant, gastropod, amphibian, bivalve mollusc, pelagic fish, benthic fish, mammal and bird. The dimensions of the abstracted ellipsoid representations for all the reference organisms are given in Table 4-2, and are consistent with those given in Chapter 2.

Coastal—estuarine ecosystem DCC's for internal and external irradiation are given in Tables 4-5 and 4-6, respectively. Freshwater ecosystem DCC's for internal and external irradiation are given in Tables 4-7 and 4-8, respectively. From such data, dose rates to organisms can be easily calculated from equilibrium concentrations of radionuclides in environmental media. For micro-organisms, calculated doses are equal to the absorbed dose in the soil or sediment in which they are located. Nuclide-specific dose conversion coefficients for the α-, β- and γ-components of are given in the Appendix (Tables A-11 to A-22). Those coefficients facilitate the calculation of weighted dose conversion coefficients.

Table 4-5 Coastal—estuarine ecosystem DCC's for internal irradiation.

Radio-	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg)											
Nuclide	Bac-teria	Phyto-plankton	Zoo-plankton	Mollusc	Worm	Vascular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crusta-cean	Mammal
^{3}H	0	3.2E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
^{14}C	0	9.3E-6	2.8E-5	2.8E-5	2.8E-5	2.8E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5
^{32}P	0	1.3E-6	1.8E-4	3.6E-4	3.2E-4	3.8E-4	3.8E-4	3.9E-4	3.8E-4	3.8E-4	3.9E-4	4.0E-4
^{36}Cl	0	2.9E-6	1.2E-4	1.5E-4	1.5E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4
^{40}K	0	1.5E-6	1.6E-4	2.8E-4	2.6E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.1E-4	3.4E-4
^{59}Ni	0	2.5E-6	3.3E-6	3.8E-6	3.6E-6	3.9E-6	3.9E-6	4.1E-6	3.9E-6	3.9E-6	4.0E-6	4.3E-6
^{63}Ni	0	7.7E-6	9.8E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6
^{60}Co	0	6.8E-6	5.9E-5	9.8E-5	8.1E-5	1.5E-4	1.7E-4	2.0E-4	1.6E-4	1.7E-4	2.3E-4	7.0E-4
^{89}Sr	0	1.6E-6	1.8E-4	3.1E-4	2.8E-4	3.2E-4	3.3E-4	3.3E-4	3.2E-4	3.3E-4	3.3E-4	3.4E-4
^{90}Sr	0	5.0E-6	2.9E-4	5.7E-4	5.0E-4	6.1E-4	6.2E-4	6.3E-4	6.1E-4	6.2E-4	6.3E-4	6.5E-4
^{95}Zr	0	6.1E-6	6.4E-5	8.1E-5	7.5E-5	9.9E-5	1.1E-4	1.1E-4	1.0E-4	1.1E-4	1.3E-4	2.8E-4
^{94}Nb	0	4.6E-6	8.9E-5	1.2E-4	1.1E-4	1.6E-4	1.8E-4	2.0E-4	1.7E-4	1.8E-4	2.2E-4	5.4E-4
^{95}Nb	0	9.6E-6	2.7E-5	3.9E-5	3.4E-5	5.8E-5	6.5E-5	7.4E-5	5.9E-5	6.4E-5	8.6E-5	2.4E-4
^{99}Tc	0	6.5E-6	5.5E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5
^{106}Ru	0	6.0E-6	1.9E-4	6.1E-4	4.8E-4	7.2E-4	7.4E-4	7.7E-4	7.2E-4	7.4E-4	7.8E-4	8.7E-4
^{125}I	0	9.1E-6	1.2E-5	1.6E-5	1.4E-5	2.0E-5	2.1E-5	2.3E-5	2.0E-5	2.0E-5	2.3E-5	3.1E-5
^{129}I	0	1.5E-5	3.7E-5	4.0E-5	3.9E-5	4.2E-5	4.2E-5	4.3E-5	4.2E-5	4.2E-5	4.4E-5	4.8E-5
^{131}I	0	4.9E-6	9.6E-5	1.2E-4	1.1E-4	1.3E-4	1.3E-4	1.4E-4	1.3E-4	1.3E-4	1.4E-4	2.3E-4
^{134}Cs	0	5.3E-6	8.3E-5	1.2E-4	1.1E-4	1.6E-4	1.7E-4	1.9E-4	1.6E-4	1.7E-4	2.2E-4	5.4E-4
^{135}Cs	0	8.3E-6	3.8E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5
^{137}Cs	0	4.7E-6	1.1E-4	1.5E-4	1.4E-4	1.7E-4	1.7E-4	1.8E-4	1.7E-4	1.7E-4	1.9E-4	3.1E-4
^{144}Ce	0	1.0E-5	2.4E-4	6.0E-4	5.0E-4	6.8E-4	6.9E-4	7.1E-4	6.8E-4	6.9E-4	7.2E-4	7.6E-4
^{210}Pb	0	1.6E-5	1.7E-4	2.3E-4	2.2E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4
^{210}Po	0	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3
^{226}Ra	0	1.7E-2	1.7E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2
^{227}Th	0	1.9E-2	1.9E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2
^{228}Th	0	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2
^{230}Th	0	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
^{231}Th	0	7.0E-5	9.4E-5	9.7E-5	9.6E-5	9.9E-5	9.9E-5	1.0E-4	9.9E-5	9.9E-5	1.0E-4	1.0E-4
^{232}Th	0	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3
^{234}Th	0	1.4E-5	2.2E-4	4.5E-4	3.9E-4	4.8E-4	4.8E-4	4.9E-4	4.8E-4	4.8E-4	4.9E-4	5.1E-4
^{234}U	0	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
^{235}U	0	2.5E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.7E-3
^{237}Np	0	2.7E-3	2.8E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3
^{238}U	0	5.2E-3	5.4E-3	5.7E-3	5.6E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3
^{238}Pu	0	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
^{239}Pu	0	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
^{240}Pu	0	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
^{241}Pu	0	3.0E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6
^{241}Am	0	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
^{242}Cm	0	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3
^{243}Cm	0	3.3E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3
^{244}Cm	0	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3

Table 4-6 Coastal—estuarine ecosystem DCC's for external irradiation.

Radio-	External dose conversion coefficients (µGy/h per Bq/kg)											
Nuclide	Bac-teria	Phyto-plankton	Zoo-plankton	Mollusc	Worm	Vascular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crusta-cean	Mammal
^{3}H	3.3E-6	1.1E-7	2.6E-9	1.8E-10	4.7E-10	1.8E-10	6.9E-11	6.6E-11	1.3E-10	8.7E-11	7.6E-11	3.5E-11
^{14}C	2.9E-5	1.9E-5	5.9E-7	4.8E-8	1.2E-7	3.4E-8	1.8E-8	1.5E-8	2.8E-8	2.1E-8	1.5E-8	5.1E-9
^{32}P	4.0E-4	4.0E-4	2.2E-4	4.0E-5	7.8E-5	2.0E-5	1.6E-5	1.1E-5	1.9E-5	1.6E-5	9.7E-6	2.3E-6
^{36}Cl	1.6E-4	1.5E-4	3.6E-5	4.1E-6	8.9E-6	2.3E-6	1.6E-6	1.2E-6	2.1E-6	1.7E-6	1.1E-6	3.1E-7
^{40}K	3.9E-4	3.9E-4	2.3E-4	1.1E-4	1.4E-4	9.6E-5	9.2E-5	8.8E-5	9.5E-5	9.3E-5	8.5E-5	5.3E-5
^{59}Ni	4.0E-6	1.5E-6	6.8E-7	1.4E-7	3.7E-7	7.6E-8	7.2E-8	-6.5E-8	6.2E-8	8.3E-8	2.6E-9	-2.9E-7
^{63}Ni	9.9E-6	2.2E-6	4.2E-8	3.1E-9	7.8E-9	2.6E-9	1.2E-9	1.0E-9	2.0E-9	1.4E-9	1.1E-9	4.4E-10
^{60}Co	1.5E-3	1.5E-3	1.4E-3	1.4E-3	1.4E-3	1.3E-3	1.3E-3	1.3E-3	1.3E-3	1.3E-3	1.3E-3	8.0E-4
^{89}Sr	3.4E-4	3.4E-4	1.6E-4	2.6E-5	5.2E-5	1.3E-5	1.0E-5	7.1E-6	1.2E-5	1.1E-5	6.4E-6	1.6E-6
^{90}Sr	6.5E-4	6.5E-4	3.7E-4	8.3E-5	1.5E-4	4.0E-5	3.4E-5	2.3E-5	3.9E-5	3.4E-5	2.0E-5	4.6E-6
^{95}Zr	4.9E-4	4.9E-4	4.3E-4	4.1E-4	4.2E-4	4.0E-4	3.9E-4	3.8E-4	3.9E-4	3.9E-4	3.7E-4	2.1E-4
^{94}Nb	1.0E-3	1.0E-3	9.2E-4	8.8E-4	8.9E-4	8.4E-4	8.3E-4	8.1E-4	8.4E-4	8.3E-4	7.9E-4	4.6E-4
^{95}Nb	4.7E-4	4.6E-4	4.4E-4	4.3E-4	4.3E-4	4.1E-4	4.0E-4	3.9E-4	4.1E-4	4.0E-4	3.8E-4	2.2E-4
^{99}Tc	5.8E-5	5.2E-5	3.5E-6	3.0E-7	7.1E-7	1.9E-7	1.2E-7	8.9E-8	1.7E-7	1.3E-7	8.9E-8	2.7E-8
^{106}Ru	9.4E-4	9.3E-4	7.5E-4	3.3E-4	4.6E-4	2.1E-4	2.0E-4	1.7E-4	2.1E-4	2.0E-4	1.5E-4	6.9E-5
^{125}I	3.5E-5	2.6E-5	2.3E-5	1.9E-5	2.1E-5	1.5E-5	1.5E-5	1.2E-5	1.5E-5	1.5E-5	1.2E-5	4.6E-6
^{129}I	5.1E-5	3.5E-5	1.4E-5	1.2E-5	1.3E-5	9.7E-6	9.2E-6	8.0E-6	9.7E-6	9.5E-6	7.8E-6	3.0E-6
^{131}I	3.3E-4	3.3E-4	2.3E-4	2.1E-4	2.2E-4	2.0E-4	2.0E-4	1.9E-4	2.0E-4	2.0E-4	1.9E-4	1.0E-4
^{134}Cs	9.9E-4	9.9E-4	9.1E-4	8.7E-4	8.8E-4	8.3E-4	8.2E-4	8.0E-4	8.3E-4	8.2E-4	7.7E-4	4.5E-4
^{135}Cs	3.9E-5	3.1E-5	1.3E-6	1.1E-7	2.5E-7	7.2E-8	4.1E-8	3.2E-8	6.0E-8	4.6E-8	3.3E-8	1.0E-8
^{137}Cs	4.7E-4	4.6E-4	3.6E-4	3.2E-4	3.3E-4	3.0E-4	3.0E-4	2.9E-4	3.0E-4	3.0E-4	2.8E-4	1.6E-4
^{144}Ce	7.8E-4	7.7E-4	5.4E-4	1.8E-4	2.8E-4	1.0E-4	9.1E-5	6.9E-5	9.9E-5	9.1E-5	6.2E-5	2.3E-5
^{210}Pb	2.4E-4	2.3E-4	7.6E-5	1.1E-5	2.2E-5	6.3E-6	4.9E-6	3.6E-6	5.9E-6	5.1E-6	3.4E-6	8.5E-7
^{210}Po	3.1E-3	5.0E-9	4.9E-9	4.8E-9	4.8E-9	4.6E-9	4.5E-9	4.4E-9	4.5E-9	4.5E-9	4.2E-9	2.5E-9
^{226}Ra	1.9E-2	1.8E-3	1.3E-3	1.0E-3	1.1E-3	9.5E-4	9.3E-4	9.0E-4	9.5E-4	9.3E-4	8.8E-4	5.4E-4
^{227}Th	2.0E-2	8.2E-4	4.5E-4	2.5E-4	2.9E-4	2.2E-4	2.1E-4	2.0E-4	2.2E-4	2.1E-4	1.9E-4	1.0E-4
^{228}Th	1.9E-2	1.4E-3	1.1E-3	9.1E-4	9.6E-4	8.6E-4	8.4E-4	8.2E-4	8.5E-4	8.4E-4	8.0E-4	5.2E-4
^{230}Th	2.7E-3	6.2E-6	9.4E-7	4.9E-7	6.4E-7	4.1E-7	3.9E-7	3.1E-7	4.0E-7	4.1E-7	3.4E-7	8.3E-8
^{231}Th	1.1E-4	3.8E-5	1.4E-5	1.0E-5	1.2E-5	8.9E-6	8.6E-6	7.5E-6	8.9E-6	8.8E-6	7.6E-6	2.8E-6
^{232}Th	2.3E-3	4.8E-6	7.6E-7	3.8E-7	5.1E-7	3.0E-7	2.9E-7	2.1E-7	3.0E-7	3.0E-7	2.4E-7	3.7E-8
^{234}Th	5.2E-4	5.1E-4	3.0E-4	7.4E-5	1.3E-4	4.3E-5	3.7E-5	2.9E-5	4.2E-5	3.8E-5	2.7E-5	1.0E-5
^{234}U	2.7E-3	4.8E-6	9.3E-7	4.8E-7	6.5E-7	3.7E-7	3.5E-7	2.5E-7	3.7E-7	3.8E-7	3.0E-7	3.9E-8
^{235}U	2.7E-3	1.8E-4	1.0E-4	9.5E-5	9.8E-5	8.9E-5	8.7E-5	8.3E-5	8.8E-5	8.7E-5	8.0E-5	4.0E-5
^{237}Np	3.0E-3	2.5E-4	1.5E-4	1.3E-4	1.3E-4	1.2E-4	1.2E-4	1.1E-4	1.2E-4	1.2E-4	1.1E-4	5.6E-5
^{238}U	5.7E-3	5.2E-4	3.0E-4	7.5E-5	1.3E-4	4.3E-5	3.8E-5	2.9E-5	4.2E-5	3.8E-5	2.7E-5	1.0E-5
^{238}Pu	3.2E-3	3.3E-6	9.3E-7	5.0E-7	6.8E-7	3.8E-7	3.6E-7	2.4E-7	3.8E-7	3.9E-7	3.0E-7	3.5E-8
^{239}Pu	3.0E-3	1.5E-6	3.8E-7	2.1E-7	2.8E-7	1.6E-7	1.5E-7	1.0E-7	1.6E-7	1.6E-7	1.2E-7	-1.2E-9
^{240}Pu	3.0E-3	3.3E-6	9.0E-7	4.8E-7	6.5E-7	3.6E-7	3.5E-7	2.3E-7	3.6E-7	3.7E-7	2.9E-7	3.5E-8
^{241}Pu	3.1E-6	9.4E-8	5.6E-9	3.1E-9	3.6E-9	3.0E-9	2.8E-9	2.6E-9	2.8E-9	2.8E-9	2.5E-9	1.1E-9
^{241}Am	3.2E-3	2.9E-5	1.8E-5	1.5E-5	1.6E-5	1.3E-5	1.3E-5	1.2E-5	1.3E-5	1.3E-5	1.1E-5	4.6E-6
^{242}Cm	3.5E-3	3.0E-6	9.5E-7	5.3E-7	7.1E-7	4.0E-7	3.9E-7	2.7E-7	4.0E-7	4.1E-7	3.2E-7	5.0E-8
^{243}Cm	3.5E-3	1.4E-4	8.2E-5	7.2E-5	7.5E-5	6.8E-5	6.6E-5	6.3E-5	6.7E-5	6.6E-5	6.1E-5	3.1E-5
^{244}Cm	3.3E-3	2.7E-6	8.7E-7	4.9E-7	6.6E-7	3.7E-7	3.6E-7	2.5E-7	3.7E-7	3.8E-7	3.0E-7	4.5E-8

Table 4-7 Freshwater—estuarine ecosystem DCC's for internal irradiation.

Radio-nuclide	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg)												
	Bac-teria	Phyto-plank-ton	Zoo-plank-ton	Crusta-cean	Insect larvae	Vas-cular plant	Gastro-pod	Amphi-bian	Bivalve mollusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	0	2.7E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6	3.3E-6
^{14}C	0	2.2E-6	2.7E-5	2.7E-5	2.7E-5	2.4E-5	2.8E-5	2.8E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5	2.9E-5
^{32}P	0	2.1E-7	7.5E-5	1.1E-4	9.3E-5	2.7E-5	3.3E-4	3.6E-4	3.8E-4	3.8E-4	3.9E-4	3.9E-4	4.0E-4
^{36}Cl	0	5.0E-7	8.1E-5	9.6E-5	8.9E-5	3.8E-5	1.5E-4	1.5E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4
^{40}K	0	3.5E-7	7.1E-5	1.0E-4	8.6E-5	2.6E-5	2.6E-4	2.8E-4	2.9E-4	3.0E-4	3.0E-4	3.1E-4	3.2E-4
^{59}Ni	0	2.9E-6	3.0E-6	3.1E-6	3.1E-6	2.8E-6	3.7E-6	3.8E-6	3.9E-6	3.9E-6	3.9E-6	4.1E-6	4.1E-6
^{63}Ni	0	3.8E-6	9.8E-6	9.8E-6	9.8E-6	9.6E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6	9.9E-6
^{60}Co	0	1.3E-6	5.0E-5	5.2E-5	5.2E-5	3.6E-5	8.1E-5	9.9E-5	1.2E-4	1.5E-4	2.0E-4	3.0E-4	3.6E-4
^{89}Sr	0	2.5E-7	8.0E-5	1.1E-4	9.6E-5	2.9E-5	2.9E-4	3.1E-4	3.2E-4	3.2E-4	3.3E-4	3.3E-4	3.3E-4
^{90}Sr	0	8.3E-7	1.4E-4	1.9E-4	1.6E-4	6.3E-5	5.2E-4	5.7E-4	6.0E-4	6.1E-4	6.3E-4	6.4E-4	6.4E-4
^{95}Zr	0	1.1E-6	5.6E-5	5.8E-5	5.7E-5	3.8E-5	7.5E-5	8.1E-5	8.9E-5	9.7E-5	1.2E-4	1.5E-4	1.7E-4
^{94}Nb	0	7.8E-7	7.0E-5	7.7E-5	7.4E-5	4.1E-5	1.1E-4	1.3E-4	1.4E-4	1.6E-4	2.0E-4	2.7E-4	3.1E-4
^{95}Nb	0	2.4E-6	2.5E-5	2.5E-5	2.5E-5	2.2E-5	3.4E-5	4.0E-5	4.8E-5	5.6E-5	7.5E-5	1.1E-4	1.3E-4
^{99}Tc	0	1.2E-6	5.0E-5	5.1E-5	5.1E-5	3.6E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5	5.8E-5
^{106}Ru	0	3.8E-6	6.0E-5	9.8E-5	7.9E-5	2.4E-5	5.0E-4	6.2E-4	6.8E-4	7.2E-4	7.6E-4	8.0E-4	8.2E-4
^{125}I	0	7.0E-6	1.1E-5	1.2E-5	1.2E-5	1.1E-5	1.5E-5	1.6E-5	1.8E-5	1.9E-5	2.2E-5	2.6E-5	2.6E-5
^{129}I	0	7.1E-6	3.6E-5	3.6E-5	3.6E-5	3.2E-5	3.9E-5	4.0E-5	4.1E-5	4.1E-5	4.3E-5	4.5E-5	4.6E-5
^{131}I	0	8.8E-7	7.4E-5	8.2E-5	7.9E-5	4.2E-5	1.1E-4	1.2E-4	1.2E-4	1.3E-4	1.4E-4	1.6E-4	1.7E-4
^{134}Cs	0	1.4E-6	6.1E-5	6.8E-5	6.5E-5	3.3E-5	1.1E-4	1.2E-4	1.4E-4	1.6E-4	2.0E-4	2.7E-4	3.1E-4
^{135}Cs	0	1.7E-6	3.6E-5	3.6E-5	3.6E-5	2.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5	3.9E-5
^{137}Cs	0	9.9E-7	7.9E-5	9.0E-5	8.5E-5	4.3E-5	1.4E-4	1.5E-4	1.6E-4	1.6E-4	1.8E-4	2.1E-4	2.2E-4
^{144}Ce	0	2.4E-6	1.1E-4	1.5E-4	1.3E-4	5.6E-5	5.2E-4	6.1E-4	6.5E-4	6.8E-4	7.0E-4	7.3E-4	7.4E-4
^{210}Pb	0	7.6E-6	1.0E-4	1.3E-4	1.1E-4	5.5E-5	2.3E-4	2.3E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4
^{210}Po	0	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3	3.1E-3
^{226}Ra	0	1.7E-2	1.7E-2	1.7E-2	1.7E-2	1.7E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2
^{227}Th	0	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2
^{228}Th	0	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2	1.9E-2
^{230}Th	0	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
^{231}Th	0	5.8E-5	9.2E-5	9.2E-5	9.2E-5	8.7E-5	9.6E-5	9.7E-5	9.8E-5	9.9E-5	9.9E-5	1.0E-4	1.0E-4
^{232}Th	0	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3	2.3E-3
^{234}Th	0	4.1E-6	1.0E-4	1.4E-4	1.2E-4	5.4E-5	4.1E-4	4.5E-4	4.7E-4	4.8E-4	4.9E-4	5.0E-4	5.0E-4
^{234}U	0	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
^{235}U	0	2.5E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.6E-3	2.7E-3	2.7E-3
^{237}Np	0	2.7E-3	2.8E-3	2.8E-3	2.8E-3	2.8E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3	2.9E-3
^{238}U	0	5.2E-3	5.3E-3	5.4E-3	5.3E-3	5.3E-3	5.6E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3	5.7E-3
^{238}Pu	0	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
^{239}Pu	0	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
^{240}Pu	0	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3	3.0E-3
^{241}Pu	0	2.7E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6	3.1E-6
^{241}Am	0	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3	3.2E-3
^{242}Cm	0	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3	3.5E-3
^{243}Cm	0	3.3E-3	3.4E-3	3.4E-3	3.4E-3	3.3E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3	3.4E-3
^{244}Cm	0	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3	3.3E-3

Table 4-8 Freshwater—estuarine ecosystem DCC's for external irradiation.

Radio-	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg)												
Nuclide	Bacteria	Phyto-plankton	Zoo-plankton	Crusta-cean	Insect larvae	Vascular plant	Gastro-pod	Amphi-bian	Bivalve mollusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	3.3E-6	5.4E-7	4.8E-9	5.4E-9	5.2E-9	1.9E-8	3.1E-10	1.8E-10	1.2E-10	1.2E-10	6.3E-11	3.6E-11	3.1E-11
^{14}C	2.9E-5	2.6E-5	1.4E-6	1.2E-6	1.3E-6	4.6E-6	8.4E-8	4.8E-8	3.1E-8	2.7E-8	1.6E-8	8.4E-9	7.0E-9
^{32}P	4.0E-4	4.0E-4	3.3E-4	2.9E-4	3.1E-4	3.7E-4	6.7E-5	3.9E-5	2.6E-5	2.0E-5	1.3E-5	6.4E-6	5.2E-6
^{36}Cl	1.6E-4	1.6E-4	7.7E-5	6.2E-5	6.9E-5	1.2E-4	7.1E-6	4.0E-6	2.6E-6	2.1E-6	1.3E-6	7.1E-7	5.9E-7
^{40}K	3.9E-4	3.9E-4	3.2E-4	2.9E-4	3.1E-4	3.7E-4	1.3E-4	1.1E-4	1.0E-4	9.6E-5	8.9E-5	7.9E-5	7.5E-5
^{59}Ni	4.0E-6	1.1E-6	9.9E-7	9.3E-7	9.3E-7	1.2E-6	2.6E-7	1.5E-7	1.0E-7	1.1E-7	6.4E-8	-1.3E-7	-1.3E-7
^{63}Ni	9.9E-6	6.1E-6	9.0E-8	8.7E-8	8.9E-8	3.3E-7	5.4E-9	3.1E-9	2.0E-9	1.9E-9	1.0E-9	5.8E-10	4.9E-10
^{60}Co	1.5E-3	1.5E-3	1.5E-3	1.4E-3	1.4E-3	1.5E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.3E-3	1.2E-3	1.1E-3
^{89}Sr	3.4E-4	3.4E-4	2.6E-4	2.2E-4	2.4E-4	3.1E-4	4.4E-5	2.5E-5	1.7E-5	1.3E-5	8.1E-6	4.2E-6	3.4E-6
^{90}Sr	6.5E-4	6.5E-4	5.1E-4	4.7E-4	4.9E-4	5.9E-4	1.3E-4	8.0E-5	5.4E-5	4.2E-5	2.7E-5	1.4E-5	1.1E-5
^{95}Zr	4.9E-4	4.9E-4	4.4E-4	4.4E-4	4.4E-4	4.6E-4	4.2E-4	4.1E-4	4.1E-4	4.0E-4	3.8E-4	3.4E-4	3.3E-4
^{94}Nb	1.0E-3	1.0E-3	9.3E-4	9.3E-4	9.3E-4	9.6E-4	8.9E-4	8.8E-4	8.6E-4	8.5E-4	8.1E-4	7.4E-4	7.0E-4
^{95}Nb	4.7E-4	4.7E-4	4.4E-4	4.4E-4	4.4E-4	4.5E-4	4.3E-4	4.3E-4	4.2E-4	4.1E-4	3.9E-4	3.6E-4	3.4E-4
^{99}Tc	5.8E-5	5.7E-5	8.7E-6	7.0E-6	7.8E-6	2.2E-5	5.4E-7	3.0E-7	1.9E-7	1.6E-7	9.6E-8	5.1E-8	4.2E-8
^{106}Ru	9.4E-4	9.3E-4	8.8E-4	8.4E-4	8.6E-4	9.1E-4	4.3E-4	3.2E-4	2.5E-4	2.2E-4	1.8E-4	1.3E-4	1.2E-4
^{125}I	3.5E-5	2.8E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.1E-5	1.9E-5	1.7E-5	1.6E-5	1.4E-5	9.8E-6	9.1E-6
^{129}I	5.1E-5	4.3E-5	1.5E-5	1.5E-5	1.5E-5	1.9E-5	1.3E-5	1.2E-5	1.1E-5	1.0E-5	8.7E-6	6.3E-6	5.8E-6
^{131}I	3.3E-4	3.3E-4	2.6E-4	2.5E-4	2.5E-4	2.9E-4	2.2E-4	2.1E-4	2.1E-4	2.0E-4	1.9E-4	1.7E-4	1.6E-4
^{134}Cs	9.9E-4	9.9E-4	9.3E-4	9.2E-4	9.3E-4	9.6E-4	8.8E-4	8.7E-4	8.5E-4	8.4E-4	8.0E-4	7.2E-4	6.8E-4
^{135}Cs	3.9E-5	3.7E-5	3.2E-6	2.6E-6	2.9E-6	9.4E-6	1.9E-7	1.1E-7	6.8E-8	5.9E-8	3.4E-8	1.8E-8	1.5E-8
^{137}Cs	4.7E-4	4.7E-4	3.9E-4	3.8E-4	3.8E-4	4.3E-4	3.3E-4	3.2E-4	3.1E-4	3.0E-4	2.9E-4	2.6E-4	2.5E-4
^{144}Ce	7.8E-4	7.8E-4	6.7E-4	6.3E-4	6.5E-4	7.2E-4	2.6E-4	1.7E-4	1.3E-4	1.0E-4	7.6E-5	4.9E-5	4.3E-5
^{210}Pb	2.4E-4	2.4E-4	1.4E-4	1.2E-4	1.3E-4	1.9E-4	1.8E-5	1.1E-5	7.4E-6	6.1E-6	4.1E-6	2.3E-6	2.0E-6
^{210}Po	3.1E-3	5.0E-9	4.9E-9	4.9E-9	4.9E-9	4.9E-9	4.8E-9	4.8E-9	4.7E-9	4.6E-9	4.4E-9	4.0E-9	3.8E-9
^{226}Ra	1.9E-2	1.8E-3	1.5E-3	1.4E-3	1.5E-3	1.6E-3	1.1E-3	1.0E-3	9.8E-4	9.6E-4	9.0E-4	8.2E-4	7.8E-4
^{227}Th	2.0E-2	8.4E-4	6.2E-4	5.6E-4	5.9E-4	7.4E-4	2.8E-4	2.5E-4	2.3E-4	2.2E-4	2.0E-4	1.8E-4	1.6E-4
^{228}Th	1.9E-2	1.4E-3	1.2E-3	1.2E-3	1.2E-3	1.3E-3	9.5E-4	9.1E-4	8.8E-4	8.6E-4	8.2E-4	7.5E-4	7.2E-4
^{230}Th	2.7E-3	8.0E-6	1.3E-6	1.2E-6	1.2E-6	2.3E-6	5.9E-7	5.0E-7	4.4E-7	4.3E-7	3.8E-7	2.5E-7	2.3E-7
^{231}Th	1.1E-4	5.0E-5	1.6E-5	1.6E-5	1.6E-5	2.0E-5	1.1E-5	1.0E-5	9.5E-6	9.2E-6	8.3E-6	6.2E-6	5.7E-6
^{232}Th	2.3E-3	6.6E-6	1.0E-6	9.5E-7	9.8E-7	1.7E-6	4.6E-7	3.8E-7	3.3E-7	3.2E-7	2.8E-7	1.6E-7	1.6E-7
^{234}Th	5.2E-4	5.2E-4	4.2E-4	3.8E-4	4.0E-4	4.7E-4	1.1E-4	7.2E-5	5.3E-5	4.3E-5	3.2E-5	2.1E-5	1.8E-5
^{234}U	2.7E-3	6.9E-6	1.2E-6	1.1E-6	1.1E-6	1.8E-6	5.9E-7	4.8E-7	4.1E-7	3.9E-7	3.5E-7	2.0E-7	1.9E-7
^{235}U	2.7E-3	2.0E-4	1.1E-4	1.1E-4	1.1E-4	1.3E-4	9.8E-5	9.5E-5	9.2E-5	9.0E-5	8.3E-5	7.2E-5	6.7E-5
^{237}Np	3.0E-3	2.7E-4	1.6E-4	1.6E-4	1.6E-4	1.9E-4	1.3E-4	1.3E-4	1.2E-4	1.2E-4	1.1E-4	9.9E-5	9.2E-5
^{238}U	5.7E-3	5.3E-4	4.2E-4	3.8E-4	4.0E-4	4.7E-4	1.1E-4	7.3E-5	5.3E-5	4.4E-5	3.2E-5	2.1E-5	1.9E-5
^{238}Pu	3.2E-3	5.3E-6	1.1E-6	1.1E-6	1.1E-6	1.4E-6	6.2E-7	5.0E-7	4.2E-7	4.1E-7	3.6E-7	1.9E-7	1.9E-7
^{239}Pu	3.0E-3	2.6E-6	4.6E-7	4.4E-7	4.5E-7	6.4E-7	2.6E-7	2.1E-7	1.8E-7	1.7E-7	1.5E-7	7.6E-8	6.9E-8
^{240}Pu	3.0E-3	5.4E-6	1.1E-6	1.0E-6	1.0E-6	1.4E-6	6.0E-7	4.8E-7	4.0E-7	3.9E-7	3.4E-7	1.9E-7	1.8E-7
^{241}Pu	3.1E-6	4.5E-7	7.5E-9	8.1E-9	7.9E-9	1.9E-8	3.4E-9	3.2E-9	3.0E-9	2.9E-9	2.7E-9	2.2E-9	2.0E-9
^{241}Am	3.2E-3	3.8E-5	1.9E-5	1.9E-5	1.9E-5	2.1E-5	1.6E-5	1.5E-5	1.4E-5	1.4E-5	1.2E-5	9.4E-6	8.5E-6
^{242}Cm	3.5E-3	4.9E-6	1.1E-6	1.1E-6	1.1E-6	1.4E-6	6.5E-7	5.3E-7	4.5E-7	4.3E-7	3.8E-7	2.1E-7	2.1E-7
^{243}Cm	3.5E-3	1.4E-4	9.1E-5	8.8E-5	9.0E-5	1.1E-4	7.4E-5	7.2E-5	7.0E-5	6.8E-5	6.4E-5	5.5E-5	5.1E-5
^{244}Cm	3.3E-3	4.4E-6	1.0E-6	9.9E-7	9.9E-7	1.3E-6	6.0E-7	4.9E-7	4.1E-7	4.0E-7	3.5E-7	2.0E-7	1.9E-7

5. Exposure to terrestrial biota from background radiation

In order to enable a comparison of exposures to biota from radioactivity released to the environment against the natural background, data on the levels of natural radionuclides in terrestrial, marine and freshwaters environments were collected. Special emphasis is given to the radionuclides ^{238}U, ^{232}Th, ^{230}Th, ^{228}Ra, ^{226}Ra, ^{222}Rn, ^{210}Po and ^{40}K. These data are used to estimate natural background exposures to biota by applying the dose conversion coefficients that are derived in Chapter 3.

5.1 External exposure

5.1.1 Background levels in the terrestrial environment

Table 5.1 summarizes average concentrations of the primordial radionuclides ^{40}K, ^{87}Rb, ^{232}Th, ^{238}U and ^{226}Ra in different rocks and soils. The table is compiled from several sources, the values should be considered as rough estimation of typical global values.

Table 5-1 Concentration of primordial radionuclides in rocks and soil (Bq/kg).

Rock type	^{40}K	^{87}Rb	^{232}Th	^{238}U	^{226}Ra [1]
Igneous rocks (range)					
Basalt (crustal average)	300	30	10–15	7–10	
Granite (crustal average)	> 1000	150–180	70	40	48
Sedimentary rocks (range)					
Shale sandstones	800	110	50	40	40
Beach sands	< 300	<40	25	40	26
Carbonate rocks	70	8	8	25	16
All rock (range) [2]	70–1500	<180	7–80	7–60	
Soils (average)	400	50	37	66	
Soils (average) [3]	400		30	35	35
Soils (range) [3]	140–850		11–64	16–110	17–60
Continental upper crust (average)	850	100	44	36	
Soil type [4]					
Gravel	300–1100		2–80		10–90
Sand	150–1100		2–80		<4–60
Eolian sand-silt	400–1000		10–20		5–20
Silt	500–1000		5–70		5–70
Clay	600–1200		10–100		15–130
Till	500–1200		15–100		10–170
Till with alum shale	600–1200		30–50		180–2500

[1] [NCRP, 1987]
[2] [Eisenbud and Gesell, 1997]
[3] [UNSCEAR, 2000]
[4] [Nordic Radiation Protection Authorities, 2000]

In Table 5-2, averages of the activity concentration of ^{40}K, ^{232}Th, ^{238}U and ^{226}Ra are compiled for various European countries [UNSCEAR, 2000]. From this compilation, soil activity concentrations of 400 Bq/kg for ^{40}K, 30 Bq/kg for ^{232}Th, 35 Bq/kg for ^{238}U and ^{226}Ra can be considered as typical.

Table 5-2 Activity concentrations of ^{40}K, ^{232}Th, ^{238}U and ^{226}Ra in soil of various European countries.

Country	Activity concentration (Bq/kg)							
	^{40}K		^{232}Th		^{238}U		^{226}Ra	
	mean	range	mean	range	mean	Range	mean	range
Denmark	460	240–610	19	8–30			17	9–29
Estonia	510	140–1120	25	5–59			35	6–310
Lithuania	600	350–850	25	9–46	16	3–30		
Norway	850		45		50		50	
Sweden	780	560–1150	42	14–94			42	12–170
Belgium	380	70–900	27	5–50			26	5–50
Germany		40–1340		7–134		11–330		5–200
Ireland	350	40–800	26	3–60	37	8–120	60	10–200
Luxembourg	620	80–1800	50	7–70			35	6–52
Netherlands		120–730		8–77		5–53	23	6–63
Switzerland	370	40–1000	25	4–70	40	10–150	40	10–900
United Kingdom		0–3200		1–180		2–330	37	
Bulgaria	400	40–800	30	7–160	40	8–190	45	12–210
Hungary	370	79–570	28	12–45	29	12–66	33	14–76
Poland	410	110–970	21	4–77	26	5–120	26	5–120
Romania	490	250–1100	38	11–75	32	8–60	32	8–60
Russian Federation	520	100–1400	30	2–79	19	0–67	27	1–76
Slovakia	520	200–1380	38	12–80	32	15–130	32	12–120
Albania	360	15–1150	25	4–160	23	6–96		
Croatia	490	140–710	45	12–65	110	83–180	54	21–77
Cyprus	140	0–670					17	0–120
Greece	360	12–1570	21	1–190	25	1–240	25	1–240
Portugal	840	220–1230	51	22–100	49	26–82	44	8–56
Slovenia	370	15–1410	35	2–90			41	2–210
Spain	470	25–1650	33	2–210			32	6–250
Median	400	140–850	30	11–64	35	16–110	35	17–60

5.1.2 External exposure

The external exposure of biota is estimated from the levels of natural radionuclides in soil and the dose conversion coefficients derived in Chapter 3. The estimation of the external exposure is based on the median concentrations indicated in Table 5-2. This assessment is not intended to provide a detailed exposure assessment to biota, but to give an idea of the order of magnitude of the exposure.

Additionally to the radionuclides given in Table 5-2, it is assumed that ^{210}Pb and ^{210}Po is in the soil in the same activity concentrations as ^{226}Ra; ^{228}Th is assumed to have the same activity concentration as ^{232}Th, and ^{234}Th and ^{234}U has the same activity concentration as ^{238}U.

The resulting dose rates are given in Table 5-3. Since the variation of the dose conversion coefficients is relatively little for a given radionuclide among the reference organisms, the exposures are given for earthworm, mouse and fox to represent organisms living in the soil. For organisms on the soil, additional dose values are specified for row deer and cattle. These examples cover most of the size range of organisms living in or on soil.

Table 5-3 Dose rates due to external exposure to natural radionuclides for organisms living on the soil and in the soil.

Radio-	Soil	Organism on soil					Organism in soil		
nuclide	activity	earthworm	mouse	fox	row deer	cattle	earthworm	mouse	fox
	(Bq/kg)	DCC (µGy/h per Bq/kg)					DCC (µGy/h per Bq/kg)		
K-40	400	3.0E–5	3.0E–5	2.6E–5	2.1E–5	9.4E–6	4.3E–5	3.4E–5	1.9E-5
Po-210	35	1.7E–9	1.7E–9	1.4E–9	1.1E–9	4.7E–10	2.3E–9	1.8E–9	8.6E-10
Pb-210	35	3.5E–7	3.4E–7	2.6E–7	1.5E–7	2.8E–8	1.9E–7	1.1E–7	3.5E-8
Ra-226	35	3.4E–4	3.4E–4	2.9E–4	2.3E–4	1.0E–4	4.6E–4	3.7E–4	1.9E-4
Th-232	30	9.5E–8	9.3E–8	7.2E–8	4.0E–8	7.7E–9	4.0E–4	3.3E–4	1.8E-4
Th-228	30	2.9E–4	2.9E–4	2.5E–4	2.0E–4	9.5E–5	2.6E–8	1.6E–8	6.4E-9
Th-234	35	4.6E–6	4.6E–6	3.8E–6	2.9E–6	1.1E–6	5.8E–6	4.5E–6	2.1E-6
U-234	35	1.2E–7	1.1E–7	8.8E–8	4.8E–8	9.0E–9	2.9E–8	1.1E–8	4.4E-9
U-238	35	8.6E–8	8.5E–8	6.5E–8	3.5E–8	6.0E–9	1.5E–8	2.3E–9	7.4E-10
		Dose rate (µGy/h)					Dose rate (µGy/h)		
K-40		1.2E–2	1.2E–2	1.0E–2	8.3E–3	3.8E–3	1.7E–2	1.4E–2	7.5E-3
Po-210		6.1E–8	6.0E–8	5.0E–8	4.0E–8	1.6E–8	8.1E–8	6.4E–8	3.0E-8
Pb-210		1.2E–5	1.2E–5	9.1E–6	5.1E–6	9.9E–7	6.7E–6	4.0E–6	1.2E-6
Ra-226		1.2E–2	1.2E–2	1.0E–2	8.1E–3	3.6E–3	1.6E–2	1.3E–2	6.7E-3
Th-232		2.9E–6	2.8E–6	2.1E–6	1.2E–6	2.3E–7	1.2E–2	9.8E–3	5.4E-3
Th-228		8.7E–3	8.6E–3	7.4E–3	6.0E–3	2.8E–3	7.8E–7	4.9E–7	1.9E-7
Th-234		1.6E–4	1.6E–4	1.3E–4	1.0E–4	3.9E–5	2.0E–4	1.6E–4	7.5E-5
U-234		4.1E–6	4.0E–6	3.1E–6	1.7E–6	3.2E–7	1.0E–6	3.9E–7	1.5E-7
U-238		3.0E–6	3.0E–6	2.3E–6	1.2E–6	2.1E–7	5.1E–7	7.9E–8	2.6E-8
		Total dose (µGy/h)					Total dose (µGy/h)		
All nuclides		3.3E-2	3.3E–2	2.8E–2	2.3E–2	1.0E–2	4.6E–2	3.6E–2	2.0E–2
		Total dose (mGy/a)					Total dose (mGy/a)		
All nuclides		0.29	0.24	0.24	0.2	0.09	0.4	0.32	0.17

The most important contributors to the external dose are ^{40}K, ^{226}Ra and ^{228}Th (daughters included), whereas the other radionuclide contribute only little to the external exposure. In general, smaller organisms are more exposed than larger organisms due to the more effective self-shielding of the latter. The differences in external dose rate for organisms living on soil is a factor of 3–4 between earthworm and cattle. For organisms living in soil the difference is only a factor of 2–3, since the difference in size is less. The differences in dose rates are more pronounced for low energy γ-emitters, since for such photons the effect of self-shielding is more important.

The sum of the dose rates estimated correspond to annual external doses in the range of about 0.1 to 0.4 mGy. This is comparable to the external exposure to terrestrial γ-radiation as reported by UNSCEAR (2000) for humans.

5.2 Internal exposure

5.2.1 Background levels in biota

The estimation of the internal exposure is more complex, since the variabilities of concentrations in biological material is more variable. Therefore the following assessments are intended to give a first idea of the background internal exposure of biota. It covers only a small range of biota, organs and tissues. Selected radionuclide concentrations are summarized in Table 5-4. Relatively high concentrations are especially found for ^{40}K in many tissues. The levels of uranium, thorium, and radium in muscle, grain seeds, leafy and root vegetables are relatively small. An accumulation of these elements is found in bone, liver and kidney, although in general the levels are relatively small.

These values are used to estimate internal unweighted and weighted doses applying the dose conversion coefficients derived in chapter 3. For the weighted dose conversion coefficients, weighting factors of 10, 3, 1 and 1 and are assumed for α-, low-energy β- ($E < 10$ keV), β- ($E > 10$ keV) and γ-radiation respectively.

For these examples, ^{40}K is the most important contributor, the exposures are equivalent to annual doses in the order of 0.3 mGy. The exposures to muscles and plant tissues caused by uranium, thorium, and radium, lead and polonium are low; however, liver, bone and kidney may be exposed to much higher levels. For these radionuclides, the impact of the weighting factor of 10 as assumed for α-radiation becomes obvious.

Under specific circumstances, much higher internal exposures may occur. Macdonals et al [1996] measured ^{210}Pb and ^{210}Po in tissues of Canadian caribou. In some herds, mean activities of 500 and 1000 Bq/kg in liver were found for ^{210}Pb and ^{210}Po respectively; corresponding levels in bones were about 1000 and 500 Bq/kg for ^{210}Pb and ^{210}Po respectively. ^{210}Pb levels of 500–1000 Bq/kg cause internal exposures of 1–2 mGy/a, both unweighted and weighted. However, the exposure to due to ^{210}Po is much higher. ^{210}Po concentrations of 500–1000 Bq/kg correspond to annual unweighted doses of about 15–30 mGy/a, if the concentration persists over the whole year. The weighted dose is 150–300 mGy/a. Such high doses are due to the importance of lichens as feed for caribou in the Arctic region. Lichens accumulate ^{210}Pb and ^{210}Po by aerial deposition. These nuclides are daughter nuclides of ^{222}Rn which emanates from the soil and decay to ^{210}Pb and ^{210}Po in the atmosphere.

Table 5-4 Radionuclide concentrations in selected biota, organs and tissues and the resulting internal unweighted and weighted absorbed doses.

Organ/tissue	Activity concentration (Bq/kg)							
	U-238	Th-230	Ra-226	Pb-210	Po-210	Th-232	Th-228	K-40
Muscle[1]	0.002	0.002	0.015	0.08	0.06	0.001	0.001	90[2]
Grain[1]	0.02	0.01	0.08	0.05	0.06	0.003	0.003	120[2]
Leafy vegetables[1]	0.02	0.02	0.05	0.08	0.1	0.015	0.015	100[2]
Roots[1]	0.003	0.0005	0.03	0.03	0.04	0.0005	0.0005	110[2]
Bone (beef)[3]			10					
Kidney (beef)[4]				1.5				66[2]
Liver (beef)[4]				2.6	1.9			85[2]
Eggs (hen)[4]				20	20			40[2]
	Unweighted internal dose conversion coefficient (µGy/h per Bq/kg)							
All tissues	2.4E–3	2.7E–3	1.4E–2	2.4E–4	3.1E–3	2.3E–3	1.9E–2	2.9E–4
	Unweighted dose rate (µGy/h)							
Muscle	4.8E–6	5.4E–6	2.1E–4	1.9E–5	1.9E–4	2.3E–6	1.9E–5	2.6E–2
Grain	4.8E–5	2.7E–5	1.1E–3	1.2E–5	1.9E–4	6.9E–6	5.7E–5	3.5E–2
Leafy vegetables	4.8E–5	5.4E–5	7.0E–4	1.9E–5	3.1E–4	3.5E–5	2.9E–4	2.9E–2
Roots	7.2E–6	1.4E–6	4.2E–4	7.2E–6	1.2E–4	1.2E–6	9.5E–6	3.5E–2
Beef (bone)			0.14					
Kidney (beef)				3.6E–4				1.9E–2
Liver (beef)				6.2E–4	5.9E–3			2.5E–2
Eggs (hen)				4.8E–3	6.2E–2			1.2E–2
	Weighted internal dose conversion coefficient (µGy/h per Bq/kg)							
All tissues	2.4E–2	2.7E–2	1.4E–1	2.4E–4	3.1E–2	2.3E–2	1.8E–1	2.9E–4
	Weighted dose rate (µGy/h)							
Muscle	4.8E–5	5.4E–5	2.1E–3	1.9E–5	1.9E–3	2.3E–5	1.8E–4	2.6E–2
Grain	4.8E–4	2.7E–4	1.1E–2	1.2E–5	1.9E–3	6.9E–5	5.4E–4	3.5E–2
Leafy vegetables	4.8E–4	5.4E–4	7.0E–3	1.9E–5	3.1E–3	3.5E–4	2.7E–3	2.9E–2
Roots	7.2E–5	1.4E–5	4.2E–3	7.2E–6	1.2E–3	1.2E–5	9.0E–5	3.5E–2
Beef (bone)			1.4					
Kidney (beef)				3.6E–4				1.9E–2
Liver (beef)				6.2E–4	5.9E–2			2.5E–2
Eggs (hen)				4.8E–3	6.2E–1			1.2E–2

Even higher doses were assessed by Macdonalds and Laverstock [1998] for small burrowing mammals that live in soil and which are exposed to high radon levels in soil. The dose was estimated on the dose model for man that is extrapolated to small mammals taking into account species-specific respiration rates and periods of hibernation and activities. The radon concentration in soil was determined to be in the range of 7500–19000 Bq/m³. Dependent on species and radon level in soil, lung doses in the range of 70–2700 mGy/a were estimated.

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[1] [UNSCEAR, 2000]

[2] [Haenel, 1979]

[3] [IAEA, 1990]

[4] [Sattler and Stahlhofen, 1974]

6. Exposures to aquatic organisms from natural background

The assessment of background exposure is focussed on doses received by organisms in European waters. However, there are substantial gaps in the data for European waters, particularly for freshwater ecosystems. Therefore, applicable non-European data have been used to fill gaps where possible in the interest of obtaining the most complete appraisal possible of the doses likely to be received by European aquatic organisms. Based on the identified gaps in data, and assessment of the likely importance in terms of dose to aquatic organisms, recommendations are made for the further research that would be desirable.

6.1 Marine Organisms

6.1.1 Concentrations of radionuclides in seawater and marine sediments

Concentrations of natural radionuclides in water, sediment and marine organisms have been reviewed by the Norwegian Radiation Protection Authority (NRPA) [Thørring and Brown, 2003]. Concentrations of radionuclides in water for use in assessing doses to marine organisms, derived from this work, are given in Table 6-1. The data presented by Thørring and Brown (2003) for radionuclide concentrations in sediments are rather limited, so additional data from a broader range of source documents have been used in this assessment, as indicated in Table 6-2. In both Tables 6-1 and 6-2 data are presented in terms of nominal median and 95th percentile values; the derivation of these figures from cited ranges is, to a degree, subjective but is intended to provide a realistic representation of the likely range of variability. Where only a single value is cited in the original source, the 95th percentile has been assumed to be a factor of 2 higher than the stated value.

Table 6-1 Concentrations of natural radionuclides in seawater (data taken from Thørring and Brown, 2003).

Radionuclide	Concentration (Bq m^{-3}, filtered seawater)	
	Median	95th percentile
^{3}H	50	100
^{14}C	6	7
^{40}K	18 000	36 000
^{210}Po	2	4
^{226}Ra	2	3
^{228}Ra	1	4
^{228}Th	0.05	0.1
^{230}Th	0.02	0.04
^{232}Th	0.001	0.002
^{238}U	40	80

Table 6-2 Concentrations of natural radionuclides in marine sediments.

Radionuclide	Concentration (Bq kg^{-1}, dry weight)		Reference
	Median	95th percentile	
^{3}H			
^{14}C	7	14	Walker and Rose, 1990
^{40}K	400	800	Baxter, 1983
^{210}Po	9	18	McDonald et al., 1991
^{226}Ra	30	60	Baxter, 1983
^{228}Ra			
228Th	21	42	Holm and Fukai, 1986
230Th	150	300	Holm and Fukai, 1986
^{232}Th	9	18	Walker and Rose, 1990
^{238}U	10	20	McDonald et al., 1991

6.1.2 Concentrations of radionuclides in marine organisms

Concentrations of radionuclides for use in assessing doses to marine organisms are given in Table 6-3. These are taken from Thørring and Brown (2003) except where otherwise indicated. As for water and sediment, values are given in terms of nominal median and 95th percentile values derived using a degree of judgment. The highest concentrations are observed for ^{40}K and ^{210}Po; the latter are of greater radiological significance because ^{210}Po is an α-emitter.

Table 6-3 Natural radionuclide concentrations in marine organisms (from Thørring and Brown, 2003, unless otherwise indicated).

	Concentration in organism, Bq kg^{-1} wet weight, as: median (95th percentile)							
Nuclide	Phyto-plankton	Zooplankton	Macroalgae	Benth. mollusc	Crus-tacean	Pelagic fish	Benthic fish	Mammal
^{40}K			300 (600)	50 (100)	50 (100)	100 (200)	100 (200)	
^{210}Po	2.5 (3.5)	25 (80)	2.1 (15)	37 (110)	50 (1000)	11 (500)	11 (500)	20 (100)[1]
^{226}Ra	2.7 (30)[1]	0.2 (0.8)[1]	0.3 (1)[1]	0.7 (1.5)[1]	0.7 (1.5)[1]	0.2 (0.5)[1]	0.2 (0.5)[1]	
^{228}Ra								
228Th	1 (3)[1]	0.3 (1)[1]	0.4 (2)	0.7 (2)	0.035 (0.2)			
230Th	0.1 (0.3)[1]	0.06 (0.2)[1]	0.08 (0.2)	2 (80)	0.045 (0.2)	0.002 (0.01)	0.002 (0.01)	
^{232}Th	0.1 (0.3)[1]	0.06 (0.2)[1]	0.19 (0.8)	0.5 (1.5)	0.006 (0.012)	0.0007 (.002)	0.0007 (.002)	
^{238}U	0.4 (0.6)[1]	0.2 (0.5)[1]	1 (5)	1 (5)	0.14 (0.2)	0.008 (0.015)	0.008 (0.015)	

The values in Table 6-2 have been selected as representative of dose to the whole organism, usually “soft tissue” for invertebrates and “muscle” for vertebrates. For some radionuclides significantly elevated concentrations are observed in some organs. For example substantially elevated concentrations of ^{210}Po are seen in the hepatopancreas of crustaceans, in the liver of fish and marine mammals, and in the pyloric caecum of fish. These elevations will lead to corresponding elevations of dose to these organs, but the biological and ecological significance of such elevation is at present unclear.

[1] Data from Cherry and Shannon (1974), for general oceanic waters

The ranges quoted for concentrations in the broad classification of organisms reflects in some cases differences between taxa—for example, between bivalve and gastropod molluscs, or dolphins and whales.

6.1.3 Radiation doses to marine organisms

Radiation doses are calculated using the methods described by Copplestone et al. [2001]. In essence:

$$C_{sed,n,wet} = C_{sed,n,dry} \cdot f_{solid} + c_{water} \cdot (1 - f_{solid}),$$

$$D_{int,org,n} = C_{water,n} \cdot CF_{org,n} \cdot DPUC_{int,org,n},$$

$$D_{ext,org,n} = DPUC_{ext,org,n} \cdot C_{sed,n,wet} \cdot [(f_{sed,org} + f_{sedsurf,org}/2) + (f_{water,org} + f_{sedsurf,org}/2) \cdot C_{water,n} / 1000],$$

where:

$C_{sed,ndry}$	sediment concentrations (Bq kg^{-1} dry weight);
C_{water}	water concentrations (Bq m^{-3} in the dissolved phase);
$CF_{org,n}$	concentration factors (m^3 kg^{-1});
$DCC_{int,org,n}$	dose per unit concentration factors for internal exposure (μGy h^{-1} per Bq kg^{-1} fresh weight;
f_{solid}	solids fraction of wet sediment (0.4);
$f_{sed,org}$	fraction of time the organism spends buried in sediment;
$f_{sedsurf,org}$	fraction of time the organism spends at the sediment/water interface;
$f_{water,org}$	fraction of time the organism spends free swimming in the water column.

Doses to marine organisms, calculated by this method, are set out in Tables 6-4 and 6-5. No doses are cited for seabirds, because of the lack of data on internally incorporated radionuclides. Doses for marine mammals include contributions only from internal ^{40}K and ^{210}Po, for which data are available. Doses are cited for benthic bacteria, which because of their small size are assumed to receive the same absorbed dose as the sediment which they inhabit.

The likely range for total dose to each class of organism is evaluated by a statistical simulation in which concentrations in water, sediment and organisms are represented by lognormal distributions with the median and 95th percentile values given in Tables 6-1, 6-2 and 6-3. The ranges cited are the 5th and 95th percentile values obtained by the simulation, based on 2000 evaluations of the total dose.

Table 6-4 Calculated unweighted absorbed doses to marine organisms.

Nuclide	Calculated absorbed dose, µGy h^{-1}							
	Bacteria	Phyto-plankton	Zoo-plankton	Macro-algae	Molluscs	Crus-taceans	Pelagic fish	Mammals
^{40}K	6.7E–2	7.0E–3	4.9E–3	3.8E–2	2.6E–2	3.2E–2	3.2E–2	3.8E–3
^{210}Po	1.1E–2	7.6E–3	7.6E–2	6.4E–3	1.1E–1	1.5E–1	6.1E–3	6.1E–2
^{226}Ra	2.2E–1	4.6E–2	3.5E–3	5.2E–3	1.9E–2	2.0E–2	4.1E–3	2.1E–3
^{228}Ra	2.4E–6	8.2E–7	6.5E–7	6.6E–7	4.6E–7	5.2E–7	4.8E–7	3.3E–7
^{228}Th	1.7E–1	1.8E–2	5.6E–3	7.5E–3	1.7E–2	5.5E–3	3.5E–4	1.3E–3
^{230}Th	1.7E–1	2.7E–4	1.6E–4	2.2E–4	7.0E–3	2.5E–3	3.3E–5	4.9E–5
^{232}Th	8.3E–3	2.3E–4	1.4E–4	4.4E–4	1.2E–3	1.5E–5	1.7E–6	2.3E–7
^{238}U	2.3E–2	2.1E–3	1.1E–3	5.3E–3	5.9E–3	1.5E–3	5.4E–5	1.6E–5
Total	6.7E–1	8.1E–2	9.2E–2	6.3E–2	1.9E–1	2.1E–1	4.3E–2	6.8E–2
5^{th} %	5.0E–1	3.7E–2	4.1E–2	4.6E–2	1.3E–1	7.3E–2	2.7E–2	1.9E–2
95^{th} %	1.0	5.3E–1	2.5E–1	1.4E–1	5.6E–1	2.9	1.0E–1	3.1E–1

Table 6-5 Calculated weighted absorbed doses to marine organisms: low energy (below 10 keV) beta doses are weighted by a factor of 3, alpha doses are weighted by a factor of 10.

Nuclide	Calculated weighted absorbed dose, µGy h^{-1}							
	Bacteria	Phyto-plankton	Zoo-plankton	Macro-algae	Molluscs	Crus-taceans	Fish	Mammals
^{40}K	6.7E–2	7.1E–3	4.9E–3	3.8E–2	2.6E–2	3.2E–2	3.8E–2	3.8E–3
^{210}Po	1.1E–1	7.6E–2	7.6E–1	6.4E–2	1.1	1.5	6.1E–2	6.1E–1
^{226}Ra	2.0	4.6E–1	3.4E–2	5.1E–2	1.3E–1	1.3E–1	3.9E–2	2.1E–3
^{228}Ra	1.9E–5	8.4E–7	6.5E–7	6.6E–7	4.6E–7	5.2E–7	4.0E–7	3.3E–7
^{228}Th	1.6	1.8E–1	5.5E–2	7.4E–2	1.3E–1	1.1E–2	3.1E–3	1.3E–3
^{230}Th	1.6	2.7E–3	1.6E–3	2.2E–3	5.5E–2	3.6E–3	3.0E–4	4.9E–5
^{232}Th	8.3E–2	2.3E–3	1.4E–3	4.4E–3	1.2E–2	1.4E–4	1.7E–5	2.3E–7
^{238}U	2.1E–1	2.1E–2	1.0E–2	5.2E–2	5.2E–2	8.0E–3	4.8E–4	1.6E–5
Total	5.7	7.5E–1	8.7E–1	2.9E–1	1.5	1.7	1.4E–1	6.2E–1
5^{th} %	4.2	6.0E–1	7.3E–1	3.3E–1	1.7	5.3E–1	1.1E–1	2.1E–1
95^{th} %	8.9	6.0	2.6	1.0	5.0	3.5E+1	6.9E–1	3.2

The calculated dose increases closely in proportion to the weighting factor applied to α-radiation, since the radionuclides contributing most significantly to dose are ^{210}Po and ^{226}Ra. Crustaceans receive the widest range of doses, largely because of the spread of concentrations of ^{210}Po between different taxa.

6.1.4 Data gaps and research needs for marine organisms

The uptake of natural radionuclides by marine organisms has been quite extensively studied, and the range of natural doses experienced by most marine organisms can be quite easily established. There is a need for data on uptake of natural series radionuclides by seabirds, and data on European marine mammals would also be highly desirable. Because the majority of the dose is from alpha radiation, internal distribution of dose may be significant and information on localisation of dose in organs of possible importance to ecological endpoints, such as gonads, would be of great interest.

6.2 Freshwater Organisms

6.2.1 Concentrations of radionuclides in freshwater and sediments

Concentrations of natural series radionuclides in freshwater bodies are liable to be much more variable than those in the marine environment, since they are heavily influenced by the local geochemistry of the watershed. Data on the full range of natural series radionuclides in European freshwater bodies is surprisingly sparse; Table 6-6 presents the range cited by IAEA [1976] together with some specific examples from Europe and further afield. Data from the Kaveri river system in India are particularly relevant to the discussion below on concentrations in biota.

Table 6-6 Radionuclide concentrations in freshwater.

Nuclide	Concentration, Bq m^{-3}				
	Global range[1]	Global average[2]	UK Lake district[3]	Spain Rio Ebro[4]	India R. Kaveri[5]
^{40}K	4 - 240	26		119 (42-336)	
^{210}Po	0.3 - 9	2			1.2
^{222}Rn	7 - 7000	800	285 (75-1040)		
^{226}Ra	0.5 - 100	5	5.6 (2.1-15)	29 (20-43)	0.93
^{228}Ra	-	0.4			
^{230}Th	-	2.6			
^{232}Th	0.04 - 0.4	0.11			
^{238}U	0.2 - 63	11	8.4 (4.0-17.4)	13 (1.9-89)	

There is obviously some difficulty in interpreting these data in terms of mean values and ranges for European freshwaters. However use of the global average data for the mean values, and the upper value cited by IAEA [1976] as nominal 95th percentile values, appears reasonable in relation to the data presented.

No references citing overall means and ranges for the concentrations of radionuclides in freshwater sediments have been identified. Therefore, for the purpose of making a general assessment of doses to freshwater biota, empirical distribution factors have been used, as indicated in Table 6-7.

6.2.2 Concentrations of radionuclides in freshwater organisms

As for water and sediments, published data on natural series radionuclides in freshwater organisms is sparse and no references citing data specific for Europe have been identified. Therefore, to make an indicative assessment of likely doses, concentration factors derived

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[1] [IAEA, 1976]

[2] [Santschi and Honeyman, 1989]

[3] [Al-Masri and Blackburn, 1999]

[4] [Pujol and Sanchez-Cabeza, 2000]

[5] [Shaheed et al., 1997; Hameed et al., 1997]

from the few published studies in other parts of the world have been used. The most useful studies have been those of the Kaveri river system in India [Shaheed et al., 1997; Hameed et al., 1997] and the Alligator River system in Northern Territories, Australia [Petterson et al., 1993; Martin et al., 1998]. Some use has also been made of a Japanese compilation [RWMC, 1994]. The concentration factors used are given in Table 6-8.

Table 6-7 Distribution factors assumed for radionuclides in freshwater sediment.

Nuclide	Distribution coefficient (m^3 kg^{-1} dry mass)	Reference
^{40}K	20	St-Pierre et al., 1999
^{210}Po	20	Shaheed et al., 1997
^{222}Rn	0.0008	Based on assumed water content
^{226}Ra	6	Hameed et al., 1997
^{228}Ra	6	Hameed et al., 1997
^{230}Th	10	Petterson et al., 1993
^{232}Th	10	Petterson et al., 1993
^{238}U	0.05	Petterson et al., 1993

Table 6-8 Concentration factors for freshwater organisms.

Radio-	Concentration factor, m^3 kg^{-1} (wet weight)						
nuclide	Phyto-plankton	Macrophyte	Benthic mollusc	Small ben. crustaceans	Large ben. crustaceans	Pelagic fish	Benthic fish
^{40}K	4.0	4.0	2.0	2.0	6.0E–1	6.0E–1	4.0
^{210}Po	2.5E+1	1.5	5.0E+1	1.0E+1	3.0E–1	1.0E+1	2.5E+1
^{222}Rn	8.0E–4	8.0E–4	8.0E–4	8.0E–4	8.0E–4	8.0E–4	8.0E–4
^{226}Ra	1.0	2.0	3.0E–1	1.0	3.0E–1	1.2	1.0
^{228}Ra	1.0	2.0	3.0E–1	1.0	3.0E–1	1.2	1.0
^{230}Th	1.0	1.0	5.0E–1	2.5E–1	2.0E–2	4.0E–2	1.0
^{232}Th	1.0	1.0	5.0E–1	2.5E–1	2.0E–2	4.0E–2	1.0
^{238}U	1.0E–1	4.0	1.0E–1	1.5E–1	1.5E–2	2.5E–1	1.0E–1

6.2.3 Radiation doses to freshwater organisms

Radiation doses to freshwater organisms have been calculated using the same methods as for marine organisms. In this case, the range of likely doses has been assessed by a simulation method based only on the assumed distribution of radionuclide concentrations in water; variability (or uncertainty) in accumulation by sediments and organisms have not been taken into account. The results of the calculations are given in Tables 6-9 and 6-10. Important classes of organism for which there are insufficient data to support any estimate of dose include zooplankton, water birds, amphibians and aquatic mammals.

As for marine organisms, the majority of the calculated absorbed dose arises from internally incorporated alpha emitters, with ^{210}Po and ^{226}Ra being the major contributors. The dose attributed is therefore closely proportional to the weighting factor assumed for alpha radiation. Calculated doses are somewhat higher than for marine organisms, and the range of doses is also much greater, reflecting the much greater variability of radionuclide concentrations in freshwater as compared to seawater.

Table 6-9 Calculated unweighted absorbed dose to freshwater organisms.

Nuclide	Calculated absorbed dose, µGy h^{-1}							
	Bacteria	Phyto-plankton	Macro-phyte	Benthic mollusc	Small ben. crustacean	Large ben. crustacean	Pelagic fish	Benthic fish
^{40}K	8.1E–2	2.1E–5	1.1E–2	2.8E–2	2.8E–2	5.6E–3	1.3E–2	8.1E–2
^{210}Po	4.9E–2	1.5E–1	9.2E–3	3.1E–1	6.1E–2	1.8E–3	6.1E–2	4.9E–2
^{222}Rn	6.0E–3	8.3E–3	8.4E–3	8.3E–3	8.3E–3	8.4E–3	8.3E–3	6.0E–3
^{226}Ra	2.2E–1	8.4E–2	1.7E–1	3.3E–2	9.4E–2	2.7E–2	1.1E–1	2.2E–1
^{228}Ra	3.8E–3	1.2E–3	2.6E–3	6.8E–4	1.6E–3	4.4E–4	1.9E–3	3.8E–3
^{230}Th	2.9E–3	7.0E–4	7.0E–4	3.8E–4	2.0E–4	1.5E–5	3.3E–5	2.9E–3
^{232}Th	1.0E–3	2.5E–4	2.5E–4	1.3E–4	6.4E–5	5.1E–6	1.0E–5	1.0E–3
^{238}U	1.3E–3	5.7E–3	2.3E–1	6.1E–3	9.2E–3	9.3E–4	1.6E–2	1.3E–3
Total	3.7E–1	2.5E–1	4.4E–1	3.8E–1	2.0E–1	4.4E–2	2.1E–1	3.7E–1
5^{th} %	1.4E–1	9.6E–2	1.5E–1	1.5E–1	9.0E–2	1.7E–2	9.1E–2	1.4E–1
95^{th}%	5.5	3.0	6.1	2.8	2.6	7.3E–1	3.4	5.5

Table 6-10 Calculated weighted dose to freshwater organisms: low energy (< 10 keV) beta doses are weighted by a factor of 3, alpha doses are weighted by a factor of 10).

Nuclide	Bacteria	Macrophyte	Benthic mollusc	Small ben. crustacean	Large ben. crustacean	Pelagic fish	Benthic fish
^{40}K	8.2E–2	3.1E–5	1.1E–2	2.8E–2	2.8E–2	5.6E–3	1.3E–2
^{210}Po	4.9E–1	1.5	9.2E–2	3.1	6.1E–1	1.8E–2	6.1E–1
^{222}Rn	5.4E–2	7.2E–2	7.2E–2	7.2E–2	7.2E–2	7.2E–2	7.2E–2
^{226}Ra	2.0	8.4E–1	1.7	2.6E–1	8.5E–1	2.5E–1	1.0
^{228}Ra	3.1E–2	1.2E–2	2.5E–2	4.0E–3	1.3E–2	3.8E–3	1.5E–2
^{230}Th	2.8E–2	7.0E–3	7.0E–3	3.5E–3	1.8E–3	1.4E–4	2.8E–4
^{232}Th	1.0E–2	2.5E–3	2.5E–3	1.3E–3	6.3E–4	5.1E–5	1.0E–4
^{238}U	1.2E–2	5.7E–2	2.3	5.7E–2	8.6E–2	8.6E–3	1.4E–1
Total	2.8	2.5	4.2	3.5	1.7	3.6E–1	1.9
5^{th} %	8.6E–1	9.4E–1	1.3	1.1	6.5E–1	1.2E–1	6.8E–1
95^{th}%	4.4E+1	3.0E+1	5.7E+1	2.5E+1	2.3E+1	6.7	3.1E+1

6.2.4 Data gaps and research needs for freshwater organisms

There is clearly a major need for data on the concentrations of natural series radionuclides in European freshwater organisms in order to understand the exposure of these organisms to natural radioactivity. Data on amphibians, water birds and aquatic mammals is lacking even at the global level.

The predicted levels of radiation dose at the upper end of the expected distribution of radionuclide concentrations in water suggests that sites with naturally elevated concentrations may present opportunities for field research on biomarkers or radiation effects.

7. Concluding remarks

This report describes the development and application of dosimetric models that allow the estimation of radiation exposures to biota due to environmental contaminations with radioactivity. For this purpose, nuclide-specific dose conversion coefficients (DCC) are derived for terrestrial and aquatic species that allow the assessment of internal and external exposures in dependence on habitat and target size. Input quantities for the dose assessment are measured or calculated activity concentrations in biota or in environmental media as soil, water or sediments. The DCC are calculated in units of unweighted absorbed doses. To illustrate the impact of possible radiation quality, weighted DCCs are presented assuming weighting of 10 and 3 for α- and low-energy-β-radiation (E<10 keV) respectively. Both, b-(E< 10keV) and γ-radiation is weighted with a weighting factor of 1.

The DCCs allow the assessment of exposures to a wide range of organisms and habitats. Although – compared to the variability of the environment – only relatively few situations were considered in detail, the data allow the interpolation to other exposure situations.

Analyzing the DCCs, the following conclusions can be drawn:

- The dose conversion coefficients for external exposure decrease with the size of the animal due to the increasing self-shielding effect.
- The exposure to small organisms (e.g. mouse) from high-energy photon emitters is higher for underground organisms, compared to aboveground organisms, whereas it is vice versa for larger organisms (e.g. fox).
- The external exposure to low-energy photon emitters is in general higher for aboveground organisms, since then the shielding effect of the soil is less pronounced.
- For internal exposure to γ-emitters, DCCs increase in proportion to the mass of the organism due to the higher absorbed fractions. This dependence is more pronounced for high-energy photon emitters (e.g. $^{137}Cs/^{137m}Ba$).
- For α- and β-emitters, the DCCs for internal exposure are nearly size-independent.
- For internal exposure, the impact of the radiation quality is especially important for tritium and the α-emitters.

With regard to the applicability of the method, the most important assumption is that concentrations in biota are in equilibrium with concentrations in the surrounding environmental media. In general, the method can be used to assess dose rates to biota in situations where the concentrations of radionuclides in the surrounding environmental media are not changing rapidly.

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9. Appendix: Numerical values for DCC

9.1 DCC for terrestrial reference organisms

9.1.1 External exposure due to mono-energetic photons

Organisms in soil

Table A-1 Dose conversion coefficients for in-soil reference organism and external exposure due to a monoenergetic isotropic volume source (depth = 50 cm) as a function of the energy of the source and the position of the organism.

Target)	Energy	Dose Conversion coefficient (µGy per photon/kg)						
depth (m)	(MeV)	woodlouse	earthworm	mouse	mole	snake	rabbit	fox
0	0.050	6.2E–06	5.4E–06	5.0E–06	5.7E–06	5.4E–06	5.7E–06	5.9E–06
0	0.100	1.3E–05	1.4E–05	1.7E–05	1.7E–05	1.4E–05	1.8E–05	1.9E–05
0	0.150	2.2E–05	2.3E–05	3.1E–05	3.1E–05	2.7E–05	3.4E–05	3.5E–05
0	0.300	6.3E–05	6.1E–05	7.7E–05	7.8E–05	7.1E–05	8.3E–05	8.6E–05
0	0.662	1.6E–04	1.6E–04	2.0E–04	2.0E–04	1.9E–04	2.1E–04	2.1E–04
0	1.000	2.8E–04	2.6E–04	3.2E–04	3.1E–04	2.9E–04	3.2E–04	3.3E–04
0	3.000	8.0E–04	8.4E–04	9.0E–04	9.2E–04	8.8E–04	9.8E–04	1.0E–03
0.05	0.050	7.3E–06	7.4E–06	nc[1]	nc	nc	nc	nc
0.05	0.100	2.3E–05	2.4E–05	nc	nc	nc	nc	nc
0.05	0.150	4.7E–05	4.5E–05	nc	nc	nc	nc	nc
0.05	0.300	1.2E–04	1.2E–04	nc	nc	nc	nc	nc
0.05	0.662	2.5E–04	2.7E–04	nc	nc	nc	nc	nc
0.05	1.000	4.1E–04	4.2E–04	nc	nc	nc	nc	nc
0.05	3.000	1.1E–03	1.3E–03	nc	nc	nc	nc	nc
0.25	0.050	1.1E–05	9.5E–06	7.0E–06	6.9E–06	7.9E–06	6.2E–06	6.0E–06
0.25	0.100	2.9E–05	2.8E–05	2.8E–05	2.7E–05	2.4E–05	2.4E–05	2.1E–05
0.25	0.150	5.7E–05	5.6E–05	5.4E–05	5.3E–05	5.2E–05	4.7E–05	4.0E–05
0.25	0.300	1.4E–04	1.4E–04	1.4E–04	1.4E–04	1.4E–04	1.2E–04	1.0E–04
0.25	0.662	3.6E–04	3.4E–04	3.4E–04	3.3E–04	3.3E–04	2.9E–04	2.4E–04
0.25	1.000	5.5E–04	5.6E–04	5.4E–04	5.1E–04	5.1E–04	4.4E–04	3.8E–04
0.25	3.000	1.6E–03	1.5E–03	1.5E–03	1.6E–03	1.5E–03	1.3E–03	1.1E–03
0.50	0.050	6.0E–06	5.2E–06	3.3E–06	3.1E–06	3.7E–06	1.7E–06	1.1E–06
0.50	0.100	1.4E–05	1.3E–05	1.0E–05	9.7E–06	1.0E–05	6.7E–06	4.4E–06
0.50	0.150	2.4E–05	2.6E–05	2.0E–05	1.8E–05	2.0E–05	1.2E–05	8.2E–06
0.50	0.300	6.6E–05	6.4E–05	5.3E–05	5.1E–05	5.6E–05	3.4E–05	2.2E–05
0.50	0.662	1.8E–04	1.7E–04	1.4E–04	1.3E–04	1.5E–04	9.3E–05	6.3E–05
0.50	1.000	2.5E–04	2.9E–04	2.2E–04	2.1E–04	2.3E–04	1.5E–04	1.1E–04
0.50	3.000	8.7E–04	8.0E–04	6.5E–04	6.8E–04	7.6E–04	5.3E–04	4.1E–04

[1] Not calculated

Table A-2 Dose conversion coefficients for in-soil reference organism and external exposure due to a monoenergetic isotropic planar source as a function of the energy and depth of the source.

Source depth (m)	Target depth (m)	Energy (MeV)	DCCs (μGy/h per photon/m^2 s)						
			woodlouse	earthworm	mouse	mole	snake	rabbit	fox
0	0	0.05	3.3E–8	2.3E–8	1.5E–8	1.1E–8	7.1E–9	5.3E–9	2.5E–9
0	0	0.1	4.6E–8	3.6E–8	2.1E–8	1.9E–8	1.1E–8	9.5E–9	5.5E–9
0	0	0.15	6.6E–8	5.2E–8	3.0E–8	2.7E–8	1.8E–8	1.6E–8	9.9E–9
0	0	0.3	1.6E–7	1.2E–7	7.4E–8	6.6E–8	4.6E–8	3.9E–8	2.4E–8
0	0	0.662	3.5E–7	2.9E–7	1.9E–7	1.6E–7	1.3E–7	9.5E–8	6.1E–8
0	0	1	5.3E–7	4.2E–7	2.7E–7	2.4E–7	2.0E–7	1.5E–7	9.6E–8
0	0	3	1.2E–6	9.1E–7	7.2E–7	6.5E–7	5.7E–7	4.1E–7	2.8E–7
0	0.05	0.05	9.0E–10	9.2E–10	nc	nc	nc	nc	nc
0	0.05	0.1	5.4E–9	5.6E–9	nc	nc	nc	nc	nc
0	0.05	0.15	1.2E–8	1.2E–8	nc	nc	nc	nc	nc
0	0.05	0.3	3.0E–8	3.2E–8	nc	nc	nc	nc	nc
0	0.05	0.662	7.3E–8	7.8E–8	nc	nc	nc	nc	nc
0	0.05	1	1.3E–7	1.2E–7	nc	nc	nc	nc	nc
0	0.05	3	4.0E–7	3.7E–7	nc	nc	nc	nc	nc
0	0.25	0.05	nc	nc	nc	nc	nc	nc	nc
0	0.25	0.1	nc	2.1E–11	2.4E–11	2.4E–11		2.1E–11	1.3E–11
0	0.25	0.15	2.6E–10	2.8E–10	1.3E–10	1.4E–10	1.0E–10	1.2E–10	7.8E–11
0	0.25	0.3	1.5E–9	1.8E–9	1.4E–9	1.3E–9	7.5E–10	9.2E–10	5.9E–10
0	0.25	0.662	7.0E–9	8.4E–9	6.1E–9	5.2E–9	4.0E–9	4.3E–9	3.2E–9
0	0.25	1	1.9E–8	1.4E–8	1.2E–8	1.1E–8	8.8E–9	9.5E–9	7.2E–9
0	0.25	3	1.2E–7	5.7E–8	6.6E–8	6.5E–8	5.1E–8	5.4E–8	4.5E–8
0	0.5	0.05	nc	nc	nc	nc	nc	nc	nc
0	0.5	0.1	nc	nc	nc	nc	nc	nc	nc
0	0.5	0.15	nc	nc	nc	nc	nc	nc	nc
0	0.5	0.3	nc	nc	1.4E–11	2.0E–11	nc	1.5E–11	1.2E–11
0	0.5	0.662	nc	nc	3.9E–10	1.8E–10	3.6E–10	2.7E–10	1.9E–10
0	0.5	1	1.7E–9	1.4E–9	1.4E–9	8.8E–10	8.2E–10	8.0E–10	5.9E–10
0	0.5	3	1.8E–8	2.4E–8	2.4E–8	1.2E–8	1.2E–8	1.0E–8	8.4E–9
0.05	0	0.05	1.3E–9	1.6E–9	6.5E–9	8.9E–9	1.9E–9	4.2E–9	2.5E–9
0.05	0	0.1	7.0E–9	8.4E–9	1.6E–8	2.0E–8	7.0E–9	9.1E–9	6.5E–9
0.05	0	0.15	1.3E–8	1.5E–8	2.4E–8	3.0E–8	1.2E–8	1.6E–8	1.2E–8
0.05	0	0.3	3.2E–8	3.8E–8	5.7E–8	6.7E–8	3.1E–8	3.7E–8	2.7E–8
0.05	0	0.662	8.1E–8	9.9E–8	1.4E–7	1.6E–7	8.2E–8	8.5E–8	6.4E–8
0.05	0	1	1.3E–7	1.4E–7	2.1E–7	2.3E–7	1.3E–7	1.3E–7	9.8E–8
0.05	0	3	3.8E–7	3.8E–7	4.9E–7	6.0E–7	3.8E–7	3.4E–7	2.8E–7
0.05	0.05	0.05	4.1E–8	3.1E–8	nc	nc	nc	nc	nc
0.05	0.05	0.1	5.1E–8	4.1E–8	nc	nc	nc	nc	nc
0.05	0.05	0.15	8.3E–8	6.6E–8	nc	nc	nc	nc	nc
0.05	0.05	0.3	1.9E–7	1.5E–7	nc	nc	nc	nc	nc
0.05	0.05	0.662	4.0E–7	3.2E–7	nc	nc	nc	nc	nc
0.05	0.05	1	5.9E–7	4.7E–7	nc	nc	nc	nc	nc
0.05	0.05	3	1.3E–6	9.4E–7	nc	nc	nc	nc	nc
0.05	0.25	0.05	nc	nc	nc	nc	nc	nc	nc
0.05	0.25	0.1	nc	1.6E–10	1.3E–10	1.0E–10	6.5E–11	8.1E–11	4.8E–11
0.05	0.25	0.15	7.3E–10	7.0E–10	5.8E–10	5.7E–10	3.3E–10	3.8E–10	2.4E–10
0.05	0.25	0.3	3.9E–9	4.2E–9	2.9E–9	2.9E–9	1.8E–9	2.1E–9	1.4E–9
0.05	0.25	0.662	1.8E–8	1.6E–8	1.3E–8	1.1E–8	7.9E–9	8.8E–9	6.1E–9

Source depth (m)	Target depth (m)	Energy (MeV)	DCCs (μGy/h per photon/m^2 s)						
			woodlouse	earthworm	mouse	mole	snake	rabbit	fox
0.05	0.25	1	2.7E–8	1.8E–8	2.0E–8	1.9E–8	1.5E–8	1.7E–8	1.2E–8
0.05	0.25	3	1.3E–7	9.4E–8	9.1E–8	9.8E–8	7.5E–8	7.4E–8	6.0E–8
0.05	0.5	0.05	nc	nc	nc	nc	nc	nc	nc
0.05	0.5	0.1	nc	nc	nc	nc	nc	nc	nc
0.05	0.5	0.15	nc	nc	1.1E–11	nc	nc	nc	nc
0.05	0.5	0.3	nc	3.8E–11	1.6E–11	5.2E–11	nc	3.9E–11	2.7E–11
0.05	0.5	0.662	nc	3.6E–10	7.7E–10	6.1E–10	7.3E–10	4.8E–10	3.4E–10
0.05	0.5	1	2.9E–9	2.0E–9	2.0E–9	1.8E–9	1.8E–9	1.3E–9	1.0E–9
0.05	0.5	3	2.2E–8	1.9E–8	2.5E–8	1.7E–8	1.8E–8	1.4E–8	1.2E–8
0.10	0	0.05	6.6E–11	8.8E–11	3.5E–10	4.5E–10	1.1E–10	5.2E–9	2.3E–9
0.10	0	0.1	1.8E–9	2.0E–9	4.2E–9	5.1E–9	1.8E–9	1.1E–8	6.4E–9
0.10	0	0.15	4.0E–9	4.6E–9	8.3E–9	9.7E–9	3.9E–9	1.9E–8	1.2E–8
0.10	0	0.3	1.5E–8	1.3E–8	2.3E–8	2.6E–8	1.2E–8	4.3E–8	2.8E–8
0.10	0	0.662	4.3E–8	4.6E–8	6.2E–8	6.6E–8	3.6E–8	9.8E–8	6.4E–8
0.10	0	1	7.0E–8	6.8E–8	8.9E–8	1.1E–7	6.2E–8	1.5E–7	9.8E–8
0.10	0	3	2.5E–7	1.8E–7	3.7E–7	3.6E–7	2.1E–7	3.9E–7	2.8E–7
0.10	0.05	0.05	1.3E–9	1.5E–9	nc	nc	nc	nc	nc
0.10	0.05	0.1	8.6E–9	8.9E–9	nc	nc	nc	nc	nc
0.10	0.05	0.15	1.6E–8	1.8E–8	nc	nc	nc	nc	nc
0.10	0.05	0.3	4.3E–8	4.5E–8	nc	nc	nc	nc	nc
0.10	0.05	0.662	1.1E–7	1.1E–7	nc	nc	nc	nc	nc
0.10	0.05	1	1.5E–7	1.5E–7	nc	nc	nc	nc	nc
0.10	0.05	3	4.4E–7	4.7E–7	nc	nc	nc	nc	nc
0.10	0.25	0.05	nc	nc	nc	nc	nc	nc	nc
0.10	0.25	0.1	6.7E–10	5.9E–10	4.0E–10	4.2E–10	2.2E–10	2.8E–10	1.7E–10
0.10	0.25	0.15	2.3E–9	2.1E–9	1.5E–9	1.3E–9	8.5E–10	1.0E–9	6.5E–10
0.10	0.25	0.3	7.2E–9	8.6E–9	6.9E–9	6.8E–9	4.1E–9	4.6E–9	3.0E–9
0.10	0.25	0.662	2.3E–8	2.0E–8	2.3E–8	2.1E–8	1.5E–8	1.6E–8	1.1E–8
0.10	0.25	1	3.7E–8	4.2E–8	3.2E–8	3.5E–8	2.7E–8	2.8E–8	2.0E–8
0.10	0.25	3	1.6E–7	8.7E–8	1.3E–7	1.3E–7	1.2E–7	1.1E–7	8.6E–8
0.10	0.5	0.05	nc	nc	nc	nc	nc	nc	nc
0.10	0.5	0.1	nc	nc	nc	nc	nc	nc	nc
0.10	0.5	0.15	nc	nc	nc	nc	nc	nc	nc
0.10	0.5	0.3	1.1E–10	2.2E–10	1.5E–10	1.3E–10	1.4E–10	9.0E–11	6.4E–11
0.10	0.5	0.662	1.8E–9	7.3E–10	2.2E–9	1.6E–9	1.2E–9	8.3E–10	6.0E–10
0.10	0.5	1	3.1E–9	4.2E–9	2.5E–9	3.1E–9	3.3E–9	2.5E–9	1.7E–9
0.10	0.5	3	2.4E–8	2.7E–8	1.1E–8	2.3E–8	2.6E–8	2.0E–8	1.7E–8
0.20	0	0.05	nc	nc	nc	nc	nc	4.9E–11	2.9E–9
0.20	0	0.1	2.0E–10	1.6E–10	3.5E–10	3.8E–10	1.4E–10	1.4E–9	7.2E–9
0.20	0	0.15	5.6E–10	6.2E–10	1.2E–9	1.3E–9	5.1E–10	3.8E–9	1.3E–8
0.20	0	0.3	2.8E–9	2.7E–9	4.6E–9	5.4E–9	2.5E–9	1.2E–8	3.0E–8
0.20	0	0.662	1.6E–8	1.4E–8	1.6E–8	1.8E–8	1.0E–8	3.4E–8	7.0E–8
0.20	0	1	2.8E–8	2.6E–8	3.0E–8	3.0E–8	2.0E–8	5.5E–8	1.1E–7
0.20	0	3	8.4E–8	7.3E–8	1.0E–7	1.1E–7	9.1E–8	1.8E–7	2.9E–7
0.20	0.05	0.05	nc	nc	nc	nc	nc	nc	nc
0.20	0.05	0.1	6.0E–10	7.7E–10	nc	nc	nc	nc	nc
0.20	0.05	0.15	2.1E–9	2.1E–9	nc	nc	nc	nc	nc
0.20	0.05	0.3	7.7E–9	8.6E–9	nc	nc	nc	nc	nc
0.20	0.05	0.662	2.6E–8	3.1E–8	nc	nc	nc	nc	nc
0.20	0.05	1	4.9E–8	4.5E–8	nc	nc	nc	nc	nc
0.20	0.05	3	1.5E–7	1.5E–7	nc	nc	nc	nc	nc

Source depth (m)	Target depth (m)	Energy (MeV)	DCCs (µGy/h per photon/m^2 s)						
			woodlouse	earthworm	mouse	mole	snake	rabbit	fox
0.20	0.25	0.05	6.5E–10	6.3E–10	4.4E–10	4.4E–10	2.0E–10	2.7E–10	1.6E–10
0.20	0.25	0.1	7.7E–9	7.2E–9	5.6E–9	5.1E–9	2.9E–9	3.5E–9	2.0E–9
0.20	0.25	0.15	1.7E–8	1.4E–8	1.3E–8	1.2E–8	6.7E–9	7.8E–9	4.8E–9
0.20	0.25	0.3	4.3E–8	4.0E–8	3.2E–8	3.2E–8	2.0E–8	2.1E–8	1.4E–8
0.20	0.25	0.662	1.0E–7	9.6E–8	7.8E–8	7.2E–8	5.3E–8	5.4E–8	3.6E–8
0.20	0.25	1	1.4E–7	1.5E–7	1.1E–7	1.1E–7	8.3E–8	8.3E–8	5.8E–8
0.20	0.25	3	4.1E–7	3.4E–7	3.6E–7	3.2E–7	2.7E–7	2.4E–7	1.8E–7
0.20	0.5	0.05	nc	nc	nc	nc	nc	nc	nc
0.20	0.5	0.1	3.5E–11	3.8E–11	3.0E–11	2.0E–11	1.5E–11	1.0E–11	7.1E–12
0.20	0.5	0.15	8.7E–11	1.8E–10	1.2E–10	7.9E–11	8.8E–11	6.4E–11	4.6E–11
0.20	0.5	0.3	1.0E–9	9.6E–10	5.1E–10	6.4E–10	7.3E–10	4.5E–10	2.9E–10
0.20	0.5	0.662	5.2E–9	2.7E–9	4.0E–9	3.7E–9	3.6E–9	2.8E–9	2.0E–9
0.20	0.5	1	9.3E–9	8.6E–9	1.1E–8	9.3E–9	8.3E–9	6.1E–9	4.7E–9
0.20	0.5	3	5.3E–8	4.7E–8	3.4E–8	3.9E–8	4.6E–8	4.0E–8	3.2E–8
0.30	0	0.05	nc	nc	nc	nc	nc	nc	1.5E–11
0.30	0	0.1	nc	nc	1.8E–11	3.1E–11	nc	1.2E–10	6.6E–10
0.30	0	0.15	6.3E–11	3.1E–11	1.3E–10	1.5E–10	6.8E–11	5.4E–10	2.0E–9
0.30	0	0.3	4.8E–10	5.0E–10	8.3E–10	1.0E–9	5.3E–10	2.6E–9	6.9E–9
0.30	0	0.662	5.8E–9	5.0E–9	5.3E–9	5.4E–9	3.3E–9	1.0E–8	2.1E–8
0.30	0	1	1.1E–8	1.1E–8	1.2E–8	1.1E–8	6.8E–9	1.9E–8	3.5E–8
0.30	0	3	5.1E–8	5.6E–8	5.6E–8	5.5E–8	4.2E–8	8.4E–8	1.3E–7
0.30	0.05	0.05	nc	nc	nc	nc	nc	nc	nc
0.30	0.05	0.1	2.9E–11	4.2E–11	nc	nc	nc	nc	nc
0.30	0.05	0.15	4.1E–10	2.4E–10	nc	nc	nc	nc	nc
0.30	0.05	0.3	1.5E–9	1.4E–9	nc	nc	nc	nc	nc
0.30	0.05	0.662	7.7E–9	1.1E–8	nc	nc	nc	nc	nc
0.30	0.05	1	1.2E–8	1.3E–8	nc	nc	nc	nc	nc
0.30	0.05	3	6.8E–8	4.4E–8	nc	nc	nc	nc	nc
0.30	0.25	0.05	nc	1.1E–9	3.8E–9	6.4E–9	1.1E–9	3.4E–9	2.4E–9
0.30	0.25	0.1	8.7E–9	9.0E–9	1.5E–8	1.8E–8	6.6E–9	9.4E–9	6.6E–9
0.30	0.25	0.15	1.7E–8	1.8E–8	2.7E–8	3.2E–8	1.3E–8	1.7E–8	1.2E–8
0.30	0.25	0.3	4.5E–8	4.6E–8	6.4E–8	7.2E–8	3.4E–8	3.9E–8	2.9E–8
0.30	0.25	0.662	9.6E–8	1.1E–7	1.5E–7	1.6E–7	8.7E–8	9.0E–8	6.7E–8
0.30	0.25	1	1.6E–7	1.7E–7	2.1E–7	2.4E–7	1.4E–7	1.3E–7	1.0E–7
0.30	0.25	3	3.3E–7	4.2E–7	5.2E–7	6.1E–7	3.9E–7	3.6E–7	2.9E–7
0.30	0.5	0.05	nc	nc	nc	nc	nc	nc	nc
0.30	0.5	0.1	2.4E–10	2.0E–10	1.4E–10	1.5E–10	1.5E–10	1.1E–10	8.3E–11
0.30	0.5	0.15	7.5E–10	8.8E–10	6.0E–10	5.9E–10	6.2E–10	4.6E–10	3.3E–10
0.30	0.5	0.3	3.6E–9	3.3E–9	3.3E–9	2.9E–9	3.2E–9	2.1E–9	1.4E–9
0.30	0.5	0.662	1.2E–8	1.4E–8	1.2E–8	1.3E–8	1.3E–8	8.8E–9	6.2E–9
0.30	0.5	1	3.0E–8	2.1E–8	2.1E–8	2.3E–8	2.3E–8	1.7E–8	1.2E–8
0.30	0.5	3	7.9E–8	9.1E–8	1.1E–7	1.0E–7	9.7E–8	7.6E–8	6.0E–8
0.40	0	0.05	nc	nc	nc	nc	nc	nc	nc
0.40	0	0.1	nc	nc	nc	nc	nc	1.1E–11	5.3E–11
0.40	0	0.15	nc	nc	4.4E–11	1.3E–11	nc	7.0E–11	2.7E–10
0.40	0	0.3	nc	3.1E–11	3.2E–10	2.3E–10	1.2E–10	5.5E–10	1.5E–9
0.40	0	0.662	nc	9.4E–10	2.7E–9	2.1E–9	8.5E–10	3.3E–9	6.5E–9
0.40	0	1	1.8E–9	4.2E–9	4.4E–9	4.4E–9	2.7E–9	7.2E–9	1.3E–8
0.40	0	3	2.7E–8	2.6E–8	3.3E–8	3.0E–8	2.4E–8	4.2E–8	6.3E–8
0.40	0.05	0.05	nc	nc	nc	nc	nc	nc	nc
0.40	0.05	0.1	nc	nc	nc	nc	nc	nc	nc

Source depth (m)	Target depth (m)	Energy (MeV)	DCCs (µGy/h per photon/m^2 s)						
			woodlouse	earthworm	mouse	mole	snake	rabbit	fox
0.40	0.05	0.15	6.3E–11	3.5E–11	nc	nc	nc	nc	nc
0.40	0.05	0.3	4.0E–10	5.9E–10	nc	nc	nc	nc	nc
0.40	0.05	0.662	1.5E–9	1.9E–9	nc	nc	nc	nc	nc
0.40	0.05	1	6.1E–9	3.7E–9	nc	nc	nc	nc	nc
0.40	0.05	3	4.3E–8	4.8E–8	nc	nc	nc	nc	nc
0.40	0.25	0.05	nc	nc	2.6E–11	2.9E–11	4.2E–12	6.4E–10	2.4E–9
0.40	0.25	0.1	6.2E–10	7.9E–10	1.1E–9	1.3E–9	5.0E–10	5.1E–9	6.6E–9
0.40	0.25	0.15	2.0E–9	2.2E–9	3.4E–9	3.8E–9	1.6E–9	1.1E–8	1.2E–8
0.40	0.25	0.3	6.9E–9	9.1E–9	1.2E–8	1.3E–8	6.4E–9	2.7E–8	2.9E–8
0.40	0.25	0.662	2.3E–8	3.1E–8	3.3E–8	3.8E–8	2.2E–8	6.7E–8	6.8E–8
0.40	0.25	1	3.8E–8	4.9E–8	6.2E–8	6.6E–8	3.6E–8	1.0E–7	1.0E–7
0.40	0.25	3	1.2E–7	1.1E–7	1.5E–7	1.9E–7	1.4E–7	2.9E–7	2.8E–7
0.40	0.5	0.05	1.0E–10	1.1E–10	6.2E–11	7.4E–11	8.1E–11	3.9E–11	2.7E–11
0.40	0.5	0.1	2.5E–9	2.4E–9	1.8E–9	2.1E–9	2.0E–9	1.4E–9	1.0E–9
0.40	0.5	0.15	5.5E–9	5.7E–9	4.2E–9	4.0E–9	4.7E–9	3.3E–9	2.4E–9
0.40	0.5	0.3	1.9E–8	1.7E–8	1.4E–8	1.4E–8	1.5E–8	9.8E–9	6.4E–9
0.40	0.5	0.662	4.9E–8	4.6E–8	3.6E–8	3.7E–8	4.3E–8	2.9E–8	2.0E–8
0.40	0.5	1	7.6E–8	7.4E–8	6.1E–8	5.9E–8	6.8E–8	4.7E–8	3.4E–8
0.40	0.5	3	2.2E–7	2.5E–7	2.0E–7	2.1E–7	2.1E–7	1.6E–7	1.2E–7
0.50	0	0.05	nc	nc	nc	nc	nc	nc	nc
0.50	0	0.1	nc	nc	nc	nc	nc	nc	nc
0.50	0	0.15	nc	nc	nc	nc	nc	nc	3.4E–11
0.50	0	0.3	nc	4.5E–11	5.5E–11	6.8E–11	2.4E–11	1.2E–10	3.3E–10
0.50	0	0.662	nc	1.8E–10	4.3E–10	3.8E–10	3.2E–10	9.5E–10	2.1E–9
0.50	0	1	1.2E–9	5.4E–10	1.8E–9	1.4E–9	9.9E–10	2.6E–9	4.8E–9
0.50	0	3	1.6E–8	1.8E–8	1.5E–8	1.7E–8	1.3E–8	2.3E–8	3.2E–8
0.50	0.05	0.05	nc	nc	nc	nc	nc	nc	nc
0.50	0.05	0.1	nc	nc	nc	nc	nc	nc	nc
0.50	0.05	0.15	nc	2.0E–11	nc	nc	nc	nc	nc
0.50	0.05	0.3	nc	3.3E–11	nc	nc	nc	nc	nc
0.50	0.05	0.662	5.0E–10	6.5E–10	nc	nc	nc	nc	nc
0.50	0.05	1	2.3E–9	3.9E–10	nc	nc	nc	nc	nc
0.50	0.05	3	3.2E–8	5.5E–8	nc	nc	nc	nc	nc
0.50	0.25	0.05	nc	nc	nc	nc	nc	3.5E–12	2.2E–10
0.50	0.25	0.1	nc	2.7E–11	8.8E–11	1.1E–10	3.6E–11	4.2E–10	2.3E–9
0.50	0.25	0.15	3.1E–10	2.6E–10	6.0E–10	5.9E–10	2.3E–10	1.4E–9	5.3E–9
0.50	0.25	0.3	1.6E–9	1.8E–9	2.3E–9	2.9E–9	1.4E–9	5.7E–9	1.5E–8
0.50	0.25	0.662	6.4E–9	1.3E–8	1.0E–8	1.1E–8	6.5E–9	1.9E–8	3.9E–8
0.50	0.25	1	1.9E–8	2.3E–8	2.0E–8	2.0E–8	1.3E–8	3.3E–8	6.2E–8
0.50	0.25	3	7.6E–8	7.0E–8	9.7E–8	9.7E–8	6.5E–8	1.2E–7	1.9E–7
0.50	0.5	0.05	6.7E–8	5.1E–8	2.4E–8	2.1E–8	3.1E–8	1.0E–8	6.9E–9
0.50	0.5	0.1	5.9E–8	4.8E–8	2.7E–8	3.0E–8	3.2E–8	1.8E–8	1.3E–8
0.50	0.5	0.15	8.0E–8	6.6E–8	4.1E–8	3.7E–8	4.6E–8	2.6E–8	1.8E–8
0.50	0.5	0.3	1.8E–7	1.5E–7	9.0E–8	8.2E–8	1.0E–7	5.0E–8	3.1E–8
0.50	0.5	0.662	4.0E–7	3.5E–7	1.9E–7	1.8E–7	2.2E–7	1.1E–7	7.1E–8
0.50	0.5	1	5.8E–7	4.7E–7	2.8E–7	2.7E–7	3.2E–7	1.7E–7	1.1E–7
0.50	0.5	3	1.4E–6	1.1E–6	7.1E–7	6.1E–7	8.1E–7	4.3E–7	3.0E–7

Organisms on soil

Table A-3 Dose conversion coefficients for monoenergetic photons emitted from a planar source on top of the soil.

Energy	Dose conversion coefficients for monoenergetic (µGy per photon/m²)													
(MeV)	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle	small egg	big egg	herbiv. bird	carniv. bird
0.01	2.5E–9	2.2E–9	1.7E–9	1.6E–9	1.6E–9	1.6E–9	1.1E–9	8.0E–10	1.6E–10	2.1E–11	1.9E–9	1.7E–9	2.8E–11	1.7E–13
0.02	7.2E–10	6.4E–10	5.4E–10	5.1E–10	5.1E–10	5.1E–10	3.9E–10	3.1E–10	1.2E–10	2.0E–11	5.8E–10	5.4E–10	1.0E–10	3.1E–11
0.03	3.5E–10	3.1E–10	2.7E–10	2.6E–10	2.6E–10	2.6E–10	2.0E–10	1.7E–10	7.4E–11	1.4E–11	2.9E–10	2.7E–10	8.5E–11	4.2E–11
0.05	1.9E–10	1.7E–10	1.5E–10	1.4E–10	1.4E–10	1.4E–10	1.2E–10	9.8E–11	4.9E–11	1.0E–11	1.6E–10	1.5E–10	6.5E–11	4.2E–11
0.07	1.8E–10	1.7E–10	1.5E–10	1.4E–10	1.4E–10	1.4E–10	1.2E–10	1.0E–10	5.2E–11	1.2E–11	1.6E–10	1.5E–10	7.0E–11	4.8E–11
0.10	2.4E–10	2.2E–10	2.0E–10	1.9E–10	1.9E–10	1.9E–10	1.5E–10	1.3E–10	7.1E–11	1.7E–11	2.1E–10	2.0E–10	9.3E–11	6.3E–11
0.20	5.5E–10	5.0E–10	4.4E–10	4.2E–10	4.2E–10	4.2E–10	3.4E–10	2.9E–10	1.7E–10	5.1E–11	4.7E–10	4.4E–10	2.0E–10	1.3E–10
0.30	8.8E–10	8.0E–10	7.1E–10	6.7E–10	6.7E–10	6.7E–10	5.4E–10	4.7E–10	2.8E–10	1.0E–10	7.5E–10	7.1E–10	3.1E–10	2.0E–10
0.50	1.5E–9	1.4E–9	1.2E–9	1.2E–9	1.2E–9	1.1E–9	9.2E–10	8.0E–10	4.7E–10	1.8E–10	1.3E–9	1.2E–9	5.2E–10	3.3E–10
0.662	2.0E–9	1.8E–9	1.6E–9	1.5E–9	1.5E–9	1.5E–9	1.2E–9	1.1E–9	6.2E–10	2.4E–10	1.7E–9	1.6E–9	6.8E–10	4.3E–10
0.80	2.3E–9	2.1E–9	1.9E–9	1.8E–9	1.8E–9	1.8E–9	1.4E–9	1.3E–9	7.4E–10	2.9E–10	2.0E–9	1.9E–9	8.0E–10	5.1E–10
1.0	2.9E–9	2.6E–9	2.3E–9	2.2E–9	2.2E–9	2.2E–9	1.8E–9	1.6E–9	9.2E–10	3.7E–10	2.4E–9	2.3E–9	9.9E–10	6.3E–10
1.5	4.0E–9	3.6E–9	3.2E–9	3.0E–9	3.0E–9	3.0E–9	2.5E–9	2.2E–9	1.3E–9	5.6E–10	3.3E–9	3.2E–9	1.4E–9	8.9E–10
2.0	5.0E–9	4.5E–9	3.9E–9	3.8E–9	3.8E–9	3.8E–9	3.1E–9	2.8E–9	1.7E–9	7.7E–10	4.1E–9	3.9E–9	1.7E–9	1.1E–9
2.5	5.8E–9	5.2E–9	4.6E–9	4.4E–9	4.4E–9	4.5E–9	3.7E–9	3.3E–9	2.1E–9	9.9E–10	4.9E–9	4.6E–9	2.1E–9	1.4E–9
3.0	6.7E–9	6.0E–9	5.3E–9	5.1E–9	5.1E–9	5.2E–9	4.3E–9	3.8E–9	2.4E–9	1.2E–9	5.6E–9	5.3E–9	2.4E–9	1.6E–9
3.5	7.4E–9	6.7E–9	5.9E–9	5.7E–9	5.7E–9	5.8E–9	4.8E–9	4.3E–9	2.8E–9	1.5E–9	6.2E–9	5.9E–9	2.6E–9	1.8E–9
4.0	8.2E–9	7.4E–9	6.5E–9	6.3E–9	6.3E–9	6.5E–9	5.3E–9	4.8E–9	3.2E–9	1.8E–9	6.9E–9	6.5E–9	2.9E–9	2.0E–9
4.5	8.9E–9	8.2E–9	7.1E–9	7.0E–9	7.0E–9	7.1E–9	5.9E–9	5.3E–9	3.6E–9	2.0E–9	7.6E–9	7.1E–9	3.2E–9	2.3E–9
5.0	9.7E–9	8.9E–9	7.8E–9	7.6E–9	7.6E–9	7.8E–9	6.5E–9	5.9E–9	4.0E–9	2.4E–9	8.2E–9	7.7E–9	3.5E–9	2.5E–9

Table A-4 Dose conversion coefficients for monoenergetic photons emitted from a planar source at a depth of 3 mm.

Energy	Dose conversion coefficients for monoenergetic (µGy per photon/kg)													
(MeV)	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle	small egg	big egg	herbiv. bird	carniv. bird
0.01	3.1E–15	3.1E–15	3.1E–15	3.1E–15	3.1E–15	3.0E–15	2.8E–15	2.5E–15	1.6E–15	2.4E–16	3.1E–15	3.1E–15	7.8E–16	0E+00
0.02	1.4E–11	1.4E–11	1.4E–11	1.4E–11	1.3E–11	1.3E–11	1.2E–11	1.1E–11	7.0E–12	1.3E–12	1.4E–11	1.4E–11	9.9E–12	4.3E–12
0.03	3.3E–11	3.3E–11	3.3E–11	3.3E–11	3.3E–11	3.2E–11	3.0E–11	2.7E–11	1.8E–11	3.6E–12	3.3E–11	3.3E–11	2.9E–11	1.8E–11
0.05	4.6E–11	4.6E–11	4.6E–11	4.5E–11	4.5E–11	4.4E–11	4.1E–11	3.7E–11	2.5E–11	5.5E–12	4.6E–11	4.6E–11	4.1E–11	3.0E–11
0.07	5.9E–11	5.9E–11	5.8E–11	5.8E–11	5.8E–11	5.6E–11	5.2E–11	4.7E–11	3.2E–11	7.5E–12	5.8E–11	5.8E–11	5.3E–11	4.0E–11
0.10	8.3E–11	8.3E–11	8.3E–11	8.2E–11	8.2E–11	7.9E–11	7.3E–11	6.7E–11	4.7E–11	1.2E–11	8.3E–11	8.3E–11	7.4E–11	5.5E–11
0.20	1.9E–10	1.9E–10	1.8E–10	1.8E–10	1.8E–10	1.7E–10	1.6E–10	1.5E–10	1.1E–10	3.6E–11	1.9E–10	1.8E–10	1.6E–10	1.2E–10
0.30	2.9E–10	2.9E–10	2.9E–10	2.8E–10	2.8E–10	2.7E–10	2.5E–10	2.3E–10	1.8E–10	7.0E–11	2.9E–10	2.9E–10	2.5E–10	1.8E–10
0.50	4.8E–10	4.8E–10	4.8E–10	4.7E–10	4.7E–10	4.5E–10	4.2E–10	3.9E–10	3.1E–10	1.2E–10	4.8E–10	4.8E–10	4.2E–10	2.9E–10
0.662	6.3E–10	6.3E–10	6.3E–10	6.2E–10	6.2E–10	6.0E–10	5.5E–10	5.2E–10	4.0E–10	1.6E–10	6.3E–10	6.3E–10	5.4E–10	3.8E–10
0.80	7.5E–10	7.4E–10	7.4E–10	7.3E–10	7.3E–10	7.1E–10	6.6E–10	6.2E–10	4.8E–10	2.0E–10	7.5E–10	7.4E–10	6.4E–10	4.6E–10
1.0	9.2E–10	9.2E–10	9.1E–10	9.0E–10	9.0E–10	8.7E–10	8.1E–10	7.6E–10	6.0E–10	2.5E–10	9.2E–10	9.1E–10	7.9E–10	5.6E–10
1.5	1.3E–9	1.3E–9	1.3E–9	1.3E–9	1.3E–9	1.2E–9	1.2E–9	1.1E–9	8.6E–10	3.9E–10	1.3E–9	1.3E–9	1.1E–9	8.0E–10
2.0	1.6E–9	1.6E–9	1.6E–9	1.6E–9	1.6E–9	1.5E–9	1.5E–9	1.4E–9	1.1E–9	5.4E–10	1.6E–9	1.6E–9	1.4E–9	1.0E–9
2.5	1.9E–9	1.9E–9	1.9E–9	1.9E–9	1.9E–9	1.8E–9	1.7E–9	1.7E–9	1.4E–9	6.9E–10	1.9E–9	1.9E–9	1.6E–9	1.2E–9
3.0	2.2E–9	2.2E–9	2.2E–9	2.2E–9	2.2E–9	2.1E–9	2.0E–9	1.9E–9	1.6E–9	8.6E–10	2.2E–9	2.2E–9	1.9E–9	1.4E–9
3.5	2.4E–9	2.4E–9	2.4E–9	2.5E–9	2.5E–9	2.4E–9	2.3E–9	2.2E–9	1.8E–9	1.0E–9	2.4E–9	2.4E–9	2.1E–9	1.6E–9
4.0	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.6E–9	2.5E–9	2.1E–9	1.2E–9	2.7E–9	2.7E–9	2.4E–9	1.8E–9
4.5	2.9E–9	2.9E–9	3.0E–9	3.0E–9	3.0E–9	3.0E–9	2.8E–9	2.7E–9	2.4E–9	1.4E–9	2.9E–9	3.0E–9	2.6E–9	2.0E–9
5.0	3.2E–9	3.2E–9	3.2E–9	3.3E–9	3.3E–9	3.2E–9	3.1E–9	3.0E–9	2.6E–9	1.6E–9	3.2E–9	3.2E–9	2.8E–9	2.2E–9

Table A-5 Dose conversion coefficients for above-soil targets for monoenergetic photons emitted from homogeneously contaminated volume source with a thickness of 10 cm.

Energy	Dose conversion coefficients for monoenergetic (µGy per photon/kg)													
(MeV)	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle	small egg	big egg	herbiv. bird	carniv. bird
0.01	1.8E–10	1.7E–10	1.7E–10	1.7E–10	1.7E–10	1.6E–10	1.4E–10	1.2E–10	4.1E–11	5.8E–12	1.7E–10	1.7E–10	1.1E–11	0E+00
0.02	3.4E–10	3.4E–10	3.4E–10	3.3E–10	3.3E–10	3.2E–10	3.0E–10	2.7E–10	1.6E–10	3.0E–11	3.4E–10	3.4E–10	2.0E–10	7.2E–11
0.03	5.5E–10	5.5E–10	5.4E–10	5.4E–10	5.4E–10	5.2E–10	4.8E–10	4.4E–10	2.8E–10	5.6E–11	5.5E–10	5.4E–10	4.4E–10	2.7E–10
0.05	1.2E–9	1.2E–9	1.2E–9	1.2E–9	1.2E–9	1.2E–9	1.1E–9	9.8E–10	6.6E–10	1.5E–10	1.2E–9	1.2E–9	1.1E–9	8.7E–10
0.07	2.2E–9	2.2E–9	2.2E–9	2.2E–9	2.2E–9	2.1E–9	2.0E–9	1.8E–9	1.2E–9	2.9E–10	2.2E–9	2.2E–9	2.1E–9	1.7E–9
0.10	4.0E–9	4.0E–9	4.0E–9	4.0E–9	4.0E–9	3.8E–9	3.5E–9	3.2E–9	2.3E–9	5.9E–10	4.0E–9	4.0E–9	3.8E–9	3.1E–9
0.20	1.0E–8	1.0E–8	1.0E–8	1.0E–8	1.0E–8	9.8E–9	9.1E–9	8.4E–9	6.3E–9	2.1E–9	1.0E–8	1.0E–8	9.8E–9	7.8E–9
0.30	1.7E–8	1.7E–8	1.7E–8	1.6E–8	1.6E–8	1.6E–8	1.5E–8	1.4E–8	1.1E–8	4.1E–9	1.7E–8	1.7E–8	1.6E–8	1.2E–8
0.50	2.9E–8	2.9E–8	2.9E–8	2.8E–8	2.8E–8	2.7E–8	2.5E–8	2.3E–8	1.9E–8	7.4E–9	2.9E–8	2.9E–8	2.7E–8	2.1E–8
0.662	3.8E–8	3.8E–8	3.7E–8	3.7E–8	3.7E–8	3.6E–8	3.3E–8	3.1E–8	2.5E–8	1.0E–8	3.8E–8	3.8E–8	3.5E–8	2.8E–8
0.80	4.5E–8	4.5E–8	4.5E–8	4.4E–8	4.4E–8	4.3E–8	4.0E–8	3.8E–8	3.0E–8	1.2E–8	4.5E–8	4.5E–8	4.2E–8	3.4E–8
1.0	5.6E–8	5.6E–8	5.6E–8	5.5E–8	5.5E–8	5.3E–8	5.0E–8	4.7E–8	3.7E–8	1.6E–8	5.6E–8	5.6E–8	5.3E–8	4.2E–8
1.5	8.1E–8	8.1E–8	8.0E–8	7.9E–8	7.9E–8	7.7E–8	7.3E–8	6.8E–8	5.5E–8	2.5E–8	8.1E–8	8.0E–8	7.6E–8	6.2E–8
2.0	1.0E–7	1.0E–7	1.0E–7	1.0E–7	1.0E–7	1.0E–7	9.4E–8	8.9E–8	7.3E–8	3.6E–8	1.0E–7	1.0E–7	9.7E–8	8.1E–8
2.5	1.3E–7	1.2E–7	1.2E–7	1.2E–7	1.2E–7	1.2E–7	1.2E–7	1.1E–7	9.1E–8	4.7E–8	1.2E–7	1.2E–7	1.2E–7	9.9E–8
3.0	1.5E–7	1.5E–7	1.5E–7	1.5E–7	1.5E–7	1.4E–7	1.4E–7	1.3E–7	1.1E–7	5.9E–8	1.5E–7	1.5E–7	1.4E–7	1.2E–7
3.5	1.6E–7	1.6E–7	1.7E–7	1.7E–7	1.7E–7	1.6E–7	1.6E–7	1.5E–7	1.3E–7	7.2E–8	1.6E–7	1.6E–7	1.6E–7	1.3E–7
4.0	1.8E–7	1.8E–7	1.8E–7	1.9E–7	1.9E–7	1.8E–7	1.8E–7	1.7E–7	1.5E–7	8.6E–8	1.8E–7	1.8E–7	1.8E–7	1.5E–7
4.5	2.0E–7	2.0E–7	2.0E–7	2.1E–7	2.1E–7	2.0E–7	2.0E–7	1.9E–7	1.7E–7	1.0E–7	2.0E–7	2.0E–7	1.9E–7	1.7E–7
5.0	2.2E–7	2.2E–7	2.2E–7	2.3E–7	2.3E–7	2.2E–7	2.2E–7	2.1E–7	1.9E–7	1.2E–7	2.2E–7	2.2E–7	2.1E–7	1.9E–7

9.1.2 Internal exposure

Absorbed fractions

Table A-6 Absorbed fraction of energy in terrestrial reference organism and internal exposure due to a monoenergetic isotropic sources uniformily distributed in the whole body, as a function of the energy of the source.

Radiation type/ Energy (MeV)	Absorbed fractions of internally released energy									
	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
Photons										
0.020	0.11	0.22	0.49	0.58	0.55	0.55	0.82	0.88	0.92	0.97
0.040	0.016	0.035	0.10	0.14	0.13	0.13	0.37	0.50	0.65	0.87
0.100	0.006	0.013	0.038	0.053	0.048	0.049	0.15	0.24	0.37	0.71
0.300	0.007	0.016	0.046	0.062	0.057	0.059	0.16	0.24	0.35	0.68
0.662	0.006	0.017	0.046	0.063	0.057	0.060	0.16	0.23	0.34	0.65
1.0	0.004	0.016	0.042	0.059	0.053	0.058	0.15	0.22	0.32	0.63
2.0	0.002	0.007	0.032	0.045	0.041	0.050	0.13	0.19	0.28	0.58
3.0	0.001	0.004	0.025	0.036	0.033	0.044	0.11	0.17	0.25	0.53
Electrons										
0.02	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.04	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.10	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.30	0.86	0.94	0.98	0.98	0.98	0.98	0.99	1.00	1.00	1.00
0.662	0.61	0.82	0.94	0.95	0.95	0.95	0.98	0.99	0.99	1.00
1.0	0.41	0.71	0.90	0.93	0.92	0.92	0.97	0.98	0.99	1.00
2.0	0.19	0.44	0.79	0.84	0.82	0.83	0.94	0.96	0.97	0.99
3.0	0.12	0.29	0.69	0.76	0.73	0.74	0.90	0.94	0.96	0.98
α-particles										
all energies	1	1	1	1	1	1	1	1	1	1

Contribution of α-, β- and γ-radiation to dose conversion coefficients for internal exposure for terrestrial reference organisms

Table A-7 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of α-particles.

Radio–nuclide	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg) for α–particles									
	wood–louse	earth–worm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H–3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C–14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K–40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl–36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni–63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni–59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr–89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr–90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb–94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tc–99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ru–106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I–129	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I–131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs–134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs–135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs–137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Po–210	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3
Pb–210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ra–226	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2	1.4E–2
Th–227	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3	3.4E–3
Th–228	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2
Th–230	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
Th–231	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th–232	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3
Th–234	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U–234	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
U–235	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3
U–238	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3	2.4E–3
Pu–238	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
Pu–239	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
Pu–240	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
Pu–241	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8
Am–241	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
Np–237	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3	2.8E–3
Cm–242	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3
Cm–243	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3
Cm–244	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3

Table A-8 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of low-energy β-radiation (E < 10 keV).

Radio	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg) low–β radiation (E < 10 keV)									
nuclide	wood–louse	earth–worm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H–3	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6
C–14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K–40	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7
Cl–36	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8
Ni–59	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6
Ni–63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr–89	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12	1.0E–12
Sr–90	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10	2.2E–10
Nb–94	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9	4.3E–9
Tc–99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ru–106	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9	2.7E–9
I–129	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6
I–131	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7	1.6E–7
Cs–134	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8	2.9E–8
Cs–135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs–137	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7	2.5E–7
Po–210	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13	3.7E–13
Pb–210	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6	4.1E–6
Ra–226	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6	1.5E–6
Th–227	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6	3.8E–6
Th–228	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6	3.4E–6
Th–230	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7
Th–231	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6	8.8E–6
Th–232	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7
Th–234	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7	9.8E–7
U–234	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7	8.1E–7
U–235	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5	1.2E–5
U–238	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7	6.7E–7
Pu–238	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7	8.7E–7
Pu–239	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6	1.2E–6
Pu–240	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7	8.3E–7
Pu–241	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6
Am–241	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6
Np–237	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6	5.5E–6
Cm–242	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7	8.2E–7
Cm–243	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6	7.9E–6
Cm–244	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7

Table A-9 Unweighted dose conversion coefficients (μGy/h per Bq/kg) for internal exposure, contribution of β-radiation ($E \geq 10$ keV).

Radio-nuclide	Unweighted internal dose conversion coefficients (μGy/h per Bq/kg) for electrons									
	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H–3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C–14	2.8E–5	2.8E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5
K–40	2.0E–4	2.6E–4	2.9E–4	2.9E–4	2.9E–4	2.9E–4	3.0E–4	3.0E–4	3.0E–4	3.0E–4
Cl–36	1.4E–4	1.5E–4	1.5E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4
Ni–59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni–63	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6
Sr–89	2.2E–4	2.9E–4	3.2E–4	3.2E–4	3.2E–4	3.2E–4	3.3E–4	3.3E–4	3.3E–4	3.4E–4
Sr–90	3.5E–4	5.1E–4	6.0E–4	6.1E–4	6.1E–4	6.1E–4	6.4E–4	6.4E–4	6.5E–4	6.5E–4
Nb–94	9.0E–5	9.4E–5	9.6E–5	9.6E–5	9.6E–5	9.6E–5	9.7E–5	9.7E–5	9.7E–5	9.7E–5
Tc–99	5.7E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5
Ru–106	2.6E–4	4.9E–4	7.0E–4	7.3E–4	7.2E–4	7.2E–4	7.8E–4	8.0E–4	8.0E–4	8.1E–4
I–129	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5	3.2E–5
I–131	1.0E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4
Cs–134	8.5E–5	9.0E–5	9.3E–5	9.3E–5	9.3E–5	9.3E–5	9.4E–5	9.4E–5	9.4E–5	9.4E–5
Cs–135	3.8E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5
Cs–137	1.2E–4	1.3E–4	1.4E–4	1.4E–4	1.4E–4	1.4E–4	1.4E–4	1.4E–4	1.4E–4	1.4E–4
Po–210	2.7E–11	3.8E–11	4.4E–11	4.4E–11	4.4E–11	4.4E–11	4.6E–11	4.6E–11	4.6E–11	4.7E–11
Pb–210	2.0E–4	2.2E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4
Ra–226	3.7E–4	4.6E–4	5.2E–4	5.3E–4	5.2E–4	5.2E–4	5.4E–4	5.4E–4	5.5E–4	5.5E–4
Th–227	2.6E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5	2.7E–5
Th–228	3.4E–4	4.3E–4	4.8E–4	4.9E–4	4.8E–4	4.9E–4	5.0E–4	5.0E–4	5.0E–4	5.1E–4
Th–230	7.7E–6	7.7E–6	7.8E–6	7.8E–6	7.8E–6	7.8E–6	7.8E–6	7.8E–6	7.8E–6	7.8E–6
Th–231	8.5E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5	8.6E–5
Th–232	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6
Th–234	2.8E–4	4.0E–4	4.7E–4	4.8E–4	4.8E–4	4.8E–4	5.0E–4	5.0E–4	5.0E–4	5.1E–4
U–234	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6	6.8E–6
U–235	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4	1.1E–4
U–238	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6	5.1E–6
Pu–238	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6
Pu–239	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6	2.7E–6
Pu–240	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6	5.3E–6
Pu–241	5.6E–9	5.6E–9	5.6E–9	5.6E–9	5.6E–9	5.6E–9	5.7E–9	5.7E–9	5.7E–9	5.7E–9
Am–241	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5
Np–237	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5	3.5E–5
Cm–242	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6	4.7E–6
Cm–243	6.8E–5	7.0E–5	7.1E–5	7.1E–5	7.1E–5	7.1E–5	7.2E–5	7.2E–5	7.2E–5	7.2E–5
Cm–244	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6

Table A-10 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of photons.

Radio–	Unweighted internal dose conversion coefficients (µGy/h per Bq/kg) for photons									
nuclide	woodlouse	earthworm	mouse	mole	weasel	snake	rabbit	red fox	row deer	cattle
H–3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C–14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K–40	2.9E–7	1.1E–6	3.4E–6	4.7E–6	4.3E–6	4.9E–6	1.3E–5	1.9E–5	2.7E–5	5.5E–5
Cl–36	8.7E–10	2.1E–9	5.5E–9	7.2E–9	6.6E–9	6.9E–9	1.6E–8	2.2E–8	3.2E–8	6.0E–8
Ni–59	2.3E–7	4.7E–7	1.0E–6	1.2E–6	1.1E–6	1.2E–6	1.4E–6	1.4E–6	1.4E–6	1.4E–6
Ni–63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr–89	2.3E–10	7.9E–10	2.1E–9	2.9E–9	2.6E–9	2.9E–9	7.6E–9	1.1E–8	1.6E–8	3.1E–8
Sr–90	1.2E–10	2.5E–10	5.6E–10	6.5E–10	6.2E–10	6.2E–10	8.9E–10	9.3E–10	9.5E–10	9.7E–10
Nb–94	4.7E–6	1.5E–5	4.0E–5	5.5E–5	5.0E–5	5.4E–5	1.4E–4	2.1E–4	3.0E–4	5.8E–4
Tc–99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ru–106	6.8E–7	1.9E–6	5.3E–6	7.3E–6	6.6E–6	7.0E–6	1.9E–5	2.7E–5	4.0E–5	7.7E–5
I–129	7.8E–7	1.6E–6	3.9E–6	4.7E–6	4.4E–6	4.5E–6	8.0E–6	9.4E–6	1.1E–5	1.3E–5
I–131	1.5E–6	3.7E–6	1.0E–5	1.4E–5	1.3E–5	1.3E–5	3.6E–5	5.3E–5	7.7E–5	1.5E–4
Cs–134	4.9E–6	1.5E–5	4.0E–5	5.5E–5	5.0E–5	5.3E–5	1.4E–4	2.1E–4	3.0E–4	5.8E–4
Cs–135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs–137	1.9E–6	5.5E–6	1.5E–5	2.1E–5	1.9E–5	2.0E–5	5.3E–5	7.7E–5	1.1E–4	2.1E–4
Po–210	2.6E–11	8.0E–11	2.2E–10	3.0E–10	2.7E–10	2.9E–10	7.8E–10	1.1E–9	1.6E–9	3.2E–9
Pb–210	2.5E–7	5.2E–7	1.2E–6	1.4E–6	1.3E–6	1.3E–6	2.0E–6	2.2E–6	2.4E–6	2.6E–6
Ra–226	4.3E–6	1.3E–5	4.1E–5	5.7E–5	5.2E–5	5.7E–5	1.5E–4	2.2E–4	3.2E–4	6.3E–4
Th–227	8.8E–7	1.9E–6	4.9E–6	6.3E–6	5.9E–6	6.0E–6	1.4E–5	1.9E–5	2.6E–5	4.5E–5
Th–228	3.1E–6	9.3E–6	3.2E–5	4.5E–5	4.1E–5	4.8E–5	1.2E–4	1.8E–4	2.7E–4	5.3E–4
Th–230	9.0E–8	1.9E–7	4.2E–7	4.9E–7	4.7E–7	4.7E–7	6.9E–7	7.3E–7	7.7E–7	8.4E–7
Th–231	1.0E–6	2.2E–6	4.9E–6	5.8E–6	5.5E–6	5.6E–6	8.7E–6	9.7E–6	1.1E–5	1.3E–5
Th–232	8.8E–8	1.8E–7	4.1E–7	4.7E–7	4.5E–7	4.5E–7	6.5E–7	6.9E–7	7.1E–7	7.4E–7
Th–234	2.1E–7	4.9E–7	1.2E–6	1.6E–6	1.5E–6	1.5E–6	3.4E–6	4.6E–6	6.3E–6	1.1E–5
U–234	1.2E–7	2.4E–7	5.4E–7	6.4E–7	6.0E–7	6.1E–7	8.7E–7	9.2E–7	9.4E–7	9.8E–7
U–235	1.9E–6	4.0E–6	9.9E–6	1.2E–5	1.2E–5	1.2E–5	2.5E–5	3.3E–5	4.5E–5	7.7E–5
U–238	9.7E–8	2.0E–7	4.5E–7	5.2E–7	5.0E–7	5.0E–7	7.1E–7	7.4E–7	7.6E–7	7.8E–7
Pu–238	1.3E–7	2.6E–7	5.8E–7	6.8E–7	6.5E–7	6.5E–7	9.3E–7	9.8E–7	1.0E–6	1.0E–6
Pu–239	5.6E–8	1.2E–7	2.6E–7	3.0E–7	2.9E–7	2.9E–7	4.0E–7	4.2E–7	4.3E–7	4.5E–7
Pu–240	1.2E–7	2.5E–7	5.6E–7	6.5E–7	6.2E–7	6.2E–7	8.9E–7	9.4E–7	9.6E–7	9.9E–7
Pu–241	1.1E–10	2.3E–10	5.4E–10	6.6E–10	6.2E–10	6.2E–10	1.1E–9	1.4E–9	1.8E–9	2.7E–9
Am–241	9.1E–7	1.9E–6	4.5E–6	5.5E–6	5.1E–6	5.2E–6	9.3E–6	1.1E–5	1.3E–5	1.6E–5
Np–237	8.9E–7	1.9E–6	4.3E–6	5.2E–6	4.9E–6	5.0E–6	8.5E–6	1.0E–5	1.2E–5	1.6E–5
Cm–242	1.2E–7	2.6E–7	5.7E–7	6.7E–7	6.4E–7	6.4E–7	9.3E–7	9.8E–7	1.0E–6	1.0E–6
Cm–243	1.1E–6	2.4E–6	6.1E–6	7.7E–6	7.2E–6	7.3E–6	1.6E–5	2.2E–5	3.1E–5	5.6E–5
Cm–244	1.2E–7	2.4E–7	5.3E–7	6.2E–7	5.9E–7	6.0E–7	8.6E–7	9.1E–7	9.3E–7	9.6E–7

9.2 DCC for aquatic reference organisms

9.2.1 Coastal—estuarine ecosystem DCC's for internal irradiation

Table A-11 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of low-energy β-radiation (*E* < 10 keV).

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)											
	Bac-teria	Phyto-plank-ton	Zoo-plan-kton	Mollusc	Worm	Vas-cular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crus-tacean	Mam-mal
^{3}H	0	3.2E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	0	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8
^{40}K	0	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7
^{59}Ni	0	2.5E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	0	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	0	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6
^{129}I	0	4.4E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6
^{131}I	0	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	0	2.3E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7
^{144}Ce	0	4.7E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7
^{210}Pb	0	4.1E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6
^{210}Po	0	3.5E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13
^{226}Ra	0	5.5E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6
^{227}Th	0	8.4E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6
^{228}Th	0	3.1E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6
^{230}Th	0	7.3E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7
^{231}Th	0	6.7E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6
^{232}Th	0	7.2E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7
^{234}Th	0	6.9E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7
^{234}U	0	5.9E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7
^{235}U	0	9.9E–6	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5
^{237}Np	0	7.2E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6
^{238}U	0	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6
^{238}Pu	0	6.3E–7	6.4E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7
^{239}Pu	0	1.0E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6
^{240}Pu	0	6.0E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7
^{241}Pu	0	2.9E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6
^{241}Am	0	4.2E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6
^{242}Cm	0	6.0E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7
^{243}Cm	0	6.4E–6	6.5E–6	6.6E–6	6.5E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6
^{244}Cm	0	5.6E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7

Table A-12 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of β-radiation ($E \geq 10$ keV) and γ-radiation.

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)											
	Bac-teria	Phyto-plank-ton	Zoo-plan-kton	Mollusc	Worm	Vas-cular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crus-tacean	Mam-mal
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	0	9.3E–6	2.8E–5	2.8E–5	2.8E–5	2.8E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5
^{32}P	0	1.3E–6	1.8E–4	3.6E–4	3.2E–4	3.8E–4	3.8E–4	3.9E–4	3.8E–4	3.8E–4	3.9E–4	4.0E–4
^{36}Cl	0	2.9E–6	1.2E–4	1.5E–4	1.5E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4
^{40}K	0	1.4E–6	1.6E–4	2.8E–4	2.6E–4	3.0E–4	3.0E–4	3.0E–4	3.0E–4	3.0E–4	3.1E–4	3.4E–4
^{59}Ni	0	2.6E–8	7.1E–7	1.2E–6	1.0E–6	1.3E–6	1.3E–6	1.5E–6	1.3E–6	1.3E–6	1.4E–6	1.7E–6
^{63}Ni	0	7.7E–6	9.8E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6
^{60}Co	0	6.8E–6	5.9E–5	9.8E–5	8.1E–5	1.5E–4	1.7E–4	2.0E–4	1.6E–4	1.7E–4	2.3E–4	7.0E–4
^{89}Sr	0	1.6E–6	1.8E–4	3.1E–4	2.8E–4	3.2E–4	3.3E–4	3.3E–4	3.2E–4	3.3E–4	3.3E–4	3.4E–4
^{90}Sr	0	5.0E–6	2.9E–4	5.7E–4	5.0E–4	6.1E–4	6.2E–4	6.3E–4	6.1E–4	6.2E–4	6.3E–4	6.5E–4
^{95}Zr	0	6.1E–6	6.4E–5	8.1E–5	7.5E–5	9.9E–5	1.1E–4	1.1E–4	1.0E–4	1.1E–4	1.3E–4	2.8E–4
^{94}Nb	0	4.6E–6	8.9E–5	1.2E–4	1.1E–4	1.6E–4	1.8E–4	2.0E–4	1.7E–4	1.8E–4	2.2E–4	5.4E–4
^{95}Nb	0	9.6E–6	2.7E–5	3.9E–5	3.4E–5	5.8E–5	6.5E–5	7.4E–5	5.9E–5	6.4E–5	8.6E–5	2.4E–4
^{99}Tc	0	6.5E–6	5.5E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5
^{106}Ru	0	6.0E–6	1.9E–4	6.1E–4	4.8E–4	7.2E–4	7.4E–4	7.7E–4	7.2E–4	7.4E–4	7.8E–4	8.7E–4
^{125}I	0	3.1E–6	6.1E–6	1.0E–5	8.3E–6	1.4E–5	1.5E–5	1.7E–5	1.4E–5	1.4E–5	1.7E–5	2.5E–5
^{129}I	0	1.1E–5	3.2E–5	3.5E–5	3.4E–5	3.7E–5	3.7E–5	3.8E–5	3.7E–5	3.7E–5	3.9E–5	4.3E–5
^{131}I	0	4.9E–6	9.6E–5	1.2E–4	1.1E–4	1.3E–4	1.3E–4	1.4E–4	1.3E–4	1.3E–4	1.4E–4	2.3E–4
^{134}Cs	0	5.3E–6	8.3E–5	1.2E–4	1.1E–4	1.6E–4	1.7E–4	1.9E–4	1.6E–4	1.7E–4	2.2E–4	5.4E–4
^{135}Cs	0	8.3E–6	3.8E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5
^{137}Cs	0	4.5E–6	1.1E–4	1.5E–4	1.4E–4	1.7E–4	1.7E–4	1.8E–4	1.7E–4	1.7E–4	1.9E–4	3.1E–4
^{144}Ce	0	9.8E–6	2.4E–4	6.0E–4	5.0E–4	6.8E–4	6.9E–4	7.1E–4	6.8E–4	6.9E–4	7.2E–4	7.6E–4
^{210}Pb	0	1.2E–5	1.7E–4	2.3E–4	2.2E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4
^{210}Po	0	5.4E–13	4.4E–11	1.9E–10	1.3E–10	4.0E–10	4.8E–10	5.8E–10	4.2E–10	4.7E–10	7.1E–10	2.5E–9
^{226}Ra	0	2.0E–5	4.8E–4	7.6E–4	6.9E–4	8.2E–4	8.5E–4	8.7E–4	8.3E–4	8.4E–4	9.0E–4	1.2E–3
^{227}Th	0	2.0E–5	3.9E–4	5.9E–4	5.6E–4	6.2E–4	6.3E–4	6.4E–4	6.2E–4	6.3E–4	6.5E–4	7.4E–4
^{228}Th	0	1.6E–5	2.9E–4	4.9E–4	4.4E–4	5.4E–4	5.6E–4	5.8E–4	5.5E–4	5.6E–4	6.0E–4	8.8E–4
^{230}Th	0	2.4E–6	7.6E–6	8.0E–6	7.9E–6	8.1E–6	8.1E–6	8.2E–6	8.1E–6	8.1E–6	8.2E–6	8.4E–6
^{231}Th	0	1.9E–5	4.3E–5	4.6E–5	4.5E–5	4.8E–5	4.8E–5	4.9E–5	4.8E–5	4.8E–5	4.9E–5	5.4E–5
^{232}Th	0	2.4E–6	6.4E–6	6.8E–6	6.7E–6	6.9E–6	6.9E–6	7.0E–6	6.9E–6	6.9E–6	6.9E–6	7.1E–6
^{234}Th	0	1.3E–5	2.2E–4	4.5E–4	3.9E–4	4.8E–4	4.8E–4	4.9E–4	4.8E–4	4.8E–4	4.9E–4	5.1E–4
^{234}U	0	3.2E–6	7.1E–6	7.5E–6	7.3E–6	7.6E–6	7.6E–6	7.8E–6	7.6E–6	7.6E–6	7.7E–6	8.0E–6
^{235}U	0	3.8E–5	1.1E–4	1.2E–4	1.2E–4	1.3E–4	1.3E–4	1.3E–4	1.3E–4	1.3E–4	1.3E–4	1.7E–4
^{237}Np	0	3.1E–5	1.3E–4	1.5E–4	1.5E–4	1.6E–4	1.6E–4	1.7E–4	1.6E–4	1.6E–4	1.7E–4	2.3E–4
^{238}U	0	1.9E–5	2.3E–4	4.6E–4	4.1E–4	4.9E–4	5.0E–4	5.1E–4	4.9E–4	5.0E–4	5.1E–4	5.3E–4
^{238}Pu	0	3.2E–6	5.6E–6	6.0E–6	5.8E–6	6.1E–6	6.1E–6	6.2E–6	6.1E–6	6.1E–6	6.2E–6	6.5E–6
^{239}Pu	0	1.7E–6	2.8E–6	3.0E–6	2.9E–6	3.0E–6	3.0E–6	3.1E–6	3.0E–6	3.0E–6	3.1E–6	3.2E–6
^{240}Pu	0	3.1E–6	5.6E–6	6.0E–6	5.8E–6	6.1E–6	6.1E–6	6.2E–6	6.1E–6	6.1E–6	6.2E–6	6.4E–6
^{241}Pu	0	5.9E–10	2.6E–9	3.0E–9	2.9E–9	3.3E–9	3.4E–9	3.5E–9	3.3E–9	3.3E–9	3.6E–9	4.9E–9
^{241}Am	0	1.5E–5	2.6E–5	2.9E–5	2.8E–5	3.1E–5	3.1E–5	3.2E–5	3.1E–5	3.1E–5	3.3E–5	3.9E–5
^{242}Cm	0	2.9E–6	5.0E–6	5.4E–6	5.2E–6	5.5E–6	5.5E–6	5.7E–6	5.5E–6	5.5E–6	5.6E–6	5.9E–6
^{243}Cm	0	1.3E–5	6.7E–5	7.7E–5	7.4E–5	8.1E–5	8.3E–5	8.6E–5	8.2E–5	8.3E–5	8.8E–5	1.2E–4
^{244}Cm	0	2.7E–6	4.5E–6	4.8E–6	4.7E–6	5.0E–6	5.0E–6	5.1E–6	5.0E–6	4.9E–6	5.0E–6	5.3E–6

Table A-13 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of α-radiation.

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)											
	Bac-teria	Phyto-plank-ton	Zoo-plan-kton	Mollusc	Worm	Vas-cular plant	Pelagic fish	Bird	Macroal gae	Benthic fish	Crus-tacean	Mammal
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	0	0	0	0	0	0	0	0	0	0	0	0
^{40}K	0	0	0	0	0	0	0	0	0	0	0	0
^{59}Ni	0	0	0	0	0	0	0	0	0	0	0	0
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	0	0	0	0	0	0	0	0	0	0	0	0
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	0	0	0	0	0	0	0	0	0	0	0	0
^{129}I	0	0	0	0	0	0	0	0	0	0	0	0
^{131}I	0	0	0	0	0	0	0	0	0	0	0	0
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{144}Ce	0	0	0	0	0	0	0	0	0	0	0	0
^{210}Pb	0	0	0	0	0	0	0	0	0	0	0	0
^{210}Po	0	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3
^{226}Ra	0	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2
^{227}Th	0	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2
^{228}Th	0	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2
^{230}Th	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{231}Th	0	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5
^{232}Th	0	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3
^{234}Th	0	0	0	0	0	0	0	0	0	0	0	0
^{234}U	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{235}U	0	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3
^{237}Np	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{238}U	0	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3
^{238}Pu	0	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
^{239}Pu	0	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
^{240}Pu	0	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
^{241}Pu	0	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8
^{241}Am	0	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
^{242}Cm	0	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3
^{243}Cm	0	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3
^{244}Cm	0	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3

Coastal—estuarine ecosystem DCC's for external irradiation

Table A-14 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of low-energy β-radiation (*E* < 10 keV).

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)											
	Bac-teria	Phyto-plank-ton	Zoo-plan-kton	Mollusc	Worm	Vas-cular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crus-tacean	Mam-mal
^{3}H	3.3E–6	1.1E–7	2.6E–9	1.8E–10	4.7E–10	1.8E–10	6.9E–11	6.6E–11	1.3E–10	8.7E–11	7.6E–11	3.5E–11
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	1.9E–8	1.0E–10	3.4E–12	2.1E–13	6.0E–13	2.5E–13	8.4E–14	8.7E–14	1.8E–13	1.1E–13	1.1E–13	5.5E–14
^{40}K	1.1E–7	9.7E–10	2.9E–11	1.9E–12	5.2E–12	2.1E–12	7.3E–13	7.4E–13	1.5E–12	9.6E–13	8.9E–13	4.5E–13
^{59}Ni	2.6E–6	8.1E–8	1.8E–9	1.3E–10	3.4E–10	1.2E–10	4.9E–11	4.7E–11	9.3E–11	6.2E–11	5.4E–11	2.4E–11
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	7.0E–9	2.7E–11	8.9E–13	5.6E–14	1.6E–13	6.7E–14	2.2E–14	2.3E–14	4.7E–14	2.9E–14	2.8E–14	1.5E–14
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	6.0E–6	7.0E–8	1.9E–9	1.3E–10	3.4E–10	1.4E–10	4.9E–11	4.9E–11	9.8E–11	6.3E–11	5.8E–11	2.8E–11
^{129}I	4.5E–6	8.8E–8	2.2E–9	1.5E–10	4.0E–10	1.5E–10	5.8E–11	5.6E–11	1.1E–10	7.3E–11	6.6E–11	3.1E–11
^{131}I	2.5E–8	3.0E–10	7.9E–12	5.3E–13	1.4E–12	5.6E–13	2.1E–13	2.0E–13	4.1E–13	2.6E–13	2.4E–13	1.2E–13
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	2.4E–7	3.0E–9	7.9E–11	5.2E–12	1.4E–11	5.6E–12	2.0E–12	2.0E–12	4.0E–12	2.6E–12	2.4E–12	1.1E–12
^{144}Ce	4.8E–7	7.6E–9	1.9E–10	1.3E–11	3.5E–11	1.4E–11	5.0E–12	4.9E–12	9.8E–12	6.4E–12	5.8E–12	2.7E–12
^{210}Pb	4.2E–6	1.2E–7	2.7E–9	1.9E–10	5.0E–10	1.9E–10	7.2E–11	6.9E–11	1.4E–10	9.1E–11	8.0E–11	3.6E–11
^{210}Po	3.6E–13	1.2E–14	2.6E–16	1.8E–17	4.8E–17	1.8E–17	7.0E–18	6.6E–18	1.3E–17	8.8E–18	7.6E–18	3.4E–18
^{226}Ra	5.7E–6	1.7E–7	3.8E–9	2.6E–10	6.9E–10	2.6E–10	1.0E–10	9.6E–11	1.9E–10	1.3E–10	1.1E–10	5.0E–11
^{227}Th	8.7E–6	3.1E–7	6.9E–9	4.8E–10	1.3E–9	4.6E–10	1.9E–10	1.7E–10	3.4E–10	2.3E–10	2.0E–10	8.9E–11
^{228}Th	3.2E–6	1.1E–7	2.5E–9	1.7E–10	4.6E–10	1.7E–10	6.8E–11	6.4E–11	1.3E–10	8.5E–11	7.3E–11	3.3E–11
^{230}Th	7.6E–7	3.2E–8	6.8E–10	4.8E–11	1.3E–10	4.6E–11	1.8E–11	1.7E–11	3.4E–11	2.3E–11	2.0E–11	8.6E–12
^{231}Th	6.9E–6	1.9E–7	4.5E–9	3.1E–10	8.3E–10	3.1E–10	1.2E–10	1.2E–10	2.3E–10	1.5E–10	1.3E–10	6.1E–11
^{232}Th	7.5E–7	3.1E–8	6.7E–10	4.7E–11	1.2E–10	4.5E–11	1.8E–11	1.7E–11	3.4E–11	2.3E–11	1.9E–11	8.5E–12
^{234}Th	7.1E–7	1.9E–8	4.5E–10	3.0E–11	8.1E–11	3.1E–11	1.2E–11	1.1E–11	2.3E–11	1.5E–11	1.3E–11	6.0E–12
^{234}U	6.0E–7	9.1E–9	2.4E–10	1.6E–11	4.4E–11	1.7E–11	6.3E–12	6.2E–12	1.2E–11	8.1E–12	7.4E–12	3.6E–12
^{235}U	1.0E–5	3.1E–7	7.1E–9	4.9E–10	1.3E–9	4.8E–10	1.9E–10	1.8E–10	3.6E–10	2.4E–10	2.1E–10	9.4E–11
^{237}Np	7.4E–6	2.0E–7	4.7E–9	3.2E–10	8.6E–10	3.2E–10	1.2E–10	1.2E–10	2.4E–10	1.6E–10	1.4E–10	6.4E–11
^{238}U	1.8E–6	3.6E–8	8.9E–10	6.0E–11	1.6E–10	6.2E–11	2.3E–11	2.3E–11	4.5E–11	3.0E–11	2.7E–11	1.3E–11
^{238}Pu	6.5E–7	1.1E–8	2.9E–10	1.9E–11	5.2E–11	2.0E–11	7.5E–12	7.4E–12	1.5E–11	9.7E–12	8.7E–12	4.2E–12
^{239}Pu	1.1E–6	4.9E–8	1.1E–9	7.4E–11	1.9E–10	7.1E–11	2.9E–11	2.7E–11	5.3E–11	3.6E–11	3.1E–11	1.3E–11
^{240}Pu	6.1E–7	1.1E–8	2.8E–10	1.8E–11	5.0E–11	1.9E–11	7.2E–12	7.0E–12	1.4E–11	9.2E–12	8.3E–12	4.0E–12
^{241}Pu	3.0E–6	8.9E–8	2.1E–9	1.4E–10	3.8E–10	1.5E–10	5.6E–11	5.4E–11	1.1E–10	7.1E–11	6.3E–11	2.9E–11
^{241}Am	4.3E–6	1.0E–7	2.5E–9	1.7E–10	4.6E–10	1.7E–10	6.7E–11	6.4E–11	1.3E–10	8.4E–11	7.5E–11	3.5E–11
^{242}Cm	6.1E–7	1.2E–8	3.0E–10	2.0E–11	5.4E–11	2.1E–11	7.8E–12	7.7E–12	1.5E–11	1.0E–11	9.0E–12	4.3E–12
^{243}Cm	6.6E–6	1.9E–7	4.5E–9	3.1E–10	8.2E–10	3.1E–10	1.2E–10	1.1E–10	2.3E–10	1.5E–10	1.3E–10	6.1E–11
^{244}Cm	5.7E–7	1.1E–8	2.8E–10	1.9E–11	5.1E–11	2.0E–11	7.3E–12	7.1E–12	1.4E–11	9.3E–12	8.4E–12	4.0E–12

Table A-15 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of **β-radiation** ($E \geq 10$ keV) and **γ-radiation.**

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)											
	Bac-teria	Phyto-plank-ton	Zoo-plan-kton	Mollusc	Worm	Vas-cular plant	Pelagic fish	Bird	Macro-algae	Benthic fish	Crus-tacean	Mammal
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	2.9E–5	1.9E–5	5.9E–7	4.8E–8	1.2E–7	3.4E–8	1.8E–8	1.5E–8	2.8E–8	2.1E–8	1.5E–8	5.1E–9
^{32}P	4.0E–4	4.0E–4	2.2E–4	4.0E–5	7.8E–5	2.0E–5	1.6E–5	1.1E–5	1.9E–5	1.6E–5	9.7E–6	2.3E–6
^{36}Cl	1.6E–4	1.5E–4	3.6E–5	4.1E–6	8.9E–6	2.3E–6	1.6E–6	1.2E–6	2.1E–6	1.7E–6	1.1E–6	3.1E–7
^{40}K	3.9E–4	3.9E–4	2.3E–4	1.1E–4	1.4E–4	9.6E–5	9.2E–5	8.8E–5	9.5E–5	9.3E–5	8.5E–5	5.3E–5
^{59}Ni	1.4E–6	1.4E–6	6.8E–7	1.4E–7	3.7E–7	7.6E–8	7.2E–8	0	6.2E–8	8.3E–8	2.5E–9	0
^{63}Ni	9.9E–6	2.2E–6	4.2E–8	3.1E–9	7.8E–9	2.6E–9	1.2E–9	1.0E–9	2.0E–9	1.4E–9	1.1E–9	4.4E–10
^{60}Co	1.5E–3	1.5E–3	1.4E–3	1.4E–3	1.4E–3	1.3E–3	1.3E–3	1.3E–3	1.3E–3	1.3E–3	1.3E–3	8.0E–4
^{89}Sr	3.4E–4	3.4E–4	1.6E–4	2.6E–5	5.2E–5	1.3E–5	1.0E–5	7.1E–6	1.2E–5	1.1E–5	6.4E–6	1.6E–6
^{90}Sr	6.5E–4	6.5E–4	3.7E–4	8.3E–5	1.5E–4	4.0E–5	3.4E–5	2.3E–5	3.9E–5	3.4E–5	2.0E–5	4.6E–6
^{95}Zr	4.9E–4	4.9E–4	4.3E–4	4.1E–4	4.2E–4	4.0E–4	3.9E–4	3.8E–4	3.9E–4	3.9E–4	3.7E–4	2.1E–4
^{94}Nb	1.0E–3	1.0E–3	9.2E–4	8.8E–4	8.9E–4	8.4E–4	8.3E–4	8.1E–4	8.4E–4	8.3E–4	7.9E–4	4.6E–4
^{95}Nb	4.7E–4	4.6E–4	4.4E–4	4.3E–4	4.3E–4	4.1E–4	4.0E–4	3.9E–4	4.1E–4	4.0E–4	3.8E–4	2.2E–4
^{99}Tc	5.8E–5	5.2E–5	3.5E–6	3.0E–7	7.1E–7	1.9E–7	1.2E–7	8.9E–8	1.7E–7	1.3E–7	8.9E–8	2.7E–8
^{106}Ru	9.4E–4	9.3E–4	7.5E–4	3.3E–4	4.6E–4	2.1E–4	2.0E–4	1.7E–4	2.1E–4	2.0E–4	1.5E–4	6.9E–5
^{125}I	2.9E–5	2.6E–5	2.3E–5	1.9E–5	2.1E–5	1.5E–5	1.5E–5	1.2E–5	1.5E–5	1.5E–5	1.2E–5	4.6E–6
^{129}I	4.6E–5	3.5E–5	1.4E–5	1.2E–5	1.3E–5	9.7E–6	9.2E–6	8.0E–6	9.7E–6	9.5E–6	7.8E–6	3.0E–6
^{131}I	3.3E–4	3.3E–4	2.3E–4	2.1E–4	2.2E–4	2.0E–4	2.0E–4	1.9E–4	2.0E–4	2.0E–4	1.9E–4	1.0E–4
^{134}Cs	9.9E–4	9.9E–4	9.1E–4	8.7E–4	8.8E–4	8.3E–4	8.2E–4	8.0E–4	8.3E–4	8.2E–4	7.7E–4	4.5E–4
^{135}Cs	3.9E–5	3.1E–5	1.3E–6	1.1E–7	2.5E–7	7.2E–8	4.1E–8	3.2E–8	6.0E–8	4.6E–8	3.3E–8	1.0E–8
^{137}Cs	4.7E–4	4.6E–4	3.6E–4	3.2E–4	3.3E–4	3.0E–4	3.0E–4	2.9E–4	3.0E–4	3.0E–4	2.8E–4	1.6E–4
^{144}Ce	7.8E–4	7.7E–4	5.4E–4	1.8E–4	2.8E–4	1.0E–4	9.1E–5	6.9E–5	9.9E–5	9.1E–5	6.2E–5	2.3E–5
^{210}Pb	2.4E–4	2.3E–4	7.6E–5	1.1E–5	2.2E–5	6.3E–6	4.9E–6	3.6E–6	5.9E–6	5.1E–6	3.4E–6	8.5E–7
^{210}Po	5.0E–9	5.0E–9	4.9E–9	4.8E–9	4.8E–9	4.6E–9	4.5E–9	4.4E–9	4.5E–9	4.5E–9	4.2E–9	2.5E–9
^{226}Ra	1.8E–3	1.8E–3	1.3E–3	1.0E–3	1.1E–3	9.5E–4	9.3E–4	9.0E–4	9.5E–4	9.3E–4	8.8E–4	5.4E–4
^{227}Th	8.4E–4	8.2E–4	4.5E–4	2.5E–4	2.9E–4	2.2E–4	2.1E–4	2.0E–4	2.2E–4	2.1E–4	1.9E–4	1.0E–4
^{228}Th	1.4E–3	1.4E–3	1.1E–3	9.1E–4	9.6E–4	8.6E–4	8.4E–4	8.2E–4	8.5E–4	8.4E–4	8.0E–4	5.2E–4
^{230}Th	8.5E–6	6.2E–6	9.4E–7	4.9E–7	6.4E–7	4.1E–7	3.9E–7	3.1E–7	4.0E–7	4.1E–7	3.4E–7	8.3E–8
^{231}Th	5.7E–5	3.8E–5	1.4E–5	1.0E–5	1.2E–5	8.9E–6	8.6E–6	7.5E–6	8.9E–6	8.8E–6	7.6E–6	2.8E–6
^{232}Th	7.2E–6	4.8E–6	7.6E–7	3.8E–7	5.1E–7	3.0E–7	2.9E–7	2.1E–7	3.0E–7	3.0E–7	2.4E–7	3.7E–8
^{234}Th	5.2E–4	5.1E–4	3.0E–4	7.4E–5	1.3E–4	4.3E–5	3.7E–5	2.9E–5	4.2E–5	3.8E–5	2.7E–5	1.0E–5
^{234}U	8.0E–6	4.8E–6	9.3E–7	4.8E–7	6.5E–7	3.7E–7	3.5E–7	2.5E–7	3.7E–7	3.8E–7	3.0E–7	3.9E–8
^{235}U	2.1E–4	1.8E–4	1.0E–4	9.5E–5	9.8E–5	8.9E–5	8.7E–5	8.3E–5	8.8E–5	8.7E–5	8.0E–5	4.0E–5
^{237}Np	2.8E–4	2.5E–4	1.5E–4	1.3E–4	1.3E–4	1.2E–4	1.2E–4	1.1E–4	1.2E–4	1.2E–4	1.1E–4	5.6E–5
^{238}U	5.4E–4	5.2E–4	3.0E–4	7.5E–5	1.3E–4	4.3E–5	3.8E–5	2.9E–5	4.2E–5	3.8E–5	2.7E–5	1.0E–5
^{238}Pu	6.5E–6	3.3E–6	9.3E–7	5.0E–7	6.8E–7	3.8E–7	3.6E–7	2.4E–7	3.8E–7	3.9E–7	3.0E–7	3.5E–8
^{239}Pu	3.2E–6	1.5E–6	3.8E–7	2.1E–7	2.8E–7	1.6E–7	1.5E–7	1.0E–7	1.6E–7	1.6E–7	1.2E–7	–1.2E–9
^{240}Pu	6.4E–6	3.3E–6	9.0E–7	4.8E–7	6.5E–7	3.6E–7	3.5E–7	2.3E–7	3.6E–7	3.7E–7	2.9E–7	3.5E–8
^{241}Pu	6.0E–9	5.4E–9	3.5E–9	3.0E–9	3.2E–9	2.8E–9	2.7E–9	2.5E–9	2.7E–9	2.7E–9	2.4E–9	1.1E–9
^{241}Am	4.4E–5	2.9E–5	1.8E–5	1.5E–5	1.6E–5	1.3E–5	1.3E–5	1.2E–5	1.3E–5	1.3E–5	1.1E–5	4.6E–6
^{242}Cm	5.9E–6	3.0E–6	9.5E–7	5.3E–7	7.1E–7	4.0E–7	3.9E–7	2.7E–7	4.0E–7	4.1E–7	3.2E–7	5.0E–8
^{243}Cm	1.5E–4	1.4E–4	8.2E–5	7.2E–5	7.5E–5	6.8E–5	6.6E–5	6.3E–5	6.7E–5	6.6E–5	6.1E–5	3.1E–5
^{244}Cm	5.3E–6	2.7E–6	8.7E–7	4.9E–7	6.6E–7	3.7E–7	3.6E–7	2.5E–7	3.7E–7	3.8E–7	3.0E–7	4.5E–8

Table A-16 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of α-radiation.

Radio-	Unweighted dose conversion coefficients (µGy/h per Bq/kg)
nuclide	all species
all	0

Freshwater ecosystem DCC's for internal irradiation

Table A-17 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of low-energy β-radiation (E < 10 keV).

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)												
	Bac-teria	Phyto-plan-kton	Zoopla nkton	Crus-tacean	Insect larvae	Vas-cular plant	Gastro pod	Amphi-bian	Bivalve mol-lusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	0	2.7E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6	3.3E–6
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	0	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8	1.9E–8
^{40}K	0	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7	1.1E–7
^{59}Ni	0	2.2E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6	2.6E–6
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	0	6.9E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9	7.0E–9
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	0	5.7E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6	6.0E–6
^{129}I	0	4.1E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6	4.5E–6
^{131}I	0	2.4E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8	2.5E–8
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	0	2.2E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7	2.4E–7
^{144}Ce	0	4.4E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7	4.8E–7
^{210}Pb	0	3.7E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6	4.2E–6
^{210}Po	0	3.1E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13	3.6E–13
^{226}Ra	0	4.9E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6	5.7E–6
^{227}Th	0	7.3E–6	8.7E–6	8.7E–6	8.7E–6	8.6E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6	8.7E–6
^{228}Th	0	2.7E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6	3.2E–6
^{230}Th	0	6.2E–7	7.6E–7	7.6E–7	7.6E–7	7.5E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7	7.6E–7
^{231}Th	0	6.0E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6	6.9E–6
^{232}Th	0	6.2E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7	7.5E–7
^{234}Th	0	6.2E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7	7.1E–7
^{234}U	0	5.5E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7	6.0E–7
^{235}U	0	8.8E–6	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5	1.0E–5
^{237}Np	0	6.5E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6	7.4E–6
^{238}U	0	1.6E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6	1.8E–6
^{238}Pu	0	5.9E–7	6.4E–7	6.4E–7	6.4E–7	6.4E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7	6.5E–7
^{239}Pu	0	8.4E–7	1.1E–6	1.1E–6	1.1E–6	1.0E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6	1.1E–6
^{240}Pu	0	5.6E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7
^{241}Pu	0	2.6E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6
^{241}Am	0	3.8E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6	4.3E–6
^{242}Cm	0	5.5E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7	6.1E–7
^{243}Cm	0	5.6E–6	6.5E–6	6.5E–6	6.5E–6	6.5E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6	6.6E–6
^{244}Cm	0	5.1E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7	5.7E–7

Table A-18 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of β- ($E \geq 10$ keV) and γ-radiation ($E < 10$ keV).

Radio-	Unweighted dose conversion coefficients (µGy/h per Bq/kg)												
nuclide	Bac-teria	Phyto-plan-kton	Zoopla nkton	Crus-tacean	Insect larvae	Vas-cular plant	Gastro pod	Amphi-bian	Bivalve mol-lusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	0	2.2E–6	2.7E–5	2.7E–5	2.7E–5	2.4E–5	2.8E–5	2.8E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5	2.9E–5
^{32}P	0	2.1E–7	7.5E–5	1.1E–4	9.3E–5	2.7E–5	3.3E–4	3.6E–4	3.8E–4	3.8E–4	3.9E–4	3.9E–4	4.0E–4
^{36}Cl	0	4.8E–7	8.1E–5	9.6E–5	8.9E–5	3.8E–5	1.5E–4	1.5E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4	1.6E–4
^{40}K	0	2.4E–7	7.1E–5	1.0E–4	8.6E–5	2.6E–5	2.6E–4	2.8E–4	2.9E–4	3.0E–4	3.0E–4	3.1E–4	3.2E–4
^{59}Ni	0	6.8E–7	4.0E–7	4.6E–7	4.5E–7	1.6E–7	1.1E–6	1.2E–6	1.3E–6	1.3E–6	1.3E–6	1.5E–6	1.5E–6
^{63}Ni	0	3.8E–6	9.8E–6	9.8E–6	9.8E–6	9.6E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6	9.9E–6
^{60}Co	0	1.3E–6	5.0E–5	5.2E–5	5.2E–5	3.6E–5	8.1E–5	9.9E–5	1.2E–4	1.5E–4	2.0E–4	3.0E–4	3.6E–4
^{89}Sr	0	2.5E–7	8.0E–5	1.1E–4	9.6E–5	2.9E–5	2.9E–4	3.1E–4	3.2E–4	3.2E–4	3.3E–4	3.3E–4	3.3E–4
^{90}Sr	0	8.3E–7	1.4E–4	1.9E–4	1.6E–4	6.3E–5	5.2E–4	5.7E–4	6.0E–4	6.1E–4	6.3E–4	6.4E–4	6.4E–4
^{95}Zr	0	1.1E–6	5.6E–5	5.8E–5	5.7E–5	3.8E–5	7.5E–5	8.1E–5	8.9E–5	9.7E–5	1.2E–4	1.5E–4	1.7E–4
^{94}Nb	0	7.8E–7	7.0E–5	7.7E–5	7.4E–5	4.1E–5	1.1E–4	1.3E–4	1.4E–4	1.6E–4	2.0E–4	2.7E–4	3.1E–4
^{95}Nb	0	2.4E–6	2.5E–5	2.5E–5	2.5E–5	2.2E–5	3.4E–5	4.0E–5	4.8E–5	5.6E–5	7.5E–5	1.1E–4	1.3E–4
^{99}Tc	0	1.2E–6	5.0E–5	5.1E–5	5.1E–5	3.6E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5	5.8E–5
^{106}Ru	0	3.8E–6	6.0E–5	9.8E–5	7.9E–5	2.4E–5	5.0E–4	6.2E–4	6.8E–4	7.2E–4	7.6E–4	8.0E–4	8.2E–4
^{125}I	0	1.3E–6	5.4E–6	5.6E–6	5.5E–6	4.9E–6	8.5E–6	1.0E–5	1.2E–5	1.3E–5	1.6E–5	2.0E–5	2.0E–5
^{129}I	0	3.0E–6	3.1E–5	3.1E–5	3.1E–5	2.7E–5	3.4E–5	3.5E–5	3.6E–5	3.6E–5	3.8E–5	4.0E–5	4.1E–5
^{131}I	0	8.6E–7	7.4E–5	8.2E–5	7.9E–5	4.2E–5	1.1E–4	1.2E–4	1.2E–4	1.3E–4	1.4E–4	1.6E–4	1.7E–4
^{134}Cs	0	1.4E–6	6.1E–5	6.8E–5	6.5E–5	3.3E–5	1.1E–4	1.2E–4	1.4E–4	1.6E–4	2.0E–4	2.7E–4	3.1E–4
^{135}Cs	0	1.7E–6	3.6E–5	3.6E–5	3.6E–5	2.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5	3.9E–5
^{137}Cs	0	7.7E–7	7.9E–5	9.0E–5	8.5E–5	4.3E–5	1.4E–4	1.5E–4	1.6E–4	1.6E–4	1.8E–4	2.1E–4	2.2E–4
^{144}Ce	0	2.0E–6	1.1E–4	1.5E–4	1.3E–4	5.6E–5	5.2E–4	6.1E–4	6.5E–4	6.8E–4	7.0E–4	7.3E–4	7.4E–4
^{210}Pb	0	3.9E–6	1.0E–4	1.3E–4	1.1E–4	5.1E–5	2.3E–4	2.3E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4	2.4E–4
^{210}Po	0	1.5E–13	1.7E–11	2.4E–11	2.1E–11	4.7E–12	1.3E–10	2.0E–10	2.9E–10	3.8E–10	5.9E–10	9.7E–10	1.2E–9
^{226}Ra	0	5.7E–6	2.8E–4	3.5E–4	3.2E–4	1.4E–4	7.1E–4	7.6E–4	7.9E–4	8.2E–4	8.7E–4	9.5E–4	1.0E–3
^{227}Th	0	7.2E–6	2.2E–4	2.8E–4	2.5E–4	1.0E–4	5.7E–4	6.0E–4	6.1E–4	6.2E–4	6.4E–4	6.7E–4	6.8E–4
^{228}Th	0	4.0E–6	1.7E–4	2.1E–4	1.9E–4	9.5E–5	4.5E–4	4.9E–4	5.2E–4	5.4E–4	5.8E–4	6.5E–4	6.8E–4
^{230}Th	0	6.2E–7	7.2E–6	7.3E–6	7.3E–6	6.2E–6	7.9E–6	8.0E–6	8.1E–6	8.1E–6	8.1E–6	8.3E–6	8.3E–6
^{231}Th	0	7.5E–6	4.1E–5	4.1E–5	4.1E–5	3.6E–5	4.5E–5	4.6E–5	4.7E–5	4.8E–5	4.8E–5	5.1E–5	5.1E–5
^{232}Th	0	6.8E–7	6.2E–6	6.2E–6	6.2E–6	5.5E–6	6.7E–6	6.8E–6	6.9E–6	6.9E–6	6.9E–6	7.0E–6	7.0E–6
^{234}Th	0	3.5E–6	1.0E–4	1.4E–4	1.2E–4	5.3E–5	4.1E–4	4.5E–4	4.7E–4	4.8E–4	4.9E–4	5.0E–4	5.0E–4
^{234}U	0	1.1E–6	6.8E–6	6.9E–6	6.9E–6	6.2E–6	7.4E–6	7.5E–6	7.6E–6	7.6E–6	7.7E–6	7.8E–6	7.8E–6
^{235}U	0	1.3E–5	1.0E–4	1.0E–4	1.0E–4	8.8E–5	1.2E–4	1.2E–4	1.2E–4	1.2E–4	1.3E–4	1.4E–4	1.5E–4
^{237}Np	0	1.0E–5	1.2E–4	1.2E–4	1.2E–4	8.9E–5	1.5E–4	1.5E–4	1.6E–4	1.6E–4	1.7E–4	1.8E–4	1.9E–4
^{238}U	0	5.5E–6	1.1E–4	1.5E–4	1.3E–4	6.4E–5	4.2E–4	4.6E–4	4.8E–4	4.9E–4	5.0E–4	5.1E–4	5.2E–4
^{238}Pu	0	1.3E–6	5.4E–6	5.4E–6	5.4E–6	5.0E–6	5.9E–6	6.0E–6	6.1E–6	6.1E–6	6.1E–6	6.3E–6	6.3E–6
^{239}Pu	0	7.6E–7	2.7E–6	2.7E–6	2.7E–6	2.6E–6	2.9E–6	3.0E–6	3.0E–6	3.0E–6	3.0E–6	3.1E–6	3.1E–6
^{240}Pu	0	1.2E–6	5.4E–6	5.4E–6	5.4E–6	5.0E–6	5.9E–6	6.0E–6	6.0E–6	6.1E–6	6.1E–6	6.3E–6	6.3E–6
^{241}Pu	0	1.8E–10	2.3E–9	2.4E–9	2.3E–9	1.8E–9	2.9E–9	3.1E–9	3.2E–9	3.2E–9	3.5E–9	3.9E–9	4.1E–9
^{241}Am	0	6.6E–6	2.5E–5	2.5E–5	2.5E–5	2.3E–5	2.8E–5	2.9E–5	3.0E–5	3.0E–5	3.2E–5	3.5E–5	3.5E–5
^{242}Cm	0	1.1E–6	4.8E–6	4.8E–6	4.8E–6	4.5E–6	5.3E–6	5.4E–6	5.5E–6	5.5E–6	5.5E–6	5.7E–6	5.7E–6
^{243}Cm	0	4.4E–6	5.8E–5	6.1E–5	6.0E–5	4.2E–5	7.5E–5	7.7E–5	7.9E–5	8.1E–5	8.6E–5	9.4E–5	9.8E–5
^{244}Cm	0	1.1E–6	4.3E–6	4.3E–6	4.3E–6	4.1E–6	4.7E–6	4.8E–6	4.9E–6	4.9E–6	5.0E–6	5.1E–6	5.1E–6

Table A-19 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for internal exposure, contribution of α-radiation.

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)												
	Bac-teria	Phyto-plan-kton	Zoopla nkton	Crus-tacean	Insect larvae	Vas-cular plant	Gastro pod	Amphi-bian	Bivalve mol-lusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	0	0	0	0	0	0	0	0	0	0	0	0	0
^{40}K	0	0	0	0	0	0	0	0	0	0	0	0	0
^{59}Ni	0	0	0	0	0	0	0	0	0	0	0	0	0
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	0	0	0	0	0	0	0	0	0	0	0	0	0
^{129}I	0	0	0	0	0	0	0	0	0	0	0	0	0
^{131}I	0	0	0	0	0	0	0	0	0	0	0	0	0
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{144}Ce	0	0	0	0	0	0	0	0	0	0	0	0	0
^{210}Pb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{210}Po	0	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3	3.1E–3
^{226}Ra	0	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2	1.7E–2
^{227}Th	0	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2	1.9E–2
^{228}Th	0	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2	1.8E–2
^{230}Th	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{231}Th	0	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5	4.4E–5
^{232}Th	0	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3	2.3E–3
^{234}Th	0	0	0	0	0	0	0	0	0	0	0	0	0
^{234}U	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{235}U	0	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3	2.5E–3
^{237}Np	0	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3	2.7E–3
^{238}U	0	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3	5.2E–3
^{238}Pu	0	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
^{239}Pu	0	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
^{240}Pu	0	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3	3.0E–3
^{241}Pu	0	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8	6.9E–8
^{241}Am	0	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3	3.2E–3
^{242}Cm	0	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3	3.5E–3
^{243}Cm	0	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3
^{244}Cm	0	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3	3.3E–3

Freshwater ecosystem DCC's for external irradiation

Table A-20 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of low-energy β-radiation (*E* < 10 keV).

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)												
	Bacteria	Phyto-plankton	Zoo-plankton	Crus-tacean	Insect larvae	Vas-cular plant	Gastro-pod	Amphi-bian	Bivalve mollusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	3.3E–6	5.4E–7	4.8E–9	5.4E–9	5.2E–9	1.9E–8	3.1E–10	1.8E–10	1.2E–10	1.2E–10	6.3E–11	3.6E–11	3.1E–11
^{14}C	0	0	0	0	0	0	0	0	0	0	0	0	0
^{32}P	0	0	0	0	0	0	0	0	0	0	0	0	0
^{36}Cl	1.9E–8	5.6E–10	5.4E–12	6.9E–12	6.3E–12	2.3E–11	3.7E–13	2.3E–13	1.5E–13	1.5E–13	8.0E–14	4.7E–14	4.0E–14
^{40}K	1.1E–7	5.2E–9	4.8E–11	5.9E–11	5.5E–11	2.0E–10	3.2E–12	2.0E–12	1.3E–12	1.3E–12	6.9E–13	4.0E–13	3.4E–13
^{59}Ni	2.6E–6	3.8E–7	3.4E–9	3.8E–9	3.7E–9	1.4E–8	2.2E–10	1.3E–10	8.4E–11	8.3E–11	4.5E–11	2.6E–11	2.2E–11
^{63}Ni	0	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	0	0	0	0	0	0	0	0	0	0	0	0	0
^{89}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{90}Sr	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Zr	7.0E–9	1.4E–10	1.4E–12	1.8E–12	1.6E–12	5.9E–12	9.7E–14	5.9E–14	3.8E–14	4.0E–14	2.1E–14	1.2E–14	1.1E–14
^{94}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{95}Nb	0	0	0	0	0	0	0	0	0	0	0	0	0
^{99}Tc	0	0	0	0	0	0	0	0	0	0	0	0	0
^{106}Ru	0	0	0	0	0	0	0	0	0	0	0	0	0
^{125}I	6.0E–6	3.6E–7	3.3E–9	3.9E–9	3.7E–9	1.3E–8	2.2E–10	1.3E–10	8.5E–11	8.6E–11	4.6E–11	2.6E–11	2.3E–11
^{129}I	4.5E–6	4.4E–7	3.9E–9	4.5E–9	4.3E–9	1.6E–8	2.6E–10	1.5E–10	9.9E–11	9.9E–11	5.3E–11	3.0E–11	2.6E–11
^{131}I	2.5E–8	1.5E–9	1.4E–11	1.6E–11	1.5E–11	5.6E–11	9.1E–13	5.5E–13	3.5E–13	3.6E–13	1.9E–13	1.1E–13	9.5E–14
^{134}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{135}Cs	0	0	0	0	0	0	0	0	0	0	0	0	0
^{137}Cs	2.4E–7	1.5E–8	1.4E–10	1.6E–10	1.5E–10	5.6E–10	9.1E–12	5.5E–12	3.5E–12	3.5E–12	1.9E–12	1.1E–12	9.4E–13
^{144}Ce	4.8E–7	3.8E–8	3.4E–10	4.0E–10	3.8E–10	1.4E–9	2.2E–11	1.3E–11	8.7E–12	8.7E–12	4.6E–12	2.7E–12	2.3E–12
^{210}Pb	4.2E–6	5.4E–7	5.0E–9	5.6E–9	5.4E–9	2.0E–8	3.2E–10	1.9E–10	1.2E–10	1.2E–10	6.6E–11	3.8E–11	3.2E–11
^{210}Po	3.6E–13	5.3E–14	4.9E–16	5.4E–16	5.3E–16	1.9E–15	3.1E–17	1.9E–17	1.2E–17	1.2E–17	6.4E–18	3.6E–18	3.1E–18
^{226}Ra	5.7E–6	7.6E–7	7.1E–9	7.9E–9	7.6E–9	2.8E–8	4.5E–10	2.7E–10	1.7E–10	1.7E–10	9.2E–11	5.3E–11	4.5E–11
^{227}Th	8.7E–6	1.4E–6	1.3E–8	1.4E–8	1.4E–8	5.1E–8	8.3E–10	4.9E–10	3.2E–10	3.1E–10	1.7E–10	9.6E–11	8.2E–11
^{228}Th	3.2E–6	5.0E–7	4.8E–9	5.2E–9	5.1E–9	1.9E–8	3.0E–10	1.8E–10	1.2E–10	1.1E–10	6.1E–11	3.5E–11	3.0E–11
^{230}Th	7.6E–7	1.3E–7	1.3E–9	1.4E–9	1.4E–9	5.1E–9	8.3E–11	4.9E–11	3.2E–11	3.1E–11	1.7E–11	9.5E–12	8.1E–12
^{231}Th	6.9E–6	9.1E–7	8.3E–9	9.4E–9	9.0E–9	3.3E–8	5.4E–10	3.2E–10	2.1E–10	2.0E–10	1.1E–10	6.3E–11	5.4E–11
^{232}Th	7.5E–7	1.3E–7	1.3E–9	1.4E–9	1.4E–9	5.1E–9	8.2E–11	4.8E–11	3.1E–11	3.0E–11	1.6E–11	9.4E–12	8.0E–12
^{234}Th	7.1E–7	8.9E–8	8.2E–10	9.2E–10	8.9E–10	3.3E–9	5.3E–11	3.2E–11	2.0E–11	2.0E–11	1.1E–11	6.2E–12	5.3E–12
^{234}U	6.0E–7	4.7E–8	4.2E–10	5.0E–10	4.7E–10	1.7E–9	2.8E–11	1.7E–11	1.1E–11	1.1E–11	5.8E–12	3.4E–12	2.9E–12
^{235}U	1.0E–5	1.4E–6	1.3E–8	1.5E–8	1.4E–8	5.3E–8	8.5E–10	5.0E–10	3.3E–10	3.2E–10	1.7E–10	9.9E–11	8.4E–11
^{237}Np	7.4E–6	9.5E–7	8.6E–9	9.7E–9	9.4E–9	3.4E–8	5.6E–10	3.3E–10	2.1E–10	2.1E–10	1.1E–10	6.5E–11	5.6E–11
^{238}U	1.8E–6	1.8E–7	1.6E–9	1.8E–9	1.7E–9	6.4E–9	1.0E–10	6.2E–11	4.0E–11	4.0E–11	2.1E–11	1.2E–11	1.1E–11
^{238}Pu	6.5E–7	5.7E–8	5.0E–10	6.0E–10	5.6E–10	2.1E–9	3.3E–11	2.0E–11	1.3E–11	1.3E–11	6.9E–12	4.0E–12	3.4E–12
^{239}Pu	1.1E–6	2.2E–7	2.0E–9	2.2E–9	2.1E–9	8.0E–9	1.3E–10	7.6E–11	4.9E–11	4.8E–11	2.6E–11	1.5E–11	1.3E–11
^{240}Pu	6.1E–7	5.4E–8	4.8E–10	5.7E–10	5.3E–10	2.0E–9	3.2E–11	1.9E–11	1.2E–11	1.2E–11	6.6E–12	3.8E–12	3.3E–12
^{241}Pu	3.0E–6	4.4E–7	3.8E–9	4.4E–9	4.2E–9	1.5E–8	2.5E–10	1.5E–10	9.6E–11	9.5E–11	5.1E–11	2.9E–11	2.5E–11
^{241}Am	4.3E–6	5.0E–7	4.6E–9	5.2E–9	5.0E–9	1.8E–8	3.0E–10	1.8E–10	1.1E–10	1.1E–10	6.1E–11	3.5E–11	3.0E–11
^{242}Cm	6.1E–7	6.0E–8	5.3E–10	6.2E–10	5.9E–10	2.1E–9	3.5E–11	2.1E–11	1.4E–11	1.4E–11	7.2E–12	4.2E–12	3.6E–12
^{243}Cm	6.6E–6	9.2E–7	8.3E–9	9.3E–9	9.0E–9	3.3E–8	5.4E–10	3.2E–10	2.1E–10	2.0E–10	1.1E–10	6.3E–11	5.4E–11
^{244}Cm	5.7E–7	5.6E–8	4.9E–10	5.7E–10	5.4E–10	2.0E–9	3.2E–11	1.9E–11	1.3E–11	1.3E–11	6.7E–12	3.9E–12	3.3E–12

Table A-21 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of **β-radiation** ($E \geq$ 10 keV) and **γ-radiation.**

Radio-nuclide	Unweighted dose conversion coefficients (µGy/h per Bq/kg)												
	Bac-teria	Phyto-plankton	Zoo-plankton	Crus-tacean	Insect larvae	Vas-cular plant	Gastro-pod	Amphi-bian	Bivalve mollusc	Pelagic fish	Benthic fish	Mam-mal	Bird
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0	0
^{14}C	2.9E–5	2.6E–5	1.4E–6	1.2E–6	1.3E–6	4.6E–6	8.4E–8	4.8E–8	3.1E–8	2.7E–8	1.6E–8	8.4E–9	7.0E–9
^{32}P	4.0E–4	4.0E–4	3.3E–4	2.9E–4	3.1E–4	3.7E–4	6.7E–5	3.9E–5	2.6E–5	2.0E–5	1.3E–5	6.4E–6	5.2E–6
^{36}Cl	1.6E–4	1.6E–4	7.7E–5	6.2E–5	6.9E–5	1.2E–4	7.1E–6	4.0E–6	2.6E–6	2.1E–6	1.3E–6	7.1E–7	5.9E–7
^{40}K	3.9E–4	3.9E–4	3.2E–4	2.9E–4	3.1E–4	3.7E–4	1.3E–4	1.1E–4	1.0E–4	9.6E–5	8.9E–5	7.9E–5	7.5E–5
^{59}Ni	1.4E–6	7.1E–7	9.9E–7	9.3E–7	9.3E–7	1.2E–6	2.6E–7	1.5E–7	1.0E–7	1.1E–7	6.4E–8	0	0
^{63}Ni	9.9E–6	6.1E–6	9.0E–8	8.7E–8	8.9E–8	3.3E–7	5.4E–9	3.1E–9	2.0E–9	1.9E–9	1.0E–9	5.8E–10	4.9E–10
^{60}Co	1.5E–3	1.5E–3	1.5E–3	1.4E–3	1.4E–3	1.5E–3	1.4E–3	1.4E–3	1.4E–3	1.4E–3	1.3E–3	1.2E–3	1.1E–3
^{89}Sr	3.4E–4	3.4E–4	2.6E–4	2.2E–4	2.4E–4	3.1E–4	4.4E–5	2.5E–5	1.7E–5	1.3E–5	8.1E–6	4.2E–6	3.4E–6
^{90}Sr	6.5E–4	6.5E–4	5.1E–4	4.7E–4	4.9E–4	5.9E–4	1.3E–4	8.0E–5	5.4E–5	4.2E–5	2.7E–5	1.4E–5	1.1E–5
^{95}Zr	4.9E–4	4.9E–4	4.4E–4	4.4E–4	4.4E–4	4.6E–4	4.2E–4	4.1E–4	4.1E–4	4.0E–4	3.8E–4	3.4E–4	3.3E–4
^{94}Nb	1.0E–3	1.0E–3	9.3E–4	9.3E–4	9.3E–4	9.6E–4	8.9E–4	8.8E–4	8.6E–4	8.5E–4	8.1E–4	7.4E–4	7.0E–4
^{95}Nb	4.7E–4	4.7E–4	4.4E–4	4.4E–4	4.4E–4	4.5E–4	4.3E–4	4.3E–4	4.2E–4	4.1E–4	3.9E–4	3.6E–4	3.4E–4
^{99}Tc	5.8E–5	5.7E–5	8.7E–6	7.0E–6	7.8E–6	2.2E–5	5.4E–7	3.0E–7	1.9E–7	1.6E–7	9.6E–8	5.1E–8	4.2E–8
^{106}Ru	9.4E–4	9.3E–4	8.8E–4	8.4E–4	8.6E–4	9.1E–4	4.3E–4	3.2E–4	2.5E–4	2.2E–4	1.8E–4	1.3E–4	1.2E–4
^{125}I	2.9E–5	2.8E–5	2.4E–5	2.4E–5	2.4E–5	2.4E–5	2.1E–5	1.9E–5	1.7E–5	1.6E–5	1.4E–5	9.8E–6	9.1E–6
^{129}I	4.6E–5	4.3E–5	1.5E–5	1.5E–5	1.5E–5	1.9E–5	1.3E–5	1.2E–5	1.1E–5	1.0E–5	8.7E–6	6.3E–6	5.8E–6
^{131}I	3.3E–4	3.3E–4	2.6E–4	2.5E–4	2.5E–4	2.9E–4	2.2E–4	2.1E–4	2.1E–4	2.0E–4	1.9E–4	1.7E–4	1.6E–4
^{134}Cs	9.9E–4	9.9E–4	9.3E–4	9.2E–4	9.3E–4	9.6E–4	8.8E–4	8.7E–4	8.5E–4	8.4E–4	8.0E–4	7.2E–4	6.8E–4
^{135}Cs	3.9E–5	3.7E–5	3.2E–6	2.6E–6	2.9E–6	9.4E–6	1.9E–7	1.1E–7	6.8E–8	5.9E–8	3.4E–8	1.8E–8	1.5E–8
^{137}Cs	4.7E–4	4.7E–4	3.9E–4	3.8E–4	3.8E–4	4.3E–4	3.3E–4	3.2E–4	3.1E–4	3.0E–4	2.9E–4	2.6E–4	2.5E–4
^{144}Ce	7.8E–4	7.8E–4	6.7E–4	6.3E–4	6.5E–4	7.2E–4	2.6E–4	1.7E–4	1.3E–4	1.0E–4	7.6E–5	4.9E–5	4.3E–5
^{210}Pb	2.4E–4	2.4E–4	1.4E–4	1.2E–4	1.3E–4	1.9E–4	1.8E–5	1.1E–5	7.4E–6	6.1E–6	4.1E–6	2.3E–6	2.0E–6
^{210}Po	5.0E–9	5.0E–9	4.9E–9	4.9E–9	4.9E–9	4.9E–9	4.8E–9	4.8E–9	4.7E–9	4.6E–9	4.4E–9	4.0E–9	3.8E–9
^{226}Ra	1.8E–3	1.8E–3	1.5E–3	1.4E–3	1.5E–3	1.6E–3	1.1E–3	1.0E–3	9.8E–4	9.6E–4	9.0E–4	8.2E–4	7.8E–4
^{227}Th	8.4E–4	8.4E–4	6.2E–4	5.6E–4	5.9E–4	7.4E–4	2.8E–4	2.5E–4	2.3E–4	2.2E–4	2.0E–4	1.8E–4	1.6E–4
^{228}Th	1.4E–3	1.4E–3	1.2E–3	1.2E–3	1.2E–3	1.3E–3	9.5E–4	9.1E–4	8.8E–4	8.6E–4	8.2E–4	7.5E–4	7.2E–4
^{230}Th	8.5E–6	7.9E–6	1.3E–6	1.2E–6	1.2E–6	2.3E–6	5.9E–7	5.0E–7	4.4E–7	4.3E–7	3.8E–7	2.5E–7	2.3E–7
^{231}Th	5.7E–5	4.9E–5	1.6E–5	1.6E–5	1.6E–5	2.0E–5	1.1E–5	1.0E–5	9.5E–6	9.2E–6	8.3E–6	6.2E–6	5.7E–6
^{232}Th	7.2E–6	6.5E–6	1.0E–6	9.5E–7	9.8E–7	1.7E–6	4.6E–7	3.8E–7	3.3E–7	3.2E–7	2.8E–7	1.6E–7	1.6E–7
^{234}Th	5.2E–4	5.2E–4	4.2E–4	3.8E–4	4.0E–4	4.7E–4	1.1E–4	7.2E–5	5.3E–5	4.3E–5	3.2E–5	2.1E–5	1.8E–5
^{234}U	8.0E–6	6.9E–6	1.2E–6	1.1E–6	1.1E–6	1.8E–6	5.9E–7	4.8E–7	4.1E–7	3.9E–7	3.5E–7	2.0E–7	1.9E–7
^{235}U	2.1E–4	2.0E–4	1.1E–4	1.1E–4	1.1E–4	1.3E–4	9.8E–5	9.5E–5	9.2E–5	9.0E–5	8.3E–5	7.2E–5	6.7E–5
^{237}Np	2.8E–4	2.7E–4	1.6E–4	1.6E–4	1.6E–4	1.9E–4	1.3E–4	1.3E–4	1.2E–4	1.2E–4	1.1E–4	9.9E–5	9.2E–5
^{238}U	5.4E–4	5.3E–4	4.2E–4	3.8E–4	4.0E–4	4.7E–4	1.1E–4	7.3E–5	5.3E–5	4.4E–5	3.2E–5	2.1E–5	1.9E–5
^{238}Pu	6.5E–6	5.2E–6	1.1E–6	1.1E–6	1.1E–6	1.4E–6	6.2E–7	5.0E–7	4.2E–7	4.1E–7	3.6E–7	1.9E–7	1.9E–7
^{239}Pu	3.2E–6	2.4E–6	4.6E–7	4.4E–7	4.5E–7	6.3E–7	2.6E–7	2.1E–7	1.8E–7	1.7E–7	1.5E–7	7.6E–8	6.9E–8
^{240}Pu	6.4E–6	5.3E–6	1.1E–6	1.0E–6	1.0E–6	1.4E–6	6.0E–7	4.8E–7	4.0E–7	3.9E–7	3.4E–7	1.9E–7	1.8E–7
^{241}Pu	6.0E–9	5.9E–9	3.7E–9	3.7E–9	3.7E–9	4.2E–9	3.1E–9	3.0E–9	2.9E–9	2.8E–9	2.6E–9	2.2E–9	2.0E–9
^{241}Am	4.4E–5	3.7E–5	1.9E–5	1.9E–5	1.9E–5	2.1E–5	1.6E–5	1.5E–5	1.4E–5	1.4E–5	1.2E–5	9.4E–6	8.5E–6
^{242}Cm	5.9E–6	4.8E–6	1.1E–6	1.1E–6	1.1E–6	1.4E–6	6.5E–7	5.3E–7	4.5E–7	4.3E–7	3.8E–7	2.1E–7	2.1E–7
^{243}Cm	1.5E–4	1.4E–4	9.1E–5	8.8E–5	9.0E–5	1.1E–4	7.4E–5	7.2E–5	7.0E–5	6.8E–5	6.4E–5	5.5E–5	5.1E–5
^{244}Cm	5.3E–6	4.3E–6	1.0E–6	9.9E–7	9.9E–7	1.3E–6	6.0E–7	4.9E–7	4.1E–7	4.0E–7	3.5E–7	2.0E–7	1.9E–7

Table A-22 Unweighted dose conversion coefficients (µGy/h per Bq/kg) for external exposure, contribution of α-radiation.

	Unweighted dose conversion coefficients (µGy/h per Bq/kg)
All radionuclide	All species: 0