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Environmental Protection: the Concept and Use of Reference Animals and Plants

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PREFACE

(1) Because environmental protection is now a global issue, and an issue that impacts upon human activities in many different ways, all forms of actual or potential threats to the environment are a cause of concern, or of action, or of regulation, and this includes ionising radiation. In May 2000, the Commission therefore decided to set up a Task Group, reporting directly to it, chaired by Lars-Erik Holm, to address these issues. The final report of the Task Group was accepted in 2002 and published as *A Framework for Assessing the Impact of Ionising Radiation on Non-Human Species*, ICRP Publication 91, in 2003. The Task Group considered (a) that a broader framework for radiation protection of the environment needed to be developed, and (b) that it should be sufficiently flexible to be applied within the context of the many existing and varied global approaches to environmental management generally, and to environmental protection in particular. It also considered that such an approach should relate as closely as possible to the current system for human radiological protection, and that these joint objectives could therefore best be met by the development of a limited number of Reference Animals and Plants.

(2) At its meeting in Vienna in May 2003, the Commission then decided to set up a second Task Group, again reporting directly to it, to continue the ICRP's work on this subject. This Task Group, again chaired by Lars-Erik Holm, was requested to consider further the end-points of interest for assessing radiation effects in non-human species, and to define an agreed set of reference organisms for assessing and managing radiation exposure in an environmental context. The membership of the Task Group was as follows: M. E. Clark, USA; N. Gentner, UNSCEAR; L.-E. Holm (Chairman), Sweden; C.-M. Larsson, Sweden; and R. J. Pentreath, UK. And the following persons served as corresponding members: R. Alexakhin, Russian Federation; F. Brechignac, France; S. Carroll, The Netherlands; K. Fujimoto, Japan; J. Loy, Australia; G. Pröhl, Germany; C. Robinson, IAEA; A. Shpyth, Canada; P. Strand, IUR; A. Tsela, South Africa; D. S. Woodhead, IUR; and Y. Xuan, P.R. of China.

(3) Because of the growing interest in this area of work, however, in October 2003 the ICRP came to the conclusion that a more structured basis was required to address it, and therefore decided to set up an entirely new committee of the Commission, Committee 5, under the Chairmanship of R J Pentreath, which would come into force in the new ICRP four year 'term' beginning in June 2005. The work of the second Task Group was therefore slightly modified, and given the more general purpose of laying the foundations for the Commission's future work in this area, and preparing for the work of the new Committee. The Task Group therefore considered the types of reference animals and plants that could be used by the ICRP in order to meet future environmental management requirements; the types of dose models that could be used; the relevance of existing information on radiation effects for such types of organisms; how such an approach could be used for assessing and managing different levels of radiation exposure in non-human species; and how it could be harmonised with the Commission's existing approach to the protection of human beings. The Commission submitted the resultant draft report of the Task Group for public consultation in April 2005.

(4) Later that year, the new ICRP Committee 5 held its first meeting (in September 2005) and used, as its base material, both the draft Task Group report and the set of

responses to it arising from the public consultation exercise. It concluded that it would be most sensible to use the draft Task Group report as a basis for a more comprehensive report on the subject, taking into account the helpful comments received, plus other material.

(5) One aspect that could clearly be advanced relatively quickly was that of bringing more rigour to the basic approach of modelling dosimetry. Committee 5 therefore immediately established its own Task Group on Reference Animal and Plant dosimetric modelling with the following objectives: following specification of reference geometries and life stages by Committee 5, to summarize current modeling approaches and identify (i) significant differences and (ii) their limitations, and then select and justify a preferred approach and use it to calculate a set of dose per unit concentration factors with respect to external and internal exposure pathways; and then to identify further issues for consideration as appropriate. The Task Group was chaired by G. Proehl (Germany, Committee 5) Chair; plus M. Doi (Japan, Committee 5); S. Kamboj (USA); S. Golikov (Russia); J. Brown (Norway) with J. Vives i Battle (UK); A. Ulanouski (Germany); and Beaugelin (France) as corresponding members.

(6) This Task Group completed their task in 2006 and presented the results to Committee 5 at their second meeting in Oregon, USA, later that year. The results have been incorporated into this report, forming the basis of Chapter 4 and its appendices.

(7) The final report has been put together by Committee 5. Sadly one of its members, M Doi, died suddenly in 2006; he was succeeded by K Sakai. The membership of the Committee was as follows. :

R. J. Pentreath (Chairman)
C-M. Larsson (Vice-chairman)
K. A. Higley (Secretary)
F. Brechignac
M. Doi (to 2006)
G. Proehl
A. Johnston (to 2007)
A. Real
K. Sakai (from 2007)
P. Strand.

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1. INTRODUCTION

1.1 The Commission's Aims with regard to Environmental Protection

(1) As the Commission states in its new Recommendations (ICRP 103, 2008), its principal objective has been, and remains, the achievement of the radiological protection of human beings. It has nevertheless previously had regard to the potential impact on other species, although it had not made any general statements about the protection of the environment as a whole. Indeed, in its *Publication 60* (ICRP, 1991) it stated that, at that time, the Commission concerned itself with mankind's environment only with regard to the transfer of radionuclides through the environment, because this directly affects the radiological protection of human beings. It did however express the view that the standards of environmental control needed to protect humans to the degree currently thought desirable would ensure that other species were not put at risk.

(2) In its new Recommendations, the Commission has systematically addressed not only planned exposure situations, but existing situations (including residues from past practices that have been operated outside of the Commission's recommendations), and emergency exposure situations. It also notes that all of the environment needs to be considered, including areas where humans are absent. The Commission is also aware of the needs of some national authorities to demonstrate, directly and explicitly, that the environment is being protected, even under planned exposure situations.

(3) The Commission has therefore broadened its scope in order to address the subject of environmental protection. Its aims now include that of preventing or reducing the frequency of deleterious radiation effects to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities, and ecosystems. In doing so, the Commission acknowledges that, compared with human radiological protection, the more detailed objectives and management of environmental protection are often more complex and difficult to articulate. There is no simple or single universal definition of 'environmental protection', and the concept differs from country to country, and from one circumstance to another.

1.2 The Commission's Approach to Environmental Protection

(4) The Commission believes that its approach to environmental protection should be both commensurate with the overall level of risk, and compatible with other approaches being made to protect the environment from all other human impacts, particularly those arising from similar human activities. And in view of its overall aims, again compared with human radiological protection, it believes that other ways of grouping radiation effects are likely to be more useful for the protection of non-human species, such as those resulting in early mortality, or morbidity, or reduced reproductive success.

(5) The Commission acknowledges that in many circumstances, exposure to radiation is but one factor to consider. It therefore intends to provide high-level guidance and advice upon which regulators and operators may draw in order to demonstrate compliance, where necessary, with the wide range of international and

national environmental legislation that already exists, or is likely to emerge in the near future.

(6) Such advice and guidance has to be transparent, and have a common basis arising from our knowledge of exposure to radiation and its effects, set within some form of overall framework. This framework should therefore serve as a basis from which national and other bodies could develop, as necessary, more applied and specific numerical approaches to the assessment and management of risks to non-human species under different circumstances, and different exposure situations. Because of the vast complexity of the living environment, and the limited radiobiological and radioecological data bases relating to it, the Commission considers that, by setting out data for a limited number of Reference Animals and Plants, this will provide a vital component of the framework to gather and interpret data in order to provide more comprehensive advice in the future. This information is, however, still fragmentary and the Commission does not therefore intend to set specific dose limits for environmental protection.

(7) This report, on the concept and use of Reference Animals and Plants, therefore serves as an introduction to the complex subject of environmental protection with regard to radiation. It introduces the rationale for selecting the Reference Animal and Plant types, and then gives emphasis to their biology, to basic aspects relevant to their dosimetry, and to a review and application of what is known about relevant irradiation effects for such types. Further publications will address in more detail such aspects as data bases for modelling exposure, refinements to dosimetry, issues such as RBE and radiation weighting factors, the application of the basic approach to different exposure situations, and how the Commission's approach to environmental protection compares with others commonly used in relation to industrial practice.

2   REFERENCE ANIMALS AND PLANTS

2.1 Introducing the concept

(8)   The concept of a 'reference human' to help manage the many different situations in which human beings would or could be exposed to ionising radiations has long been used and recognized by ICRP, which began the work to define the first reference individual (standard man) in the 1940s and published its first comprehensive report on Reference Man in 1975 (ICRP, 1975). The purpose of Reference Man was to create *points of reference* (or 'benchmarks') for the procedure of dose estimations, for considering the relationships between doses to different parts of the human body and their effects, and for the derivation of relevant quantities (equivalent dose and effective dose) and units for their interpretation in the context of human radiological protection. The Commission has recently adopted a report that provides up-dated information on Reference Man (ICRP, 2003a).

(9)   The Commission has now decided to use a similar system of discrete and clearly defined Reference Animals and Plants for assessing radiation effects in non-human organisms (ICRP, 2003b, 2008) based on the concept developed by Pentreath (1998, 1999, 2002 a,b, 2003, 2004, 2005). This approach involves the use of a limited number of different types of animals and plants as a systematic basis for relating exposure to dose, and dose to different categories of effect, that could be interpreted in terms of the normal biology of these particular types of animals and plants in environmental situations. The effects considered to be of relevance were those of early mortality, morbidity, reduced reproductive success, or some form of observable chromosomal damage, irrespective of whether or not they arose from stochastic or non-stochastic dose effect relationships. It was further considered that it would be helpful to decision making if this information was set out in terms of multiples of the natural background dose rates typically experienced by each type of animal or plant, in the form of Derived Consideration Levels.

(10)   The approach therefore acknowledged that one cannot provide a general assessment of the effects of radiation on the environment as a whole. Nevertheless, it was considered that it should be possible to derive, in time, a reasonably complete set of internally related information for a few types of organisms that were typical of the major environments. Thus, by using sets of dosimetric models and environmental geometries relating to such reference animals and plants, with precisely defined biological characteristics and life histories, and applying them to distributions of radionuclides in different environments, one should be able to make a judgement about the probability and severity of the likely effects of the radiation exposure on such organisms. One should then, in turn, be able to make an assessment of the likely consequences either for individuals, or for the relevant population (depending on the environmental management issue being addressed) using these and other environmental data and information, for such types of animals and plants.

(11)   The concept is therefore similar to that used for human radiological protection, in that it is intended to act as a foundation for the making of a number of basic calculations, and to serve as points of reference for drawing comparisons with other – and probably more limited – sets of information on other organisms. Such a basic reference-animals-and-plants approach had been used previously to provide

advice at an international level, primarily in order to establish release rate limits to evaluate potential environmental impacts of radionuclide releases into the marine environment (Pentreath and Woodhead, 1988). This was applied by the IAEA to redefine annual release rate limits for the purposes of the London Convention (IAEA, 1988). It is also similar to the concept of assessment and measurement endpoints used in ecological risk assessments frameworks (Suter, 1999), and to the approach recently used in the shape of 'reference organisms' (variously described over a range from multi-phylogenetic assemblages, to generalised phylogenetic types, down to individual species) to assess ecological radiation exposures in Arctic and European environmental situations (Brown et al, 2003; Larsson, 2004). The need for such a basic and generalised framework for environmental protection had also been strongly supported by the International Union of Radioecology (Strand et al, 2000).

(12) But because the needs, in relation to any particular circumstance, are by definition local and specific, it is evident that the types of organisms represented by the Reference Animals and Plants will not necessarily be the *direct* objects of protection – although one or more of such types may be, or could be chosen to be. Equally, they could be used to serve as a screening mechanism for excluding the need for further detailed studies. The point to note here is that, in any of these cases, the existence of a well-defined *basic* reference set of data is still likely to be of value because it enables other, more site specific (but probably less complete) data sets to be compared and contrasted with the reference set. Such differences could relate to aspects of dosimetry, of radiation effects, or of biology and ecological characteristics. In some circumstances it may therefore be useful to compile a 'secondary set' of reference organisms for a specific purpose or geographical area. But because of the enormous potential range of animals and plants to consider, the Commission believes that its general advice would best be based on a small set of Reference Animals and Plants that would serve as a 'test bed' upon which different concepts, data bases, and models can be explored and examined.

2.2 Criteria for choosing different types of animals and plants

(13) There are many factors that have had to be considered in the selection, description, definition, and potential application of reference animals and plants, and the Commission has been greatly assisted in their consideration of these issues by being able to draw upon the many studies, seminars, conferences, and research programmes that have recently been held on this general topic, including the following: symposia on the protection of the environment from ionising radiation in Stockholm, (Amiro et al, 1996), Canada (Anon, 2001), Darwin (IAEA,2003), and Stockholm (IAEA, 2005); IAEA Reports (IAEA, 1999, 2002); the IUR (Strand and Oughton, 2002); the NEA (2002); and the results of the EPIC and FASSET projects (Brown et al, 2003; Williams, 2004).

(14) Given that the objective is to provide a starting point for the assessment of radiation exposure, of radiation dose, and of possible dose responses, for such an enormous variety of living animals and plants, it is clearly not easy to select a few biological types for the purpose of creating a small reference set. Thus notwithstanding the need for number of scientific criteria for their selection, one of the first consideration is that of what the information is likely to be used for, and under what circumstances. These are anticipated to include the following:

- *requirements to meet existing or expected environmental legislation*, particularly in relation to wildlife conservation and habitat protection, that may apply to particular species of animals and plants, their populations, or to specific habitats and communities, and that may need to be applied to existing practices;

- *requirements for 'environmental impact assessments'* in relation to existing or proposed nuclear facilities that, as well as including the above requirements, may necessitate evaluations to be made with respect to potential impacts on other forms of environmental management, such as those relating to fisheries, agriculture, and so on, and of the consequences of major accidents and emergencies; and

- *requirements to achieve consistency in regulatory approaches* to large industries, particularly with regard to the need to consider, explicitly, not only their potential impact on the general public but also their potential impact on the environment generally.

(15) The feature common to all of these requirements is the need to have a consistent and transparent approach to relating exposure to dose, and then relating dose to what is known about different sorts of effects on different types of animals and plants. But it is appreciated that the application of this type of information will vary substantially at national or regional level.

(16) Bearing these points in mind, it was considered that a mixture of animals and plants was needed that reflected both the variety of operational and regulatory requirements, and the need to be pragmatic in terms of developing a flexible framework to accommodate future needs and the acquirement of new knowledge. It would therefore appear that, in relation to the anticipated requirements:

- for the purposes of *existing or expected environmental legislation,* particularly with regard to wildlife and habitat conservation, any likely list of candidate types would need to include a number of vertebrate animals, such as a mammal and a bird, and possibly a reptile or amphibian, and that wetland habitats appeared to be particularly subject to international and national concerns, often with respect to the transboundary movements of wildlife within geographic regions;

- that for evaluations in relation to *environmental impact assessments*, particularly where these interface with other forms of environmental management, any list would necessarily require examples of animals and plants that were relevant to such practices as fisheries, agriculture, and forestry; and

- with regard to *achieving consistency in regulatory approaches*, it was noted that in other forms of pollution control a number of 'toxicity-test' type organisms are already routinely used, and thus some overlap with such types of organisms would be desirable, and that because *ecotoxicological studies* are also increasingly, it would be important to ensure that the total reference set

had a reasonable coverage of the major ecological compartments of terrestrial and aquatic ecosystems.

(17) Notwithstanding such requirements, however, it is also necessary to be pragmatic. It is simply not possible to gain the necessary information about radiation effects on some types of wildlife that are the subject of conservation measures, or are fished, or are otherwise harvested commercially in aquatic and terrestrial environments. Nor is it possible to gain sufficient information to represent the wide range of potential exposure situations of animals and plants in the environment with respect to normal, existing, or accident and emergency situations. Fortunately, however, quite a lot of information does already exist. Various animals that can be held in captivity have been studied, as have a number of fish species, and other invertebrate animals that have commercial value. Several agricultural crops and other plants have also been studied in some detail. These, in turn, occupy a range of ecological niches.

(18) They also need to display a range of different life histories. Thus the different exposure situations throughout the life cycle for birds, and reptiles that lay eggs, are very different from mammals that carry their young internally, or from amphibians that have aquatic eggs and tadpoles but adults that live primarily on the land. Similarly, some fish that are pelagic lay their eggs on the sea or river bed, whereas some fish that live on the bottom have pelagic eggs and larvae. The life cycles of some animals, particularly insects, may last only days or weeks; other animals have life spans that far exceed that of human beings. Some plants complete their life cycles within a year; others may live for centuries. And to all of these considerations, it is also necessary to consider the sheer practicality of gathering sufficient information, in a reasonable amount of time, to produce some useful guidance.

(19) Collectively, therefore, in selecting a small but practical set of reference animals and plants, the following criteria were used:

- that there is a reasonable amount of radiobiological information already available on them, including data on probable radiation effects;
- that they are amenable to future research, in order to obtain the necessary missing or imprecise data, particularly with regard to radiation effects;
- that they are considered to be typical representative fauna or flora of particular ecosystems;
- that 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, lifecycle and general biology;
- that their life-cycles are likely to be of some relevance for evaluating total dose or dose-rate, and of producing different types of dose-effect responses;
- that their exposure to radiation can be modelled using relatively simple geometries;
- that there is a reasonable chance of being able to identify any effects at the level of the individual organism that could be related to radiation exposure; and

- that 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.

(20)   A final consideration is that of how best to describe the chosen selected reference animals and plants, bearing in mind that it has not been the intention to select particular species, but equally not to generalize to the extent that the characteristics of the selected types are of little biological meaning.

2.3 Achieving an appropriate level of generalization

(21)   The taxonomic framework for past and present life on Earth has always been somewhat flexible, and is still the subject of much debate. Nevertheless, virtually all forms of life can be, simply for convenience, divided into either the Animal or Plant Kingdoms, with viruses and similar micro-organisms being grouped separately. Bacteria, too, are often considered as a separate 'Kingdom', although they have also been – and sometimes still are – grouped with the plants. The same applies to the fungi. Single-celled organisms have also been considered separately – as the Protista.

(22)   The classification of animals and plants is primarily a reflection of their morphological characteristics, plus physiological and biochemical features, and often draws upon what is known or assumed about their evolutionary history. Such approaches are now greatly strengthened by the use of DNA analyses. Animals are grouped into **Phyla**, on the basis that each Phylum has, more or less, the same 'body plan' (such as chordates, or echinoderms, or arthropods) and within each Phylum they are further grouped into **Classes**, then **Orders**, then **Families** (which share 'typical' traits and features), and then *Genera* as the number of features they have in common increases; finally, *Genera* are divided into *species*. There is no absolute definition as to what a species actually is, but it is usually taken as a description of individuals that (it is either known or expected) can only produce fertile offspring as a result of mating with similar individuals. In some cases, even further distinctions are made – into *sub-species*, or into races and varieties. Plants, too, are characterized in relation to features such as anatomy, embryo characteristics, and biochemistry, and are similarly classified except that they are usually grouped into Divisions rather than Phyla. Features that differentiate either animals and plants at the level of Class or Order are often fairly detailed, and may be more a reflection of their evolutionary history than a factor that is relevant to their general biology today. Such groupings are subject to considerable fluctuations and are the subject of academic study and debate. Thus there are no internationally accepted 'rules' on classification above Family (or 'Super Family') level, and this has therefore been suggested as the most suitable level of generalisation (Pentreath, 2002 b, 2005; Pentreath and Woodhead, 2001) for reference types of animals and plants.

(23)   The total number of species of animals and plants is not known with any certainty, although the majority of 'large' organisms have probably been the subject of description and classification. Thus probably 99% of birds and 90% of other land vertebrates have already been described (Goto, 1982). It is generally assumed that here are certainly well over a million species of animals, and at least half that number of plants on Earth at present; although some recent estimates place the former as high as 3 to 4.5 million, and the latter as low as 0.35 million (Sauchanka, 1997). New

species of animals and plants have been described in recent decades at the rate of about 10,000 per year, and approximately half of these are insects, the remainder consisting largely of a wide variety of other invertebrate animals, and plants.

(24) Animals usually have between 12 and 60 pairs (2n) of chromosomes, but there is considerable variation, even within Orders and Families (for example, in the Diptera (flies) 2n varies from 4 to 20; in the Lepidoptera (butterflies and moths) it varies from 14 to 446). The molecular biology of plants is much more variable than that of animals, with more frequent recombination and re-assortment of genes during meiosis. Nuclei, mitochondria, and plastids within plant cells, all have their distinct DNA systems. Polyploidy is common in plants (50% of all flowering plants), usually because a diploid (2n) plant, by irregular division, gives rise to a tetraploid (4n) plant. Then, as a result of pollination, triploid (3n) plants are formed. These are unable to produce gametes compatible with either 'parent', and thus the 2n and 4n forms often diverge because of the resultant genetic isolation (Collinson, 1988).

2.4 A definition of Reference Animals and Plants

(25) Because no clear algorithm for the selection of Reference Animals and Plants can be defined, their selection therefore has to be made on best judgment, bearing in mind the need to keep the total number low, to try and cover terrestrial, freshwater, and marine environments, and to satisfy the various criteria discussed in this chapter.

(26) Based on all of these criteria, therefore, and in an attempt to be consistent with the original concept of Reference Man, a Reference Animal or Plant can be described as follows. ***A Reference Animal or Plant is a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.***

2.5 The set of Reference Animals and Plants

(27) Working within this definition, and taking into consideration both the needs and the selection criteria, a 'set' of Reference Animals and Plants has been identified, as set out in **Table 1.** A deliberate emphasis has been placed on vertebrate animals but, in compiling the overall 'set', consideration has also been given to the range of habitats covered (**Table 2**), the variety of life histories and life spans represented, and the potential for extrapolating the basic 'Reference' animal or plant data to other forms of animal or plant, or to place them in other environments. Thus, again bearing in mind that the primary purpose is to use the Reference Animals and Plants to relate exposure to dose, and dose to effect, it should be possible to adapt the basic data in relation to, for example, the marine flatfish to that of a similar fish in an estuarine situation, or to adapt the freshwater salmonid fish data to those of a marine 'round' fish, and so on.

Table 1. Subjective assessment of the types of Reference Animals and Plants against some key criteria used in their selection (+low; ++medium; +++high affinity).

	Legislation relating to wildlife protection	Use in toxicity testing	Human resource	Data on radionuclide accumulation	Data on radiation effects	Amenable to further study
Deer	+		++	+	+	+
Rat	+	+++		++	+++	+++
Duck	+++		+	+	+	+++
Frog	++		+	+	+	++
Trout	++	+++	+++	+	+++	+++
Flatfish		+	+++	+++	++	++
Bee	+	+	++	++	+	+++
Crab		+	+++	+++	+	++
Earthworm		+++		++	+	+++
Pine tree	+		+++	++	+++	+++
Grass		+	+++	++	+++	+++
Seaweed			+	+++	+	++

Table 2. General types of selected reference animals and plants in relation to their ecological spread.

Organism	Terrestrial	Freshwater	Marine
[Reference Man]	[X]		
Deer	X		
Rat	X		
Duck	X	X	
Frog	X	X	
Trout		X	X
Flat Fish			X
Bee	X		
Crab		X	X
Earthworm	X		
Pine Tree	X		
Grass	X	X	
Brown Seaweed			X

(28) Equally, however, a balance has had to be struck in keeping the Reference Animals and Plants as simple as possible, with descriptions and numerical information proportionate to the amount of radiobiological information currently available, and the purposes to which the data will be put. The set is essentially one of 'wild' animals and plants rather than domesticated ones. With regard to farm animals

- primarily large mammals that live essentially in a human environment - it was considered that the use of the human animal itself was probably sufficient for such managed environmental or ecological situations.

(29) It is perhaps also worth stressing at this point what Reference Animals and Plants are *not* intended to be. As indicated previously, they are not necessarily the objects of protection – although they might be in certain situations. And they are not intended to serve as 'sentinel' organisms or species, in the sense that it is considered that if such types are protected then other types will also be protected: as will be seen later, there is insufficient information on radiation effects on different types of organisms to enable such an approach to be made, even if it was desired. Nor are these types of organisms the particular ones that the Commission considers should be particularly protected; the Commission does not intend to make such judgments – although that does not preclude others from making them. They are, however, considered to be organisms that are 'typical' of different environments, in the sense that one might expect to find them there (earthworms in soil, ducks in estuaries, flatfish and crabs in coastal waters, trout in rivers and lakes and so on) and thus that a more detailed understanding of the relationships between dose and effect for such types should prove to be generally helpful as a basis for more detailed comparisons where necessary. They are also not intended to represent key links in food chains, although some basic ones could be constructed from the set (deer eat grasses; frogs eat worms, fish eat crabs and so on). And they are also not intended to represent key links in ecosystem functioning. Certain components of ecosysytems, such as bacteria, have been deliberately excluded because they are known to have such a high resistance to radiation that they would not serve as useful reference points within the environmental ranges of dose rate that are of interest.

2.6 The Individual Reference Animals and Plants

(30) It is not possible to provide a comprehensive biological background here to all of the reference types chosen, but some additional general information relating to their biology and ecology is provided in **Appendix A**, together with a more general discussion on populations. This information should be regarded as also being of relevance in the application of any particular Reference Animal or Plant to any specific application. The following is therefore merely a brief introduction and description of each type. It should again be stressed however that, as is the case for Reference Man, they merely represent a hypothetical animal or plant type. Each reference is *not* a set of data compiled to describe an average or median individual of, nor a description of, a specific species. These are merely 'typical' data of particular 'types' of animals and plants, but nevertheless precisely defined numerically so that where differences in such values are necessarily made (for example, with regard to size or shape, or in the time span of different stages of a life cycle) there is a known basis for the dose estimation procedure and hence for any variations that others might use to describe any *specific* animal or plant.

2.6.1 A large terrestrial mammal – the *Reference Deer*

(31) Deer are hoofed mammals, belonging to the Family **Cervidae**. They are the characteristic ungulates of the tundra, forest, and woodland zones of the entire Northern hemisphere as well as of areas south of the equator (Corbet, 1966; Nowark,

1991). There are some 45 recognised species across North and South America, Europe, Asia, and North Africa. Many species have also been introduced into some geographic areas where native species already exist (in Europe five species of deer are native and five have been introduced from elsewhere), and some species have also been introduced into countries where deer are not native at all, such as Cuba, New Guinea, Australia and New Zealand.

(32)   Deer are therefore important components of the ecosystem; indeed some, such as the migratory reindeer and caribou, are the principal large mammals over very large areas of land. They are used for human food, and some species have been domesticated. In captivity they have lived for well over twenty years. In some countries deer are the subject of special protective legislation, and they are also featured in cultural and religious beliefs. They have also been the subject of various radioecological studies.

(33)   The Reference Deer is taken to have the characteristics of a large woodland deer with an average life span of fifteen years, the females producing one calf per year (gestation period 250 days) for an average of ten years.

2.6.2 A small terrestrial mammal – the *Reference Rat*

(34)   Rats are rodents that, along with mice, hamsters, voles, lemmings, and gerbils are all members of the Family **Muridae**. There is probably more information on the effects of radiation on rodents than on any other mammal, with the exception of the human being. Rats and mice have been used extensively in laboratory experiments for a vast range of studies, particularly in relation to human medicine, including a large number in relation to the metabolism of radionuclides, and on the effects of radiation from both internal and external sources. In the environment they are fairly ubiquitous, with a worldwide distribution. Although generally regarded as a human pest, some species are rare, threatened, and thus legally protected in some countries.

(35)   The Reference Rat is taken to have the characteristics of a rat that feeds at night and rests during the day time in a burrow, and living in a colony (a clan), the members of which have a 'home' territory of 0.5km radius. Life expectancy is 2 years. Gestation is 24 days. Breeding occurs from the age of 100 days old. Average litter size is seven, and there are seven litters in a lifetime.

2.6.3 An aquatic bird – the *Reference Duck*

(36)   Ducks, geese, and swans collectively are members of the Family **Anatidae.** Ducks occur in rural and urban areas, and a number of species have been domesticated in various parts of the world and hence bred in captivity and used as a human food source. Wild ducks are also taken for food in some countries, but many species are increasingly protected, and 'wildfowl' generally are regarded as vital components of 'wetland' ecosystems; and 'wetlands' are, in turn, variously protected to provide habitats for wildfowl, either in relation to breeding or in relation to feeding and resting areas for migratory species. Ducks, in general, can thus be viewed as birds that are 'typical' of wetland areas, and their exposure to radiation throughout their life histories could arise, externally, from radionuclides on soil or in fresh, estuarine, or

sea water, and internally from the ingestion of a wide range of small aquatic animals and from both aquatic and terrestrial plant materials.

(37) The Reference Duck is assumed to have the characteristics of a typical 'dabbling' duck. (These are the most ubiquitous, being found in urban and rural areas.) It lays 10 elliptical eggs (that is, broadest in the middle) at one-day intervals and incubation takes 30 days. The nestlings spend their time equally divided between being on the ground and on the water. They are fledged at 60 days. The birds remain as juveniles for 1 year, at which age they breed for the first time. They then breed annually for 10 years, thus having a total life span of 11 years.

2.6.4 An amphibian - the *Reference Frog*

(38) Frogs and toads are also typical of wetland areas in many parts of the world. Some species are extremely rare and many are now protected. Wild frogs and toads are taken for human food in a number of countries, and some species are farmed as a food source. With a typical life cycle involving an aquatic egg, a tadpole stage, and then a terrestrial adult, frogs are likely to encounter a wide range of potential exposure situations in both freshwater and terrestrial environments.

(39) The 'Reference Frog' is assumed to have the characteristics of a member of the Family **Ranidae**, living in a temperate region around fresh water, spending its non-breeding time out of water, and hibernating over the winter period, in mud, for 16 weeks. It is carnivorous. It attains sexual maturity at 3 years of age. An average of 3000 eggs are laid each spring in shallow water, in clumps of about 400 per clump. The tadpoles emerge after 10 days. Metamorphosis into a 'froglet' is complete 100 days after hatching, the young frogs emerging from the water at a body length of 1.5 cm. They have a life span of 10 years.

2.6.5 A freshwater fish - the *Reference Trout*

(40) Salmon and trout belong to the Family **Salmonidae**. Salmonids occur in both marine and fresh waters, and some species are anadromous. The freshwater forms are essentially Northern hemisphere fish, but several species have now been widely introduced into fresh waters all over the world. Salmonids include some of the species of fish that are amongst the most valued commercially. Salmon and trout are regarded as biological indicators of good water quality and are the subject of much environmental and fisheries legislation. They have also been the subject of many laboratory studies on fish physiology, and on radionuclide metabolism and radiation effects, as well as being used to investigate the accumulation and effects of many other environmental contaminants. They are used in toxicity tests for a range of pollutants. Trout, in particular, are also widely farmed throughout the world.

(41) The reference salmonid is taken to be a 'trout' rather than a 'salmon' in order to avoid the complication of migratory effects of the salmon from fresh water to the marine environment. The reference trout is therefore assumed to have the characteristics of a trout that lives its life in the same ('soft') body of water, spawning in a stream that runs into that water. The eggs are laid in late autumn, taking 100 days to hatch. It attains maturity at 4 years old and spawns twice (1500 eggs each year) before dying at the age of 6 years.

2.6.6 A marine fish – the *Reference Flatfish*

(42) Teleost (bony) flatfish species are the basis of commercial inshore fisheries in many parts of the world, and a number of species are farmed commercially. Of particular importance are members of the Family **Pleuronectidae**, examples of which are widely distributed in cool temperate waters of the Atlantic, Pacific, and Indian Oceans. The majority are shallow-water, bottom-living fish. Many species also penetrate estuaries and brackish waters. Typical Pleuronectids are the plaice, the flounder, dab and halibut. They have been the subject of many laboratory studies, and extensively studied with regard to their accumulation of radionuclides and the effects of radiation. In contrast to salmonid fish, teleost flatfish produce eggs that float in the water column. The larvae remain in the water column for several weeks and thus, together with the eggs, form part of the plankton. The larvae metamorphose and settle on the sea bed, both juveniles and adults living predominantly in or on the bottom sediments. They inhabit both marine and brackish waters.

(43) The reference flatfish is assumed to have the characteristics of a typical pleuronectid, living in shallow-water. The female produces an average of 300,000 eggs each year. The eggs hatch in 15 days and are fully metamorphosed into adult form at the age of 50 days, and then settle onto the seabed and grow into adult form. They grow continuously throughout life, mature at four years of age, and have a life expectancy of 10 years.

2.6.7 A terrestrial insect - the *Reference Bee*

(44) There are probably more species of insects on the planet than of all other forms of life put together. They play a vital role in the ecology of terrestrial ecosystems, as predators and prey, parasites and scavengers, and as pollinators of flowering plants. A few species are directly harmful to man, by way of carrying diseases, although immense indirect damage can also be done to crops and building structures by other species. Equally, however, many species are essential for crop pollination, and hence in human food production. Many species are also legally protected, either because of their own 'value' (such as butterflies) or because they provide a vital role in maintaining the ecology of other 'valued' animal or plant species. The most studied and easily reared insects are the bees. Although the majority of bees are solitary and relatively short lived, the best studied are the social bees, particularly the honeybees.

(45) The reference bee is assumed to have the characteristics of a typical social bee of the Family **Apidea**. (The grouping of bees into Families is often the subject of much debate – see Appendix 1.) The queen mates in the autumn and sets up her own colony within which she lives for 3 years. She lays 200000 eggs per year, 600000 in a lifetime. The eggs hatch after 4 days. The larvae pupate after 6 days and emerge as adults after 20 days. The average life of the worker bees is 100 days. Some of the workers also lay (unfertilised) eggs, some of which mature into (male) adults. Some of the queen's eggs develop into young queens. In the late summer the young queens and males leave the nest. Queens and males mate, the latter die, the queens hibernate, and the cycle is repeated the following year.

2.6.8 A marine crustacean - the *Reference Crab*

(46)   Crabs and lobsters are amongst the few types of invertebrate animals that grow to a reasonably large size and they have comparatively long life spans. Crab larvae form part of the plankton, where their size and feeding patterns are very similar to other types of crustaceans that spend their entire life cycle as part of the plankton. Although the majority of crabs are marine species, there are many that inhabit brackish waters, and fresh waters, and some are essentially terrestrial. Crabs are widely taken for human food in coastal waters all over the world, and many species are farmed commercially. Their biology has therefore been well studied, and they have been the subject of many radiobiological studies and radiochemical analyses.

(47)   The reference crab is assumed to have the characteristics of a reasonably large temperate water crab of the Family **Cancridae**. The female produces an average of 2 million fertilised eggs in the late autumn and retains them for 6 months before the larvae are released. The larvae spend 60 days in the water column before settling on the bottom. The male crabs mature at the age of 5 years, females at the age of 10 years, and both live to an average age of 15 years. As adults, they are assumed to moult just once a year.

2.6.9 A terrestrial annelid - the *Reference Earthworm*

(48)   Earthworms occur all over the world, although somewhat rarely in deserts, areas under constant snow and ice, and in areas entirely lacking in soil and vegetation. They make a very large contribution to the total biomass of soils, particularly in temperate regions. They also play a vital part in the breakdown of dead plant and animal material in soil and forest litter, and thus in soil fertility, as well as in the maintenance of soil structure and aeration. They also provide a food source for a large variety of mammals and birds. They have been extensively used in the toxicity testing of inorganic and organic chemicals, particularly insecticides, fungicides, herbicides, and heavy metals. Some species grow and reproduce well in organic wastes and have been used to feed both fish and livestock. They have also been used in the amelioration of contaminated land, in land reclamation (such as mine wastes), and as indicators of environmental contamination.

(49)   The reference earthworm is assumed to have the characteristics of a member of the Family **Lumbricidae**, which occur naturally in Europe, western Asia, and North America. It is taken to be hermaphrodite but are not self-fertilizing. It produces 25 capsules per year, from which a single hatchling emerges after 50 days. The adult reaches maturity at 1 year and lives for 5 years.

2.6.10 A large terrestrial plant – the *Reference Pine Tree*

(50)   Pine trees (Family **Pinacea**) occur naturally across the whole of the Northern hemisphere, from the Arctic Circle to just south of the Equator, in a wide variety of environments. They have also been introduced into many southern hemisphere countries worldwide. They have been extensively used by man for building materials, for fuel, and for resin. They have also been well studied with regard to their physiology and general biology, and are easily cultivated. There is also a large amount of information on them with regard to exposure to radiation and its effects.

(51) The reference pine tree is taken to have the characteristics of a large tree growing in temperate regions. It attains reproductive maturity at 10 years and lives for 200 years. Young trees grow at the rate of 1m per year. It produces cones that are ovoid, taking 18 months to mature.

2.6.11 A small terrestrial plant - the *Reference Wild Grass*

(52) All grasses belong to the same Family, the **Poaceae (**formerly the **Gramineae**). Grasses of one form or another are the predominant plants throughout much of the terrestrial environment. They have a word-wide distribution and occur naturally in a wide variety of forms, including reeds and bamboos, as well as the more familiar cereal crops and the dominant plants of natural pasture land. They serve as food for a wide range of herbivorous mammals, including (as herbage) domesticated forms of cattle, sheep, and horses. They are also the basic food crop for humans all over the world. Their biology has therefore been well studied, including their accumulation of a wide range of chemicals. Their life cycle is highly seasonal.

(53) The reference wild grass is assumed to have the characteristics of a 'barley type' grass with a flowering spikelet carried on a stalk above the ground. It is a perennial.

2.6.12 A seaweed - the Reference Brown Seaweed

(54) Seaweeds are the principal macroscopic 'plants' of the marine environment, occurring in coastal waters all over the world. They have complicated life-cycles. Some species are commercially harvested for human food, some for fertilizer, or for use as cattle food, and some are harvested for the extraction of alginates and gums. Seaweeds have also been used extensively to examine the adsorption, or absorption, of a wide range of chemicals, particularly metals, in marine or brackish water environments. Their chemical compositions have therefore been well studied, and they have also been used extensively as indicators of the dispersion of radionuclides in the aquatic environments. And, because some species are eaten by humans, these have been extensively monitored in the vicinities of coastal nuclear sites. Brown seaweeds have a very wide geographical range. They may occur on any part of the intertidal or sub-tidal zone and may therefore be exposed to seawater or covered in silt or mud for different periods of time.

(55) The classification of seaweeds is a subject of continuing debate. The reference brown seaweed is taken here to have the characteristics of a **Cyclosporean** brown intertidal seaweed, living in such a position that it is covered by seawater for 75% of the time and dries out and is covered with a coating of silt for 25% of the time. It has a simple life cycle, in that the adult plant is a diploid sporophyte that has male and female conceptacles on the same thalli (monoecious). It reproduces annually and lives for 5 years.

2.7 Populations

2.7.1 Introduction

(56) In some cases it may be useful or necessary to know something about the risks to individuals as a result of exposure to radiation. In other cases, however, consideration may largely be directed towards the population. A population can be most usefully and simply described as a group of individuals of the same species that live in the same place at the same time. In terms of spatial scales, the area considered of relevance to the maintenance of populations is usually regarded as that which is sufficient for the organisms to carry out their normal functions (including migration, if migratory), and where immigration and emigration rates are roughly balanced (Berryman, 1999). Populations can also be considered as a group of genetically similar individuals that can be meaningfully characterised in terms of such factors as birth rate, death rate, sex ratio, and age structure (Emmel, 1976).

(57) Although the subject of population biology has many basic features in common, it is also important to recognise significant differences that may be of relevance in terms of the time and extent of the exposure of populations to radiation, and thus the nature of any likely effect. Thus some species reproduce several times in their life times (*iteroparous*), and such reproduction may be more or less at any time of the year, or limited to a specific season. Such populations will therefore have overlapping generations, although in the case of the latter, discrete cohorts of the population can usually be identified. Some species, however, reproduce only once in a lifetime (*semelparous*), and if this occurs seasonally, then each entire population will consist of a discrete (genetic) generation.

(58) In considering the effects of radiation at a population level, therefore, it is essential to specify what precisely are the characteristics of the population being considered, the fraction of the population known or assumed to be exposed to different rates of dose, and hence their total dose, and the stages in the life cycle receiving the relevant dose, plus any other factors of relevance. The following is therefore a brief summary of the assumed basic population characteristics for the set of Reference Animals and Plants, which need to be considered along with the assumed characteristics of individuals, as described in the preceeding section.

2.7.2 Populations of Reference Animals and Plants

(59) The Reference Animals and Plants are assumed to have the general population characteristics as set out in **Table 3**.

(60) These population characteristics need to be borne in mind when considering the potential consequences of any assumed or observed effects of radiation. The geographic area necessary to support populations of these sizes is also of relevance. It is also recommendeded that any future ecosystem modelling of radiation effects should start with such basic assumptions of population parameters, as indicated in **Table 3**, in order to relate the different categories of the effects of radiation observed in individuals, or groups of individuals, as discussed later in this report, to effects that might be expected at the level of populations, and of communities of different populations.

Table 3. Basic population characteristics of Reference Animals and Plants

Reference Animal or Plant	Population characteristics
Deer	Iteroparous, distinct cohorts, high female to male ratio, low fecundity, population number < 500
Rat	Iteroparous, equal sex ratio, high fecundity, population number <1000
Duck	Iterparous, distinct cohorts, equal sex ratio, low fecundity, population number < 500
Frog	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number < 500
Trout	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number < 500
Flatfish	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number > 10000
Bee	Semelparous (for males), high male to female ratio, high fecundity, population number < 10000
Crab	Iterparous, distinct cohorts, equal sex ratio, high fecundithigh fecundity, population number > 500
Earthworm	Semelparous, hermaphrodite, low fecundity, population number > 10000
Pine tree	Iteroparous, canopy forming, high fecundity, population size > 1000
Grass	Iteroparous, high fecundity, perennial with yearly re-growth, population size >1000
Brown seaweed	Iteroparous, low recruitment to adult population, population size >1000

3 PATHWAYS OF EXPOSURE

3.1 Introduction

(61) It is useful to consider radiation in an environmental context, as in any other, by relating it to a 'source', where the term 'source' indicates any physical entity or procedure that results in a potentially quantifiable radiation dose. If radioactive materials are released from an installation to the environment, the installation as a whole may be regarded as a source; if they are already dispersed in the environment, the portion of them to which exposure is of interest may be considered as a source.

(62) With regard to the exposure of humans to a source, the Commission considers it useful to recognise three *types* of *exposure situations*, which collectively address all conceivable circumstances. These are as follows.

(a) *Planned exposure situations,* which involve the planned introduction and operation of sources. This would also include their decommissioning, disposal of associated radioactive waste, and rehabilitation of the previously occupied land in the case of installations.

(b) *Emergency exposure situations,* which are unexpected situations that occur during the operation of a planned situation, or from a malicious act, requiring urgent action.

(c) *Existing exposure situations,* which are exposure situations that already exist when a decision on control has to be taken, including natural background radiation and residues from past practices that have been operated outside the Commission's recommendations with regard to human radiation protection, or long-term exposure situations following emergency situations. Thus what the Commission has hitherto called 'practices' could be the origin of planned, emergency, and existing exposure situations.

(63) It is therefore likely that any consideration of the exposure of plants and animals, or any action taken as a result of their exposure, in an environmental context, would similarly fall within one of these three categories. Priorities would, however, be somewhat different with regard to environmental protection.

(64) Plants and animals may therefore be exposed to ionising radiation in the environment from different sources, and under different types of exposure situations. In all of these, factors affecting the doses received will vary enormously. Radionuclides distributed in the environment will result in the external radiation exposure of the organisms living in, or close to, a contaminated medium, the dose received being the result of the complex and non-linear interactions of various factors including the contamination levels in the environment; the radionuclide-specific decay properties characterised by the radiation type, the energies emitted, and the yield; the geometrical relationship between the source of the radiation and the target; the composition and shielding properties of materials in, and the nature of, the surrounding medium; and the location and size of the organism. Internal exposure results from the accumulation of radionuclides into the tissues and organs of organisms, and from radionuclides that may pass through the gut or otherwise

temporarily enter cavities within an organism, and will depend on both the physical decay properties and characteristics of the radionuclide and the biological half life of the radionuclide at either a whole body or organ-specific level.

3.2 Data needs with regard to different exposure situations

(65)   As with human radiation exposure, the basis of estimates of dose received, or that might be received, will vary from one exposure situation to another. Under many planned or existing exposure situations, in which radionuclides are present in the environment, direct measurements can be made of water, sediment, or soil in order to estimate doses from sources external to an organism. It should also usually be possible to obtain direct radionuclide concentration data in order to estimate doses from internal sources. In other situations, however, a different approach is needed, where resort has to be made to modelling approaches, plus their attendant data bases. This is particularly the case with regard to anticipated exposures from the creation of sources in the future, under planned situations, and in relation to potential emergency situations. All of this work would normally form part of an overall 'Environmental Impact Assessment'. The modelling approaches might also require different sets of data to relate exposure to dose.

(66)   Thus the relationships between the concentrations of radionuclides external to, and those contained within, an organism will differ very considerably under the three different types of exposure situations. For convenience, such relationships are usually considered as being either in a 'steady state equilibrium', or in some form of dynamic, non-steady state, condition. For the former, the data are often expressed in terms of a concentration ratio (actually a derived quotient) between the organism and the surrounding medium. Thus, for example, for aquatic organisms, the steady state situation may be expressed as a 'Concentration Factor' value to represent the ratio of the concentration of the radionuclide in the organism to that of the ambient water (filtered or un-filtered). For terrestrial organisms, this relationship has sometimes been represented by a 'Transfer Factor' value, being the quotient of the concentration of the radionuclide in the organism to that of the soil. Many tabulations have been made of such values, particularly for aquatic organisms, but these have usually been formulated for the purpose of estimating pathways leading to human exposure. They therefore often relate to the concentration of a radionuclide within a specific part of the organism – the part that would normally be consumed by humans. Such data are not therefore always of much relevance to the needs of calculating the dose received by the organism itself, particularly with respect to any particular organ or tissue that would be of interest in terms of estimating specific types of radiation effect.

(67)   Such data also usually relate to the adult organism. In this regard therefore, as can be seen by the selection of the Reference Animals and Plants, important pathways of exposure, and particularly those relating to the most sensitive stage in the life cycle, may not be estimated at all. Thus although exposure may result from contaminated soil, sediment, water, or air, this may differ throughout the life cycle. The eggs of frogs are laid in water, and the tadpoles also have an aquatic existence, and both have contact with the sediment; but the adult frog may spend a considerable amount of time out of water and travel considerable distances over land. Trout live in the water column, but the sensitive egg stage is spent in close proximity to the bed of the lake or stream. Conversely, a flatfish may spend most of its adult life in contact

with the seabed, but its eggs and larvae live high up in the water column. And terrestrial situations can be equally difficult, as in defining the relationships between the concentrations of radionuclides in the buds or cones of pine tees relative to either the air or the soil, or in the tissues of burrowing animals such as the rat.

(68) Unfortunately there are very few data available that can be used to represent the relationships between the ambient medium and these sensitive stages of the life cycle for many forms of aquatic organism, or even for the adults. Many models do exist, however, to describe the environmental distribution of radionuclides consequent upon various exposure situations. It is therefore reasonably feasible to estimate, at a first approximation, the potential dose rate implications for many different types of animals and plants.

(69) The establishment of a 'reference' data base would therefore be extremely useful. Again bearing in mind the different exposure situations, a number of factors need to be considered, including the following:

   - external exposure from contaminated soil, sediment, or water;

   - contamination of fur, feathers and skin;

   - inhalation of (re)suspended contaminated particles or gaseous radionuclides;

   - ingestion of radionuclides; and

   - the direct uptake from the water in the case of aquatic organisms.

(70) Such data bases need to be carefully considered and compiled, and will therefore be the subject of a subsequent report in relation to Reference Animals and Plants.

4 CALCULATION OF DOSE CONVERSION FACTORS FOR REFERENCE ANIMALS AND PLANTS

4.1 Introduction

(71) Although many different approaches have been used to estimate the doses received by animals and plants, from both internal and external sources, they have many features in common (Woodhead, 1979; IAEA, 1976 1979, 1992; Pentreath and Woodhead, 1988; NCRP, 1991, Amiro, 1997; DOE 2002; Golikov and Brown, 2003; Higley et al., 2003; Vives i Battle et al. 2004; Taranenko et al., 2004; Beaugelin-Seillier et al., 2006; Ulanovsky and Pröhl, 2006). All have had to strike a balance between the complexity of the modelling that is theoretically possible, and the availability of data to apply to them. There are two issues here: one is the vast range of shapes and sizes that occur throughout the animal and plant kingdoms; the second is the fact that radionuclide concentrations in animals and plants display all of the variations amongst tissues and organs that occur in human beings, but there are few internally consistent data sets for any one particular type of animal or plant. Thus an extreme simplification has often been made (but one that has nevertheless been very useful in drawing out comparative differences with respect to the relative contribution of different radionuclides to the total dose amongst different types of animals) and that is the reduction of the whole organism to a simple shape.

(72) Thus, compared with human dosimetric models, where mathematical and voxel phantoms are now used to represent humans of different ages and sexes, with various organs, the dosimetric models for biota remain much more simplified. Although a few more detailed models have nevertheless been developed, such as those created by Woodhead (1970, 1979) to describe the special cases of exposures of the embryos of developing fish eggs.

(73) Several different analytical approaches to the calculation of dose rates to animals and plants have also been used or suggested in recent years, for various and different purposes. A number of them have made use of uniform isotropic models, or have applied simplified analytical or semi-analytical methods. These have been described in some detail in NCRP (1991); IAEA (1992); Amiro (1997); DOE (2002) and Higley et al. (2003); Copplestone et al. (2001) and Vives i Battle et al. (2004). Such methods are often sufficient to assess exposures in aquatic environments, because of the low difference in densities between the organism and the external medium.

(74) In the terrestrial environment, however, the radiation source may be in or on the soil, and the exposure targets may live in the soil (such as the earthworm), on the soil (such as the deer) or above the soil (such as birds, or the canopies of trees). Soil, air and organic matter also differ considerably in composition and density that cannot, in general, be adequately taken into account by simplified analytical or semi-analytical methods. The estimation of external exposures in the terrestrial environment is therefore more complex. Radiation transport equations are therefore solved by Monte Carlo methods using numerical simulations of particle transfer across various media. Such simulations provide several advantages, including the following:

- materials differing in composition and density can be considered;
- complex realistic geometries of sources and targets can be used;
- the physics of the radiation transport can be adequately accounted for ;
- the self-shielding is implicitly considered; and
- the uncertainty of the estimates can be very low.

(75)   Because of these advantages, nearly all of the most recent approaches apply, at least in part, Monte Carlo techniques, and these have therefore been considered here in more detail.

4.2 Some general considerations

4.2.1 Dose concept

(76)   The basic quantity for calculating exposures to ionizing radiation is the absorbed dose, which is defined as the amount of energy absorbed per unit mass of tissue of an organ or organism; it is given in units of *Gray* (*Gy*). The dose can be created by energy deposition in the living tissue caused by different types of radiation, such as α-, β-, and γ-radiation, neutrons, heavy ions, or fission fragments. Different types of radiation are known to produce different degrees of effect in the same biological tissue, for the same absorbed doses, for many types of organisms.) It should also be noted that, in the case of human radiological protection, it has been found useful to use other quantities - the equivalent dose and the effective dose. For the former, a set of radiation weighting factors has been chosen by the Commission, largely based on the known relative biological effect of different radiations. It should also be noted that the effects of radiation are most usually related to dose, whereas exposure is usually recorded in terms of dose rate; hence the need for time-specific reference values for different stages in the life cycle of Reference animals and Plants.

4.2.2 Absorbed fraction

(77)   A key quantity for estimating internal doses is the absorbed fraction, ϕ, which is defined as the fraction of energy emitted by a radiation source that is absorbed within the target tissue, organ or organism. In the simplest case, the organism is assumed to be in an infinite homogeneous medium with activity uniformly distributed throughout its body, the densities of the medium and the organism's body being the same. This was called a uniform isotropic model by Loevinger and Berman (1976). Under these conditions, both internal (D_{int}) and external (D_{ext}) dose conversion coefficients (defined as absorbed dose rate per activity concentration in organism or medium) for mono-energetic radiation can be expressed as function of the absorbed fraction:

$$D_{int} = E \times \phi(E) \qquad\qquad\qquad (1a)$$

$$D_{ext} = E \times \left(1 - \phi(E)\right) \qquad\qquad\qquad (1b)$$

where *E* is the energy of a mono-energetic source. Equation (1b) is an approximation that, in a strict sense, only holds if the organism and the surrounding medium are of the same density and elemental composition.

(78)   In an infinite homogeneous medium with uniform isotropic radiation sources, the dose per unit source strength cannot exceed the full absorption limit, which equals the absorbed dose in a uniform infinite medium (see e.g. NCRP, 1991). So, for any given mono-energetic particle or photon, the upper limit for the dose is:

$$D_{\infty} = 1.384 \times 10^{-2} \, E \quad (\mu Gy \, d^{-1} \, Bq^{-1} \, kg) \tag{2}$$

where E is the energy (MeV) of a mono-energetic source.

(79)   If the organism's dimensions are much smaller than the radiation range in the medium, then the internal dose approximates to zero due to the escape of radiation from the body, and the external dose approximates D_{∞}. And, in contrast, when the size of the organism is much larger than the radiation range in the medium, the whole body internal dose approaches the value of D_{∞}, whereas the external one tends to zero ($D_{ext} \to 0$). Ranges of the different radiations are compared in **Fig. 1** (Ulanovsky and Pröhl, 2006), which shows 'continuous slowing-down approximation' (CSDA) ranges for electrons $\Lambda(E_{\beta})$ (solid line) and α-particles $\Lambda(E_{\alpha})$ (dotted line) as well as mean free path for photons $\lambda(E_{\gamma})$ (dashed line). All ranges and the mean free path are derived from Hubbel and Seltzer (1995) and Berger (1999) and are given in meters for particles with energies in range from 10 keV to 10 MeV.

(80)   The figure shows that, in many cases of practical relevance, the ranges for α-particles and low-energy electrons are small (less or equal to 50 – 100 μm) and their absorbed fractions are high: $\phi \approx 1$. Consequently, following Eqs. (1 and 2), $D_{int} \approx D_{\infty}$ and $D_{ext} \approx 0$; but, for extremely small organisms and for longer-range radiations (high-energy electrons and photons) the absorbed fractions are very small: $\phi \ll 1$, thus $D_{int} \approx 0$ and $D_{ext} \approx D_{\infty}$.
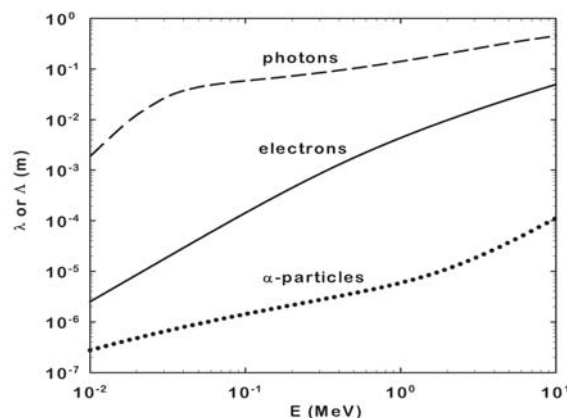
Fig. 1 Comparison of ranges for charged (Λ) and photon mean free path (λ) in water. CSDA-ranges (Berger 1999) for electrons (solid line) and for alpha-particles (dotted line), mean free path (Hubbel and Seltzer 1995). From Ulanovsky and Pröhl (2006).

4.2.3 Common modelling assumptions

(81) Due to the complexity of the processes involved in estimating doses to organisms, and the enormous variability of organisms and their natural habitats, it is impossible to cover all radiation exposure conditions. Models have therefore to be based on selected typical assumptions for energies, contaminated media, and organism sizes that are to be used for detailed consideration. Exposure conditions for which such detailed calculations are not available are then determined by interpolation between appropriate cases. Although not completely similar amongst different models, the following cases are usually taken into account.

- Dose conversion values are calculated for β-and γ-emitters. Due to the short range of α-radiation, the external exposure from α-particles is not usually considered (although it is in one model).

- A distinction is made between those organisms that live either in or on the soil.

- Input quantities are either measured or calculated radioactivity concentrations in biota, or in their immediate environment. Nuclide-specific dose rate conversion values are then derived as a function of habitat, target size and exposure route (internal or external).

- In all models, radiation transport is simulated for mono-energetic electrons or photons with energies in the range of approximately 0.01–5 MeV. Data for other energy values in this range are then obtained by interpolation.

- For the calculations of dose conversion values for targets living in the soil, uniformly contaminated volume sources are assumed. In some models, the thickness of the volume source is assumed to be infinite; in other models values for thickness are assumed to be 10, 20 or 50 cm. In addition to volume sources, a planar source at depth 0.5 g cm^{-3} is commonly used to simulate fresh deposition at surface with roughness.

All of these factors were considered in selecting the most appropriate choice of existing modelling techniques to apply to the Reference Animals and Plants.

4.3 Selection of the methodology used for Reference Animals and Plants

(82) A special exercise was undertaken to examine and compare the most recent Monte Carlo based models used within the EPIC project (Golikov and Brown, 2003), the RESRAD-BIOTA computer code that implements the U.S. Department of Energy's 'graded approach methodology' (DOE, 2002), the French EDEN code (Beaugelin-Seiller et al, 2006), and those used within the FASSET and ERICA projects (Taranenko and Pröhl, 2004; Ulanovsky and Pröhl, 2006). The results are given in **Appendix B**.

(83) Of the models tested, the largest set of geometries and exposure situations was that of the FASSET-ERICA programme, based on its flexible dosimetry method (Taranenko and Pröhl, 2004; Ulanovsky and Pröhl, 2006). This model allowed for the calculation of dose conversion values for a sufficiently wide range of organisms to

include the specific dimensions of the Reference Animals and Plants. It was therefore used to calculate a comprehensive set of values for all of them.

4.4 Specific considerations for Reference Animals and Plants

(84) With regard to the application of such models to the chosen Reference Animals and Plants, a number of other factors have also had to be taken into consideration. These have included the following:
- comparative shapes and sizes;
- the need for dosimetry based only on whole body or to include internal organs;
- body composition and density;
- environmental geometries;
- the possible use of the same geometries for more than one case;
- allowance for external coverings;
- the choice of radionuclides to be included in the calculations;
- the appropriate time integral for the dose-rate calculations; and
- the potential extrapolation of the models and data to other biota.

(85) The values required are those that provide radionuclide-specific conversion factors that can relate activity concentration values of a radionuclide, either in an organism or in its surrounding medium (in units of Bq per unit weight) to an absorbed dose-rate (in units of μGy per unit time). This approach had first been used in the context of calculating the potential exposure of organisms in relation to the defining of limits for the disposal of radionuclides into the marine environment (Pentreath and Woodhead, 1988; IAEA, 1988). Apart from the issue of shapes, as discussed below, it is also necessary to consider the relevant useful units. Because some of the Reference Animals and Plants have life spans of less than a year, and life stages that last only a matter of a few days, but for which differences in dose rate of less than a day are of no significance (or cannot, in any case, be taken into account) then the relevant values would appear to $\mu Gy\ day^{-1}$ per $Bq\ kg^{-1}$. These values are referred to here as Dose Conversion Factors (DCFs).

(86) With regard to shapes, many of the early approaches to dosimetry have attempted to greatly simplify complex geometries by assuming them to be simple shapes, such as solid spheres or cylinders (IAEA, 1976), or solid ellipsoids (Pentreath and Woodhead, 1988; IAEA, 1988; NCRP, 1991). This approach has many advantages, not simply in terms of mathematical simplicity but because the same simplified shape can then be used to represent different organisms of similar size. This has been done here with respect to the egg of a fish and the larva of a crustacean.

(87) There are, however, other aspects to take into account. A practical method to estimate absorbed fractions for a wide range of ellipsoids and spheres has been developed by Ulanovsky and Pröhl (2006). Fractions of energy deposited in the organism from internal photon and electron sources are computed by means of Monte Carlo simulations with the Monte Carlo code MCNP4C Briesmeister (2000). The body composition is assumed to be equivalent to the four-component composition as defined in ICRU (1989), and a body density of 1.0 g cm^{-3}. The organisms are assumed to be in an infinite water medium to ensure that there is sufficient medium for secondary photon transport. The transport of electrons and photons has been followed until their energies fell below energy cut-offs of 1 keV for photons and 10

keV for electrons; local deposition is then assumed to be due to the short mean free path and range respectively. The mass of the organisms considered covered a range from 10^{-3} g to 10^6 g in steps of an order of magnitude. For both photons and electrons the energies ranged from 10 keV to 5 MeV. The method of estimation of the absorbed fractions is then based on re-scaling of the absorbed fraction for tissues in water (Ulanovsky and Pröhl, 2006).

(88) Furthermore, with regard to ellipsoids, such non-spherical shapes are defined by the body mass and the relative lengths of the minor and major axes. From these quantities, a 'non-sphericity' parameter η is derived, which is defined as the ratio of surface area of a sphere to that of a non-spherical body of equal mass, i.e. $\eta = A_0 / A$. Photon and electron sources are simulated separately; however, transport of secondary photons and electrons has been accounted for in both cases.

(89) In Ulanovsky and Pröhl (2006), rescaling factors are expressed as a function of the non-sphericity parameter η for given mass and energy of source particle:

$$RF(\eta) = \left(1 - \left|1 - \eta^{\frac{1}{s}}\right|\right)^s ,$$ (3)

where s is the approximation parameter. The parameter has been found to depend on type and energy of the source particle as well as on the organism mass, thus it was approximated against a "scaled radius", r_0, of the equal mass sphere:

$$r_0 = \frac{R_0}{\Lambda(E_\beta)} \quad \text{(electrons)}$$ (4)

$$r_0 = \frac{R_0}{\lambda(E_\gamma)} \quad \text{(photons)}$$ (5)

where R_0 is a radius of the equal mass sphere; $\Lambda(E)$ is the electron CSDA-range in water and $\lambda(E)$ is the photon mean free path in water. The electron range and the photon mean free path depend on energy and the material's density and composition, while R_0 is simply related to the mass of the organism. The following approximation for the parameter s has been derived:

$$s(r_0) = C + \frac{a}{1 + \left(\dfrac{r_0}{x_0}\right)^b} + \frac{c}{d + \lg^2\left(\dfrac{r_0}{x_1}\right)} .$$ (6)

where the approximation parameters C, a, b, x_0, c, d, x_1 are given in **Table 4.**

(90) The values of the parameter s are plotted against r_0 and compared with approximation of Eq. (6) in **Figs. 2** and **3**.

Table 4 Values of the parameters of Eq. (6) derived by non-linear least-square fitting.

Parameter	Value for	
	electron	photon
a	0.783	0.677
b	0.549	1.830
x_0	0.506	4.97
c	0.235	0.079
d	0.495	0.247
x_1	0.940	9.90
C	0.0147	0.071

(91) The re-scaling method of Ulanovsky and Pröhl (2006) makes it possible to evaluate   internal and external exposure DCFs for aquatic organisms, with different ellipsoidal body shapes, over a wide range of body masses (10^{-6} to 10^3 kg) for source particle energies from 10keV to 5 MeV, thus covering all of the radionuclides listed in the ICRP Publication 38 (ICRP, 1983). Uncertainties in the approximations depend on the source particle type and energy, and on the organism's mass. Estimates by Ulanovsky and Pröhl (2006) have shown that the mean absolute coefficient of variation does not exceed 10% for electrons, and 15% for photons. In many practically relevant cases, the uncertainty does not exceed 3% for electrons and is bounded between 5 and 10% for photons.
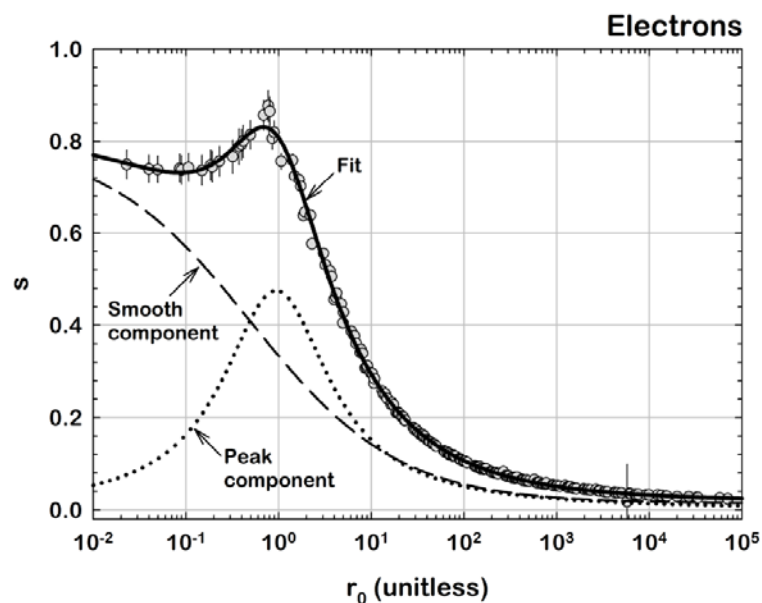
Fig. 2. Parameter s of the approximation (Eq. (3)) for the re-scaling factors $RF(\eta)$ for electrons as a function of the scaled radius of the equal mass sphere r_0. Solid line is the least square fit by two-component "logistic+Lorentzian" function (Eq. (6)).
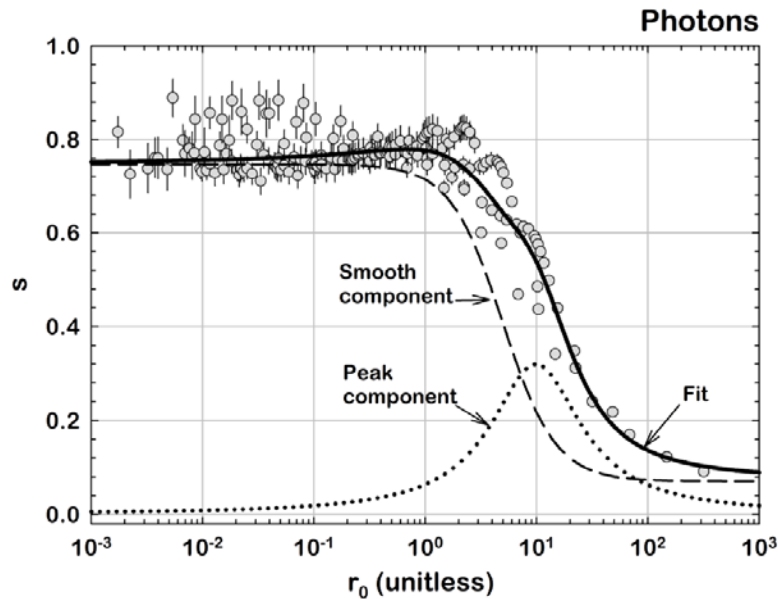
Photons

Fig. 3. Parameter *s* of the approximation (Eq. (3)) for the re-scaling factors $RF(\eta)$ for photons as a function of the scaled radius of the equal mass sphere r_0. Solid line is again the least square fit by function (Eq. (6)).

(92)   Finally, the absorbed fractions for both photons and electrons have been estimated as

$$\phi(E) = RF(\eta) \times \phi_0(E) , \qquad (7)$$

where $\phi_0(E)$ is a value of the ``spherical'' absorbed fraction. The re-scaling factor, $RF(\eta)$, assessed according to Eq. (3) and a value of the parameter *s* is evaluated for the given mass and energy using the approximation represented by Eq. (6).

(93)   The nuclide-specific decay data on energies and yields of radiations emitted by the radionuclides were taken from electronic version (Eckerman et al, 1994) of the ICRP Publication 38 (ICRP, 1983). Continuous energy β–spectra are integrated numerically. The DCFs include contributions from both parent and daughter nuclides (if any). Only radioactive daughters with half-lives less than 10 days were included; in these cases the parent and daughter were thus assumed to be in secular equilibrium.

4.5 Calculation of Specific Dose Conversion Factors for Reference Animals and Plants

(94)   The assumed shapes and dimensions of the Reference Animals and Plants are given in **Table 5**. All are assumed to be single organisms with the exception of the crab eggs, which are treated as 'mass' of eggs; the frog eggs are treated both as individuals and as a mass. The other exception is the grass meristem, which is modelled as a homogeneous layer parallel to the surface of the ground.

Table 5. Dimensions, habitats, and relevant time periods for dose rate integration for Reference Animals and Plants

Organism	Major axis (cm)	1st minor axis (cm)	2nd minor axis (cm)	Body mass (kg)	Habitat	Time - span or life-span
Adult Deer	130	60	60	245.0	terrestrial	15 y
Rat	20	6	5	0.314	terrestrial	2y
Duck egg	6	4	4	0.0503	terrestrial	30d
Duck	30	10	8	1.26	aquatic/ terrestrial	11y
Frog egg	1	1	1	5.24×10^{-4}	aquatic	10 d
Frog mass of spawn	20	6	5	0.314	aquatic	10d
Tadpole	1.5	0.75	0.75	4.42×10^{-4}	aquatic	100d
Frog	8	3	2.5	0.0314	aquatic/ terrestrial	10 y
Trout egg/Crab larvae	0.4	0.4	0.4	3.35×10^{-5}	aquatic	100 d
Trout	50	8	6	1.26	aquatic	6 y
Flatfish egg	0.2	0.2	0.2	4.19×10^{-6}	aquatic	15 d
Flatfish	40	25	2.5	1.31	aquatic	10 y
Bee	2	0.75	0.75	5.89×10^{-4}	terrestrial	100 d
Bee colony (natural)	60	30	30	28.3	terrestrial	3 y
Crab egg mass	6.0	4.0	1.0	0.0126	aquatic	0.5 y
Crab	20	12	6	0.754	aquatic	15 y
Earthworm egg	0.5	0.5	0.5	6.54×10^{-5}	terrestrial	50 d
Earthworm (elongated)	10	1	1	5.24×10^{-3}	terrestrial	5 y
Pine tree trunk	1000	30	30	471	terrestrial	200 y
Grass (Meristem)	*Modelled only as a homogeneous layer*				terrestrial	1 y
Grass spike	5	1	1	2.62×10^{-3}	terrestrial	50 d
Brown Seaweed	50	50	0.5		aquatic	5 y

(95) The Dose Conversion Factors (DCFs) for aquatic organisms have been assessed using a uniform isotropic model, thus assuming that the organism is present in an infinite homogeneous medium and having activity uniformly distributed throughout its body. The densities of the medium and the organism's body are assumed equal. Within this approximation, DCFs for both external and internal exposure, defined as an absorbed dose rate per specific source activity (**$\mu Gy\ d^{-1}$** per **$Bq\ kg^{-1}$**), can be expressed in terms of absorbed fractions, $\phi(E)$, as follows:

$$D_{\mathrm{int}} = \sum_v \left(\sum_i E_i\, Y_i\, \phi_v(E_i) + \int N_v(E)\, E\, \phi_v(E)\, dE \right),$$

(8)

$$D_{ext} = \sum_v \left(\sum_i E_i\, Y_i\, \left(1 - \phi_v(E_i)\right) + \int N_v(E)\, E\, \left(1 - \phi_v(E)\right)\, dE \right),$$

(9)

where v denotes a radiation type (α-, β-, γ-radiations and spontaneous fission fragments); E_i (MeV) and Y_i (decay^{-1}) are energy and yield respectively of the discrete energy radiations per decay of the radionuclide; $N_v(E)$ (decay^{-1} MeV^{-1}) is the energy spectrum for continuous energy radiations of type v (here, for β-particles only); and $\phi_v(E)$ is the absorbed fraction. Equation (2), for external exposure, is an approximation and holds only in the case of the organism's body and surrounding medium being of the same density and elemental composition.

(96) In the case of an infinite homogeneous medium, uniformly filled with isotropic radiation sources, the DCF per unit source strength cannot exceed the full absorption limit, which is the absorbed dose in uniform infinite media. Thus, for any given nuclide, the upper bound for the DCF is represented by the value of full absorption limit:

$$D_\infty \approx 1.384 \times 10^{-2}\, \overline{E} \quad (\mu Gy\, d^{-1}\, Bq^{-1}\, kg),$$

(10)

where $\overline{E}$ is the source energy (MeV) averaged over the source emission spectrum (discrete and/or continuous):

$$\overline{E} = \sum_v \left(\sum_i E_i\, Y_i + \int N_v(E)\, E\, dE \right).$$

(11)

(97) DCFs for internal exposure of the terrestrial animals and plants have been assessed using Equation (1) and a technique suggested in Ulanovsky and Pröhl (2006). External exposure of the terrestrial animals has been evaluated based on results derived by Pröhl et al., (2003) and presented in Taranenko et al. (2004). The external DCFs from FASSET were derived for adult terrestrial animals of different shapes covering range of body masses ranging from 1.7×10^{-4} g to 550 kg. Only photon sources were assumed to contribute to external exposure of the animals. The external DCFs have been calculated here as a product of free-in-air kerma, K_a, in a place occupied by the animals' body and pre-computed dose-to-kerma ratios, $R(E_i, M)$:

$$D_{ext} = \sum_i K_a(E_i) \times R(E_i, M) \times Y_i,$$

(12)

where Y_i is a yield of specific photon (decay^{-1}), M is a mass of the animal (kg).

(98) Kerma values have been computed for two sources: an infinite planar source in soil at depth 0.5 g cm^{-2}; and for an infinite uniform volume source of 10 cm thickness. External exposures of plants have been estimated for infinite homogeneous

layers of varying density. The DCFs for both planar and volume sources have been used as given in Taranenko et al. (2004).

(99) It should be noted that the underlying, basic, calculations for the absorbed fractions are made for organisms immersed in water. These values are also applied for organisms living in other media, such as soil or air, or at the interface soil/air, although they are slightly different due to the different backscattering of photons, which is more pronounced the higher the density of the surrounding medium. The effect is highest if the mass of the organism is small and the photon energy is high. However, the overall effect of the surrounding material on the absorbed fraction is small. Using Monte Carlo simulations made for a spherical organism with a mass of 1 mg in water and in air for a photon energy of 1.5 MeV, it would appear that the difference in the absorbed fraction is about 6%; for a photon energy of 0.15 MeV, the difference is less than 1%.

(100) The computation of the DCFs has been performed using a special-purpose program (Ulanovsky and Pröhl, 2006b), compatible with that incorporated into the ERICA Assessment Tool (Børretzen et al. 2005). The dose conversion coefficients are given in tables for every reference animal or plant and computed for the list of 75 radionuclides. The radioactive progeny with a half-life less than or equal to 10 days are included as being in secular equilibrium with the parent. However, if the daughter decay rate is less than that of the parent (i.e. no secular equilibrium is achievable), then the daughters are excluded. The DCFs are summarised in **Appendix C**.

(101) For the derivation of DCFs for external exposure, a differentiation has been made between aquatic and terrestrial animals and plants. For aquatic organisms, which are immersed in water, there is no substantial difference between the density in water and the organism. The conditions for radiation transport are therefore relatively homogeneous. Under those circumstances, the application of analytical approaches allows estimates with sufficient accuracy. For this case, DCFs are derived in accordance with Equations (4.1) and (4.2). For terrestrial Reference Animals and Plants, however, the estimation of external exposures is more complex.

(102) To enable the use of specific weighting factors to account for the different radiation types for the absorbed dose, the fractions of the absorbed dose that are due to different types of radiation are also given in **Appendix C**. The fractions are presented only for internal exposure because weakly penetrating short-range radiations (α-particles, fission fragments, and low-energy electrons) are likely to be absorbed by the outer protective layers of the body (skin). The percent fractions of the internal DCFs that are due to α-particles and spontaneous fission fragments, f_1, as well as to low-energy electrons ($E < 10$ keV) and β-particles, f_2, are given in the Tables provided in **Appendix C**. The fractions for photons and high-energy electrons ($E_\beta \geq 10$ keV), f_3, are not given in the table because they can be easily derived as complementary to the above given: $f_3 = 100\% - f_2 - f_1$.

(103) The internal exposure DCFs are given as absorbed dose rate per unit concentration for all organisms except grass meristem (which is considered as a infinite homogeneous layer). Fractions of the total dose are given which are due to types of radiations with assumed different irradiation weighting factors, i.e. (1) alpha-particles and strongly ionizing fission fragments, (2) electrons with energy less than

10 keV, and (3) electrons with energy higher or equal 10 keV and photons of all energies.

(104) The DCFs for external exposure are given depending on the assumed habitat of the animal or plant. Aquatic organisms are treated as submerged in infinite water medium. For those living on interface (air-water or water-sediment) dose coefficients can be easily derived from geometrical considerations by halving the listed DCF. Terrestrial organisms have two possible irradiation geometries: on the top of and in contaminated soil. Exposure on the top of the soil is treated with either of two radioactive sources: (a) infinite isotropic plane sources buried at depth 0.5 g cm^{-2} and (b) infinite isotropic 10 cm depth volume source. The former is a good representation for a fresh radioactive deposit (Jacob et al., 1990), while the latter one serves as a good approximation of aged or natural contamination. Exposure in soil is considered as occurring in the middle of an infinite isotropic 50 cm depth uniform soil layer.

(105) Finally it should be noted that the DCF values relate to dose rate. In order to estimate the dose, the dose rate has to be integrated over specific periods of time. In some cases the period of time is limited to the life span, or the time period of that stage of the life cycle. Thus, for example, the dose to a duck egg can only be integrated over a period of 30 days, for it then is no longer an egg – irrespective of the levels, or decay characteristics of the radionuclides. Similarly, the frog egg and tadpole will only be totally immersed in water for a few months. At the other end of the scale, however, it is assumed that a pine tree will live for a very long time, and care needs to be taken with regard to integration of doses over such time periods. The relevant values for the biological periods of integration for the Reference animals and Plants are also given in **Table 5**.

(106) The following is a brief introduction to each Reference Animal and Plant dosimetry, the DCF values for each on are given in **Appendix C**. [A summary of the exposure situations is given at the end of this chapter as **Table 7.**]

4.5.1 The *Reference Deer*

(107) The reference adult deer has a mass of 245 kg and is represented by an ellipsoid with dimensions of 130×60×60 cm. The deer is a terrestrial animal, thus external exposure on soil is considered relative to plane and volume radioactive sources. Being such a large animal, some preliminary considerations were also given to the relative dosimetry of internal organs, such as the liver and gonad, but essentially for illustrative purposes rather than as definitive models. The additional level of detail was also considered warranted in view of the range of information relating to radiation effects on large mammals.

(108) Two cases can therefore be considered. In the first, a radionuclide with activity, A (Bq) is homogeneously distributed throughout the entire body of the organism of mass, m_{wb}; and in the second, the same activity is concentrated with an organ of mass, m_{org}. Under these conditions, and when the absorbed fractions for emitted energies are equal to unity, it can be shown that:

$$\frac{D_{org}}{D_{wb}} \approx \frac{m_{wb}}{m_{org}} \qquad\qquad (13)$$

where D stands for the absorbed dose and m for the mass of the whole body and the organs considered. This relationship is valid for organisms and organs, which are large enough to justify the assumption of an absorbed fraction for both, α- and β-radiation.

(109) The situation is more complicated for γ-radiation. Due to the longer range, dependent on the specific geometry, a considerable part of the photon energy may be deposited remote from the γ-source. To estimate the impact of non-homogeneous radionuclides distribution of γ-emitters on the absorbed dose, Monte Carlo simulations were performed as follows. The following assumptions were made.

- As defined above, for dosimetric considerations, a deer is approximated by an ellipsoid with the axes 130 cm, 60 cm and 60 cm, which correspond to a body mass of 244 kg.

- The mass of the liver is 2% (4.9 kg) of the whole body, simulated by an ellipsoid with the axes 14.4×9×9 cm.

- The mass of the testes is $5.3 \cdot 10^{-2}$ % (129 g) of the whole body, simulated by an ellipsoid with the axes 4.3×2.7×2.7 cm; these are the same proportion as for reference man.
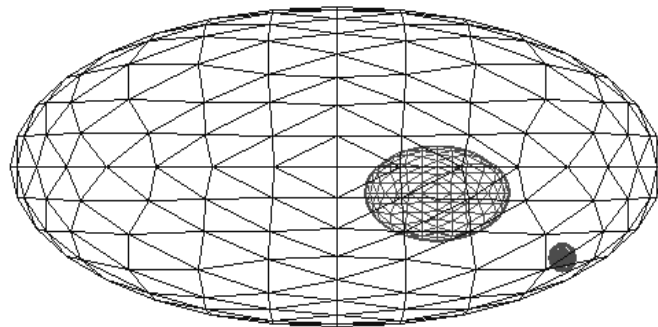
Fig. 4 Geometrical model of deer body with liver (large inner ellipsoid) and testes (small inner ellipsoid).

(110) The relative dose distribution of the absorbed dose rate for different source target relationships is summarized for four photon energies in **Table 6**. If the radiation source in the deer body is the liver, the absorbed dose rate in whole body and testes will be approximately 4% and 2% in relation to the value of the absorbed dose rate in a liver. If the whole body is homogenously contaminated, the absorbed dose rate in the liver will be 14% higher than the average whole body dose because the liver is

surrounded by the source. The absorbed dose of the testes will be 14% lower than the whole body dose because this organ is located in the periphery of the body.

Table 6. Relative dose rate for inhomogeneous radionuclide distribution in deer; the values are normalized to the combination "whole body" (source) – "whole body" (target) or "liver" (source) – "liver" (target) for each of the photon energies

Photon energy (keV)	Radiation source	Relative dose rate in the target:		
		Whole body	Liver	Testes
60	Liver	0.04	1.00	0.02
	Whole body	1.00	1.14	0.86
122	Liver	0.04	1.00	0.02
	Whole body	1.00	1.14	0.84
662	Liver	0.04	1.00	0.02
	Whole body	1.00	1.13	0.85
1250	Liver	0.04	1.00	0.02
	Whole body	1.00	1.13	0.85

(111) The results infer that radionuclides accumulated in a specific organ for animals of this size provide only minor contributions to the absorbed dose in other organs or for the whole body. These findings are more or less independent of the photon energy.

4.5.2 The *Reference Rat*

(112) The reference rat has a mass of 0.314 kg and is represented by an ellipsoid with dimensions of 20×6×5 cm. The rat is a terrestrial burrowing animal, thus external exposure is considered on the top of the soil to plane and volume radioactive sources as well as in soil in the middle of a 50 cm depth contaminated layer.

4.5.3 The *Reference Duck*

(113) The reference duck has a mass of 1.26 kg and is represented by an ellipsoid with dimensions of 30×10×8 cm. The duck is considered both as a terrestrial and aquatic specimen, thus external exposure on soil is considered to plane and volume radioactive sources as well as external exposure in water. The latter situation (in water) accounts for the 4π-geometry, but for floating on the water surface (2π-geometry) dose coefficients must be halved.

(114) Models were also made for the Reference Duck egg, which has a mass of $5.03×10^{-2}$ kg and is represented by an ellipsoid with dimensions of 6×4×4 cm. External exposure on soil is considered in relation to plane and volume radioactive sources.

4.5.4 The *Reference Frog*

(115) The Reference Frog egg has mass of $5.24×10^{-4}$ kg and is represented by a sphere with a diameter of 1 cm. The frog egg is an aquatic organism, thus external

exposure in water is taken into account. The Reference Frog mass of spawn has a mass of 0.314 kg and is represented by an ellipsoid with dimensions of 20×6×5 cm. The Reference Frog tadpole has mass of $4.42×10^{-4}$ kg and is represented by ellipsoid with dimensions of 1.5×0.75×0.75 cm. The tadpole is aquatic.

(116) The adult Reference Frog has mass of $3.14×10^{-2}$ kg and is represented by an ellipsoid with dimensions of 8×3×2.5 cm. The frog is considered to be both terrestrial and aquatic, thus the external exposure on soil is considered to plane and volume radioactive sources as well as external exposure in water.

4.5.5 The *Reference Trout*

(117) The Reference Trout has a mass of 1.26 kg and is represented by an ellipsoid with dimensions of 50×8×6 cm. The Reference Trout egg has a mass of $3.35×10^{-5}$ kg and is represented by a sphere with a diameter of 0.4 cm.

4.5.6 The *Reference Flatfish*

(118) The Reference Flatfish egg has a mass of $4.19×10^{-6}$ kg and is represented by a sphere with diameter of 0.2 cm. The adult Reference Flatfish has a mass of 1.31 kg and is represented by an ellipsoid with dimensions of 40×25×2.5 cm.

4.5.7 The *Reference Bee*

(119) The Reference Bee has a mass of $5.89×10^{-4}$ kg and is represented by an ellipsoid with dimensions of 2×0.75×0.75 cm. External exposure on soil is considered to plane and volume radioactive sources. The Reference Bee colony, in a natural setting, has been modelled by assuming a mass of 28.3 kg and is represented by an ellipsoid with dimensions of 60×30×30 cm.

4.5.8 The *Reference Crab*

(120) The Reference Crab egg mass has a mass of $1.26×10^{-2}$ kg and is represented by an ellipsoid with dimensions of 6×4×1 cm. The Reference Crab larva is considered to be approximately the same size as the Reference Trout egg, and is thus represented by a sphere with a diameter of 0.4 cm. The adult Reference Crab has a mass of 0.754 kg and is represented by an ellipsoid with dimensions of 20×12×6 cm.

4.5.9 The *Reference Earthworm*

(121) The Reference Earthworm egg has a mass of $6.54×10^{-5}$ kg and is represented by a sphere with diameter of 0.5 cm. The adult Reference Earthworm has a mass of $5.24×10^{-3}$ kg and is represented by an ellipsoid with dimensions of 10×1×1 cm. (Earthworm eggs are located in soil, but the mass of the earthworm eggs is below the limit that can be currently considered to calculate DCFs for external exposure for RAPs in the terrestrial environment. Therefore, for the purpose of the calculation, it is assumed that earthworm eggs is surrounded by water rather than by soil, which causes slightly lower DCFs for external exposure.)

4.5.10 The *Reference Pine Tree*

(122) The Reference Pine Tree has a mass of 471 kg and is represented by an ellipsoid with dimensions of 1000×30×30 cm. This shape has been used to compute only internal DCFs. The dose conversion factors for external exposure have been assessed for a 9 m height homogeneous layer of density 2.6 kg m^{-3} located between 1 and 10 m heights.

4.5.11 The *Reference Wild Grass*

(123) The Reference Wild Grass spike has a mass of $2.62×10^{-3}$ kg and is represented by an ellipsoid with dimensions of 5×1×1 cm. The grass meristem is modelled as an infinite homogeneous layer of density 13.7 kg m^{-3}. The layer has a thickness of 10 cm and overlaying the air-ground interface. DCFs are only given only external exposure scenarios.

4.5.12 The *Reference Brown Seaweed*

(124) The reference brown seaweed is represented by an ellipsoid with dimensions of 50×50×0.5 cm. Exposure dose rates can be considered for various periods of immersion.

Table 7. Summary of exposure situation assumptions

RAP	Aquatic	Planar source	Volume source (10cm)	In soil
Deer adult		X	X	
Rat adult		X	X	X
Duck egg		X	X	
Duck	X	X	X	
Frog egg	X			
Frog egg mass	X			
Frog tadpole	X			
Frog adult	X	X	X	
Trout egg	X			
Trout	X			
Flatfish egg	X			
Flatfish	X			
Crab egg mass	X			
Crab larvae	X			
Crab	X			
Bee		X	X	
Bee colony		X	X	
Earthworm egg				X
Earthworm				X
Pine tree trunk		X	X	
Pine tree layer		X	X	
Grass meristem		X	X	
Grass spike		X	X	
Brown seaweed	X			

5 THE EFFECTS OF RADIATION AND ITS RELEVANCE TO REFERENCE ANIMALS AND PLANTS

5.1 Introduction

(125) There is a large data base on the effects of radiation on plants and animals and all of it, or limited sections of it, have been regularly reviewed from one standpoint or another, particularly over the last decade or so (IAEA, 1992; UNSCEAR, 1996; Whicker and Hinton, 1996; Pentreath, 1996; Woodhead, 1998; Copplestone et al, 2001; Real, et al, 2004). The data reviewed have been variously derived, and for different purposes. Some studies have examined the relative effects of high dose rates on different types of animals and plants, presumably in the context of evaluating the impact of nuclear weapons. Many studies have been carried out on mammals in order to provide information of relevance to human radiological protection. And some studies have been carried out to study the effects of radiation on specific biological end points in certain types of biota, such as mutation rates in insects.

(126) With an increasing awareness of the need to develop a more systematic approach to this subject, several recent reviews have examined the available data base of radiation effects with respect to different biological end points across various animal and plant groups. A number of different approaches can and have been used to organize the data. Particularly valuable has been the FREDERICA Radiation Effects Database, developed as part of the ERICA project (Larsson, 2004; Real et al, 2004; Copplestone et al., in press).

(127) Experiments have therefore been carried out at high dose rates over short periods of time, and at lower dose rates over extended periods of time. Some experiments have been carried out by irradiating animals and plants under external 'field' conditions; others have been carried out under carefully controlled laboratory conditions. Some have involved small groups of individuals; others have simultaneously exposed breeding 'populations'. Some studies have used carefully calibrated external sources of radiation; others have involved the use of external or internal exposure to radionuclides, where the actual doses received are not always well described. Some have attempted to relate selected biological effects to ambient radionuclide concentrations, or ambient dose rates, in environmental locations that have been contaminated in various ways, although such 'epidemiological' type studies are few. Thus not only has the range of individual species studied varied enormously, but so has the mode of exposure, the dose rates, and the selection of 'biological effects' recorded. It is therefore not surprising that the majority of reviews conclude with broad estimates of dose-effect relationships, and that such ranges demonstrate considerable uncertainty and overlap.

(128) As a result of the very large number of studies that have been carried out in support of human radiological protection, an increasingly clearer picture is emerging of the details by which ionising radiation affects living cells, tissues, and organs – at least in mammals. Such information is thus of interest to the reference mammalian types selected in Chapter 2, and serves as an introduction to the basic understanding

of the effects of radiation on them at a sub-cellular, cellular, and tissue and organ level. The rest of this Chapter then briefly reviews the current state of knowledge with respect to the effects of ionising radiation on other animals, and on plants, either relating directly to the particular types selected or, where such information is lacking, to the nearest similar types. In some cases, there is simply no reliable information at all. It needs to be borne in mind, however, that the purpose of this review is to identify broad categories of dose-related effects that could subsequently be of value in providing management advice under different exposure situations, as discussed in Chapter 6.

5.2 Current understanding of radiation effects in general, and within the context of the human animal.

5.2.1   Effects at a sub-cellular level

(129) As discussed in ICRP 103 (2008), it is now reasonably clear (as a result of the further development of Monte-Carlo track structure codes) that a high proportion of radiation induced damage in DNA is represented by the occurrence of complex clusters of chemical alterations. Such clustered damage can arise as a result of one or more of the main ionisation tracks, secondary electrons, or secondary reactive radical species. Double and single strand breaks in the DNA sugar-phosphate backbone, plus a variety of damaged DNA bases, can combine together in clusters, so that a substantial fraction of the total damage is closely spaced. It is also relatively clear that both the frequency and complexity of such clustered damage depends upon the linear energy transfer (LET) of the radiation. Collectively, the complex clustered damage may constitute as much as 60% and 90% of total DNA damage after low and high LET radiations respectively. In this respect, DNA lesions induced by radiation are substantially different from those arising spontaneously via oxidative attack by reactive chemical radicals, the latter being randomly distributed and comparatively simple in their chemical structure.

(130) Differences in the repair effectiveness of simple and complex DNA lesions are an important factor in the development of effects after low doses of radiation. There is now more direct evidence that implicates chromosomal DNA as the principal cellular target for biological effects. Much of the early evidence on this issue concerned the greater radiobiological effectiveness (RBE) of radionuclides incorporated into DNA in the cell nucleus as compared with cellular proteins in general (UNSCEAR, 1993). But more recently, the use of microbeam irradiation facilities, capable of delivering a defined dose to different parts of the cell, has fully confirmed the particular radiosensitivity of the cell nucleus.

(131) The critical importance of DNA damage for radiobiological effects, including cancer induction, has also been emphasised by a large number of studies with cells and animals that are genetically deficient in DNA damage response. Many of these specific genetic deficiencies increase the frequency of radiobiological effects (UNSCEAR 1993, 2000; ICRP-79, 1998; NAS/NRC 2005) and it appears that error-prone repair of chemically complex DNA double strand lesions best explains the well-known cellular radiobiological responses such as the induction of chromosome aberrations, gene mutation, and cell killing.

(132) The activity of DNA damage response and repair processes are major determinants of dose, dose rate, and radiation quality effects in cells. And although the potential for error-free, re-combinational repair of radiation induced DNA double strand lesions is recognised, because it is thought to be restricted to the later phases of the cell cycle, its impact on radiation risk overall is not considered to be great. Thus in terms of protective effects, the apoptotic elimination of radiation damaged cells may be viewed as an alternative to repair; in other words, apoptotic death reduces the frequency of viable cells carrying mutations. There is also now compelling evidence that perturbation of DNA damage response/repair and apoptotic/cell cycle control are often closely associated with tumorigenic development. This concept gives increased confidence that these cellular activities are integral to the cellular defences mounted against post-irradiation tumour development in mammals.

(133) Many studies with mammals have shown that, in general, mutational dose-responses are linear-quadratic for low LET, and tend towards linearity as LET increases. For low LET radiations, reduction in dose-rate usually reduces the frequency of induced gene or chromosomal mutations in mammalian somatic and germ cells. The maximum dose-rate reduction factor is usually 3 to 4, but it can be somewhat higher for chromosome aberration induction in human lymphocytes. A reasonably consistent relationship between RBE and LET for mutation induction has also been recorded in mammals, with maximum values for RBE of around 10 to 20 usually being seen in the LET range 70 to 200 keV μm^{-1}.

(134) An interesting discovery as a result of recent studies involving 'chromosome painting' techniques is that complex chromosome exchanges, involving the interaction of more than two breakpoints, are infrequent at low doses of low LET radiation but can be a significant fraction of high LET induced events, at all doses. Advances in the understanding of radiation action on cellular DNA has included modelling of the formation of chromosomal exchanges, but it is still not clear as to whether or not these exchanges demand the interaction of two damaged sites, or whether a significant fraction derives from the interaction of damaged and undamaged sites (UNSCEAR 2000). Since 1990 considerable effort has been made to investigate the induction of gene and chromosomal mutations at low doses. There are many technical factors that limit the resolution of such low dose effects.

(135) One interesting feature worth noting is that whereas conventional DNA damage response is known to result in the expression of genomic damage within the first or second post-irradiation cell cycles, the term 'induced genomic instability' broadly describes a set of phenomena whereby genomic damage and its cellular consequences are expressed after many post-irradiation cell cycles (Little 2003; Morgan 2003). This instability, as expressed in cultured cells, can take the form of increased frequencies of chromosome aberrations, gene mutations and apoptosis or cell death; other manifestations have also been recorded (ICRP-99, 2005).

5.2.2 Tissue and organ effects

(136) The deposition of energy by ionising radiation is a random process. Even at very low doses it is possible that sufficient energy may be deposited into a critical volume within a cell to result in cellular changes, or cell death. The killing of one or a small number of cells will, in most cases, have no consequences in tissues; but

modifications in single cells - such as genetic changes or transformations leading ultimately to malignancy - may have serious consequences. Effects resulting from damage in a single cell are termed 'stochastic' effects, and there is thus a finite probability of the occurrence of such stochastic events, even at very low doses. There will therefore be no threshold dose, unless all such events can be repaired - up to some level of dose. As the dose is increased, the frequency of such events increases; but in the absence of other modifying factors, the severity of the resultant effects is not expected to increase.

(137) With larger doses, there may be a substantial amount of cell killing, sufficient to result in detectable tissue reactions. These reactions may occur early or late after irradiation. In order to reach the level of detection, a given proportion of cells must be depleted. This constitutes a threshold, which depends on the specified level of injury.

(138) When the term 'stochastic' was first introduced regarding single-cell effects, those effects that were caused by injury in populations of cells were called non-stochastic effects (ICRP, 1984). This was later considered an unsuitable term, and it was replaced by the term 'deterministic', meaning "causally determined by preceding events" (ICRP, 1991). But it is now recognised that both early and late tissue reactions are not necessarily predetermined, and that they can be modified after irradiation. Thus it has since been considered preferable to refer to these effects as early or late tissue or organ reactions. These reactions are distinct from the stochastic effects in single cells, which are the induction of cancers from irradiated somatic cells, and from genetic diseases in offspring following parental germ cell irradiation.

(139) It is also evident from studies with mammals that the structure of tissues and organs plays a major role in their response to irradiation. In most tissues, responses are greater when irradiated volumes are larger. With early skin reactions, the volume effect is due largely to the decreasing ability to heal large areas, mainly because of limited cell migration from the margins. With late reactions the volume effect relates to organ architecture.

(140) Paired organs, or organs where the functional subunits are arranged in parallel rather than in series, can sustain inactivation of many functional subunits without clinical signs of injury, because of a substantial reserve capacity and compensation by the remainder. This is one of the major reasons for the presence of a threshold dose for overt injury, and in particular for a high tolerance to partial-body irradiation, where a critical part of such organs may be spared.

(141) Late tissue injury is progressive and strongly dose dependent, and it has been shown that the incidence of late morbidity after radiotherapy in humans continues to increase gradually to 10 years and beyond (Jung et al. 201). Tissues vary not only in their temporal responsiveness, but also in their overall radiosensitivity. Among the most radiosensitive tissues are the ovary and testes, bone marrow, and the lens of the eye. In general, the dose-incidence relationship for these tissues will be sigmoid in shape when plotted on linear axes, the effect becoming more frequent as the dose increases.

5.2.3 Radiation tumourigenesis

(142) Lympho-haemopoietic cancers, and solid tumours, are both believed to originate from single, stem-like, cells in their respective tissues. Certain gene and chromosomal mutations that are often tissue-specific can confer cellular properties that allow these target stem cells partially to escape from their normal constraints of growth and development. In some cases these cells acquire novel properties via mutations in 'oncogenes'; in others, they suffer a loss of function in 'tumour-suppressor' genes. The full potential for malignancy in these tumour-initiated cell clones then appears to be developed in a step-wise fashion via the appearance of other mutations, or via the non-mutational silencing of key genes. Then, over time, tumours develop increasing malignant potential by growth selection and the bypass of cell senescence. In some cases the rate of tumour development may be increased following the acquisition of subsequent mutations.

(143) Various animal models have been used to investigate the point of action of radiation in multistage tumour development (UNSCEAR, 1993; 2000; NCRP 2001; ICRP-99, 2005; NAS/NRC, 2005) from which it appears that radiation is only a weak 'promoter' of tumour development, and a role in the earliest (initiation) phase of tumorigenesis seems more likely. Molecular and cytogenetic studies using animal models also imply that radiation acts early in the tumorigenic process via a gene loss mechanism.

5.2.4 Mutations causing heritable diseases

(144) The application of molecular genetic techniques has provided detailed knowledge of the molecular basis of naturally-occurring mutations that cause heritable diseases in humans, and of radiation-induced gene (specific locus) mutations in mouse germ cells. There is now strong evidence that large multi-locus deletions of the genome constitute the predominant class of radiation-induced mutation. It seems that only a proportion of such multi-gene loss events will be compatible with embryonic or foetal developmental and live birth. These findings have led to the concept that the principal adverse genetic effect in humans is likely to take the form of multi-system developmental abnormalities rather than single gene diseases.

5.2.5 RBE and related issues

(145) In contrast to the situation with human radiation protection, there is at present no formal or universally accepted approach for making allowance of such factors as LET or RBE in the description of absorbed dose by any other animal, or any plant, and hence of use in evaluations of environmental radiation protection. Nevertheless, the need for such an approach has been widely recognized, for several different reasons. Firstly, it is known that the RBE phenomenon exists in animals other than man; indeed, much of the RBE information used in human radiation protection has been gained from animal studies and thus it seems reasonable that allowance should be made for it in the assessment of the relationship between dose and effects for those same animals. Secondly, it is known that many animals and plants have very high levels of naturally occurring alpha-emitting nuclides in their tissues, and thus the use of weighting factors would be useful in attempting to normalise comparative radiation

dose rates, including natural background. And thirdly, many environmental protection problems relate to concerns over the actual or potential presence of alpha-emitting nuclides and thus the concern that their potential effects on wildlife could be underestimated if such RBE factors were not taken into account. This is, however, a large subject and will be discussed in a separate ICRP report.

5.3 Relevant Radiation Effects for Reference Animals and Plants

5.3.1 Introduction

(146) For the protection of human beings, under different exposure situations, the objectives are relatively clear: to manage and control exposures to ionising radiation so that tissue reactions are prevented and the risks of cancer and hereditary effects are reduced to the extent that is reasonably achievable. And of course such criteria apply to individuals, or small groups of individuals, rather than to the population as a whole.

(147) But for animals and plants, the objectives, as noted in Section 2, are more variable. The grouping of effects into those that are stochastic, or not, are therefore of less value because it is the biological consequences that are likely to be of interest, and particularly at the population level rather than at the level of the individual. Nevertheless, the effects of radiation take place at the level of the individual, and thus it is useful to consider such effects in terms of how they might effect populations – such as early mortality, reduced reproductive success, some forms of morbidity, or other effects that are 'scorable' but the consequences are not known, such as chromosomal damage. These types of effects on individuals are discussed below in relation to the types of Reference Animals and Plants. No attempt is made here to interpret such effects at a 'population' level because this would also require a detailed description, evaluation, and interpretation of the dynamics of a 'model' population of each type in order for the data to be sensibly interpreted.

(148) With respect to all of the types of animals and plants selected in Chapter 2, in many cases it has been necessary to draw upon wider information in order to construct as complete a picture as possible, and the section headings therefore reflect this fact. It has also not always been possible to differentiate amongst different types of radiation, and no attempt has been made to differentiate between 'acute' and 'chronic' in any formal sense.

5.3.2 Mortality

Introduction

(149) In animals in general, mortality after irradiation is usually the result of severe cell depletion, or some other major dysfunction, of one or more vital organs of the body. After partial body irradiation, or inhomogeneous whole body irradiation, the probability of death of an individual will therefore depend upon the particular organs exposed, the volume irradiated, and the level of dose. After whole body irradiation, which is fairly homogeneous, death may occur from one of several distinct syndromes that are characteristic of particular dose ranges, and which are due to injury in specific organ systems. Mortality is best understood in mammals, and it is therefore useful

first to consider what is known about a large and long-lived mammal, the human being.

(150) For a specific syndrome potentially leading to death, the relationship between the percentage of survivors and the dose is sigmoid in shape on a linear plot. The survival-dose relationship is often described by its midpoint, the LD_{50} (the dose that is lethal for half of the individuals), and the slope of the curve. The $LD_{50/60}$ (i.e. within 60 days) for human beings is around 4 Gy midline dose, but may range from 3 to 5 Gy. Estimates of LD_{10} (lethal to 10%) are around 1 to 2 Gy, and for LD_{90} (lethal to 90%) around 5 to 7 Gy (UNSCEAR, 1988; NUREG, 1997). The cause of death is haemopoietic failure, resulting primarily from a lack of progenitor cells that produce functional short-lived granulocytes, as well as from haemorrhages without the replacement of radioresistant red cells. At doses in excess of about 5 Gy, additional effects occur, including severe gastrointestinal (stem cell and endothelial capillary cell) damage which, when combined with haemopoietic damage, causes death in 1 to 2 weeks. There are few human data to assess accurately the LD_{50} for this syndrome, but it may be approaching 10 Gy acute dose (UNSCEAR, 1988; NUREG, 1997). If some bone marrow and most of the gut have been spared, because of inhomogeneous irradiation, then at acute doses above 10 Gy to the lungs, acute inflammation (pneumonitis) may occur, leading to death. Renal damage also occurs in the same dose range, if the kidneys have been irradiated. At even higher doses, towards 50 Gy and above, there is acute damage to the nervous and cardiovascular systems, and the individual dies of shock after a few days (NCRP, 1974).

(151) If the dose is given over a period of hours or more, a greater whole body dose is required for these effects to occur. For example, if the dose-rate is about 0.2 Gy per hour, LD_{50} values for humans may be increased by around 50% (NUREG, 1997). If the dose is delivered over a month, the $LD_{50/60}$ may be doubled (UNSCEAR, 1988). At low (chronic) radiation dose rates, there is evidence of a chronic radiation syndrome in humans, particularly affecting the haemopoietic, immune, and neural systems (Guskova et al., 2001; AFRRI, 1994; 1998; Akleyev et al., 2002). The threshold doses for depression of the immune system in humans is about 0.3 to 0.5 Gy per year (Akleyev et al., 1999). Severe reactions do not occur in most body tissues of adults or children after annual doses below 0.1 Gy over many years. Red bone marrow, reproductive cells, and the lens of the eye show the greatest sensitivity.

Reference Deer (large mammals)

(152) Deer are also large mammals, but with a shorter life span than human beings. There is very little in the way of information on Cervidae specifically. The only relevant data are those relating to reindeer inhabiting the Novaya Zemlya archipelago during nuclear tests, for which it was estimated that a dose of 8.7 Gy from mixed radiation produced 50% mortality in young animals during the summer and autumn months (Klevezal and Sokolov, 1999). There are, however, LD_{50} values for a variety of adult large mammals (cattle, sheep, goat, pig, donkey, horse, dog) dying from haemopoietic syndrome. These span a range of between 1.2 and 3.9 Gy (Bond et al., 1965; Kruglikov et al., 1992, UNSCEAR, 1996), although some studies have reported rather higher $LD_{50/30}$ values, such as 5.8 to 7.84 Gy for donkeys exposed to gamma radiation (Rust et al., 1954; Trum et al., 1959a). Adult pigs irradiated with gamma

rays have also been reported to have an $LD_{50/30}$ of 6.18 Gy, while irradiation of 14 day-old pigs gave values of 2.86 Gy (Mandel et al., 1980).

(153) In terms of chronic irradiation, there are no controlled experimental data on deer, although some field observations have been made. Thus different species of deer living in a territory contaminated after the Kyshtym accident were estimated to have received chronic irradiation from Sr-90 (14 Bq/kg in soil). After estimated accumulated doses of 0.1 Gy there was a 5-fold decrease in the number per km^2 of roe deer (*Capreolus pygargus)* from 1970 to 1977, while the numbers of European elk (*Alces alces L.*) were 3 times higher in 1977 than in 1970. Estimated chronic exposure of European elk (*Alces alces L.*) and Roe deer (*Capreolus pygargus*) at 100 mGyd^{-1} (cumulative dose of 10 Gy), decreased the numbers of even-toed ungulates in the period 1957-1958, in comparison with the period before the Kyshtym accident (Kryshev, 1997).

(154) The most detailed experimental data relate to canines. X-irradiation of 10 to 12 month old female beagle dogs, with 1 or 3 Gy, produced life span shortening relative to controls of 9.5% and 20.7% respectively. Differences between subgroups receiving fractionated exposures were only apparent at 3 Gy (Andersen and Rosenblatt, 1969). At lower doses, the acute exposure of dogs to 0.16 to 0.89 Gy of gamma radiation had no significant effect on their life span, regardless of whether the dogs were irradiated on day 2, 8 or 28 post coitus, or 2 days after birth (Benjamin et al., 1998).

(155) Other studies have shown that dogs irradiated with gamma-rays at dose-rates of 38 mGy d^{-1} (total dose 4.5 Gy) showed no differences in life-span compared with the control group (Carnes and Fritz, 1991; 1993), but cumulative doses of 7.5 Gy at 1.7 mGy d^{-1} produced a 30% decrease in life span (Grigoriev, 1989). Dogs exposed from 1 year of age until death to 40.9 mGy d^{-1} gamma radiation (total dose 16.4 Gy), showed a 64% reduction in lifespan.

(156) With respect to internal deposition of radionuclides, male and female dogs exposed to a single inhalation of Pu-238, at doses of 1.64 Gy or higher (cumulative dose in lung to death; ILB = 1.05 kBq/kg body weight) reduced the lifespan to 80% the control value (Muggenburg et al., 1996; Park et al., 1997; Weller et al., 1995).

(157) Exposure of dogs to beta radiation (Sr-90), either from a single injection or from a body burden accumulated via ingestion from the foetal stage to 540 days of age (1.44 mGy d^{-1}), did not produce a significant reduction of lifespan compared with controls. Dose rates, from mid-gestation until 540 days of age, of 4.32 mGy d^{-1} (dose-rate to the skeleton) produced a 24 % reduction in survival. At higher dose rates the survival rate decreased even further (Raabe et al., 1981).

Reference Rat (small mammals)

(158) Adult rats and mice have LD_{50} values for gastrointestinal syndrome (5 to 10 days) of 11 Gy and 12 Gy, respectively (Vriesendorp and van Bekkum, 1984). The LD_{50} values for haemopoietc syndrome (usually measured over 30 days) in a variety of adult small mammals (rabbit, hamster, mouse) have been shown to be between 6 and 10 Gy (Bond et al, 1965). Fractionation of the dose increased the LD_{50} in mice,

resulting in $LD_{50/30}$ values of 6.21 (single dose) and 11.2 Gy (10 fractions in 12 days). For mouse embryos the LD_{50} is 1 Gy (Gasinska et al., 1985).

(159) Data regarding radiation-induced life shortening in adult rats is more limited than for mice, but it appears that the response in both rodents for low LET radiation doses below 6 Gy is not significantly different. In mice it has been established that for low LET radiation there is a 5% reduction in lifespan per Gy (equivalent to 20% of the population dying at 75% of the normal mean life expectancy) (UNSCEAR, 1996). Irradiation with X-rays to a cumulative dose of 2 Gy (0.5 Gy fractions) produced a 45% reduction in the lifespan of rats compared with controls (Oghiso and Yamada, 2003). Statistically significant decreases in the life spans of rats (no % reduction available) have been observed after gamma irradiation with 30 mGy d^{-1} (total dose 16.0 Gy) (Korytny et al., 1996) and dose rates of 5.76 mGy d^{-1} (total dose 2.1 Gy) have been described to produce a 45% reduction in life-span (French et al., 1974).

(160) Several factors affect the life-shortening produced by acute irradiation in mice: the strain of mouse used (4 Gy gamma radiation reduced life time to 61% and 88% the control values in RFM and BALB/c mice, respectively) and the fractionation of the dose administered (life shortening per 10 mGy of 0.4 ± 0.035 and 0.2 ± 0.01 for single dose and 24 weekly irradiation, respectively). No significant differences were seen between sexes (Thomson et al., 1981; Storer et al., 1979).

(161) In adult mice exposed to gamma radiation, the Lowest Observable Effect Dose (LOED) for significant reduction in life shortening (38% reduction) was 0.9 Gy (Thomson et al., 1985). The life shortening induced by 5.7 Gy of gamma radiation in adult mice was very similar regardless of the age at irradiation (17 days post coitus, at birth or 35 days of age) (Sasaki, 1991). Irradiation of male mice with 3.0 Gy gamma rays (mated with control females) had no effects on life span of the F1 offspring (Iwasaki et al., 1996).

(162) No effects have been observed in life span of adult mice after exposure to dose rates of 11 mGy d^{-1} gamma radiation, or lower (during up to 526 days; total dose 5.8 Gy) (Upton et al., 1967). Mice irradiated with 22.9 mGy d^{-1} gamma radiation (total dose 8.0 Gy) showed some decrease in lifespan (11to14% reduction, depending on gender) (Tanaka et al., 2003). A life span decrease of 20 to 30% was seen in mice gamma irradiated at dose-rates of 23 mGy d^{-1} (total dose 5.8 Gy) (Mole and Thomas, 1961; Upton et al., 1967; Thomson and Grahn, 1989). Exposure to 120 mGy d^{-1} (total dose 35.4 Gy) produced a 50% decrease in life-span (Spalding et al., 1964), while dose rates of 500 mGy d^{-1} (total dose 14.0 Gy) reduced life span more than 60% (Mole et al., 1961).

(163) After gamma irradiation with 91.2 mGy d^{-1}, life-shortening in mice shows a linear response with doses up to 0.45 Gy. Chronic exposure is less effective, by a factor of 7 (UNSCEAR, 1996). Combining the data for four different strains of mice, and for both sexes, the values of life shortening (days) per 10 mGy of gamma radiation obtained were: 0.031 ± 0.008 for dose rates of 31.7 to 288.0 mGy d^{-1}; 0.047 ± 0.04 for dose rates of 576 mGy d^{-1} and 0.064 ± 0.005 for dose rates of 763.2 mGy d^{-1}. It has been suggested that the dose rate effect crosses the chronic-acute boundary at about 720 mGy d^{-1} and that all exposures above 240 mGy d^{-1} should probably be

considered acute exposures (Spalding et al, 1964; 1978; Grahn et al., 1978; Lesher et al., 1965).

(164) At lower dose rates, no effect on the survival of adult mice has been observed after gamma irradiation with doses up to 0.64 Gy. However, irradiation of mice during the developmental stage at doses of 0.009 Gy increased postnatal mortality. The magnitude of the effect was dependent on the gestation day on which irradiation took place (pre-implantation, early or late organogenesis). The postnatal mortality rate increased compared with control values in all the irradiated groups, except in the group receiving 0.009 Gy during the pre-implantation phase. Irradiation on day 6.5 of gestation with 0.05 Gy increased postnatal mortality, which was the LOED (Hande et al., 1990; Covelli et al. 1988). In adult mice, gamma irradiation with 61.92 mGy d^{-1} (total dose 13.2 Gy) produced a 50% reduction in survival. Dose rates of 144 mGy d^{-1} (total dose of 35.4 Gy) reduced 70 to 80% the survival of mice (Grahn et al., 1978.)

(165) One useful conclusion drawn from such studies (NCRP, 2005) is the observation that, if data are normalised to expected (ie control) life span, the effects of continuous exposure is very similar across mammals of different sizes and longevities, as shown in **Figure 5** (from NCRP, 2005)
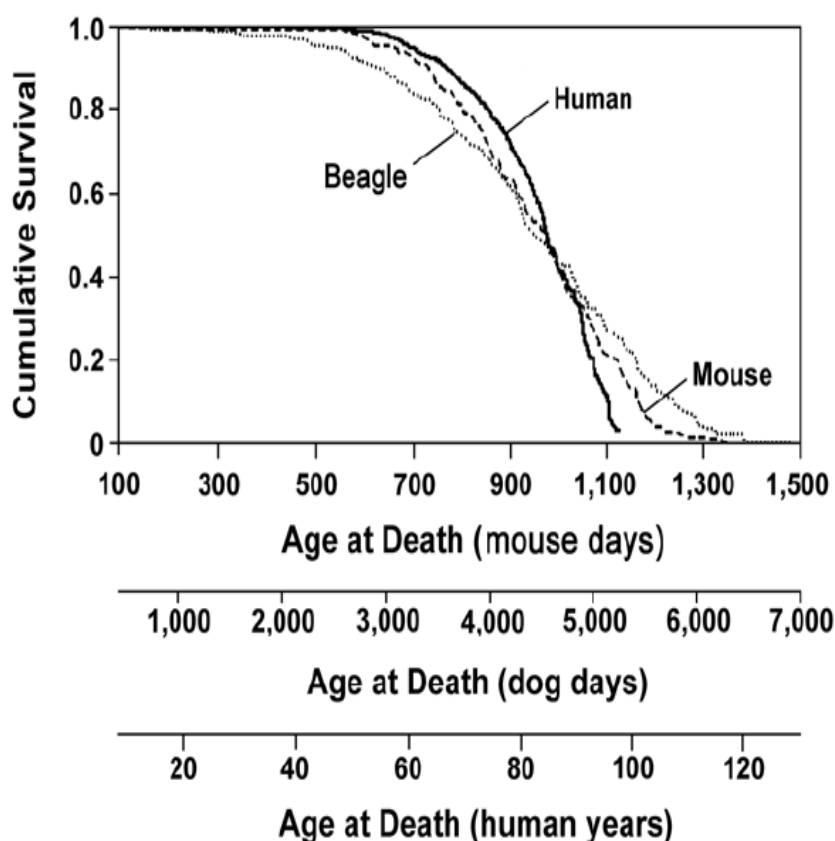
Fig 5 Cumulative survivorship curves of the mouse, beagle and humans for 'intrinsic' causes of death (Carnes *et al.,* 1996). Adapted from NCRP 150 (2005)

(166) With regard to internal exposures, adult rats exposed to nose-only inhalation of Pu-239, receiving cumulative doses at the time of death of 0.45 Gy, showed a 53% reduced lifespan compared with controls; a cumulative dose of 0.16 Gy had no effect on lifespan. Pu-239 administered via inhalation to adult rats, at a dose accumulated in the lung during 18 months of 5.5 Gy, produced 70% mortality; whereas accumulated doses in lung during 18 months of 40.0 Gy from inhaled Pm-147 has been reported as having no effect on rat survival (Scott et al., 1990). Ingestion of Sr-90 during life-time (200 mGy d^{-1}, total dose 90 Gy) reduced life-span of rats to 80% the control value, mainly due to radiation-non specific diseases. Total accumulated doses of 250Gy (700 mGy d^{-1}) reduced life-span to 63% the control value (Korytny et al., 1996).

Reference Duck (birds)

(167) In spite of their domestic and wildlife importance, there do not appear to be any data on the effects of radiation on ducks. There has been some experimental work done with chickens, however, from which it would appear that chicks 3 to 4 days old, have LD$_{50/30}$ values of 7 to 11 Gy when irradiation was given in less than 1 hour, and of 12 to 20 Gy when the irradiation time was of 24 hours (Stearner and Christian, 1972). Domestic poultry have also been reported to exhibit LD$_{50/60}$ values of 9 Gy (Bell et al., 1971). Other studies, with the black-headed gull and domestic chicken, have shown that eggs irradiated at day 10 of development and incubated artificially gave LD$_{50}$ values at hatching of between 12 to 13 Gy for gull and 9.0 Gy for chicken (Phillips and Coggle, 1988). Data for wild birds have apparently shown LD$_{50}$ values of between 5 to 12 Gy, and thus lie in the same general range as small mammals (Mellinger and Schultz, 1975).

Reference Frog (amphibians)

(168) The data on mortality for mammals and birds are usually reported with respect to relatively short time periods that relate to the metabolism and cell replacement rates in critical tissues. Being poikilothermic, reptiles, amphibians and fish, however, have quite different and variable metabolisms, and there is no *a priori* reason as to why mortality should be measured with respect to similar time scales. Nevertheless, such data have been experimentally derived.

(169) There are few data available for amphibians. For the frog (*Limnodynastes tasmaniensis*) the LD$_{50}$ after gamma irradiation ranged, depending on the life stage exposed, from 2.7 Gy (exposure of 3 to 18 day-old tadpoles; 54h irradiation) to 32.1 Gy (exposure of 25 to 27 days-old tadpoles; 219.5 h irradiation). The most sensitive stage to radiation exposure was the fertilised egg, with an LD$_{50/40}$ of 0.6 Gy, while the most 'resistant' stages of the life cycle were medium to large tadpoles at limb-bud and toe development stages (LD$_{50/60}$ ~ 25Gy). At metamorphosis, sensitivity increased significantly to an LD$_{50/160}$ of 18.3Gy, with a similar result for young adult frogs (LD$_{50/160}$ of 18.7 Gy) (Panter, 1986).

(170) Studies with toads have shown that adults, juveniles and tadpoles have LD$_{50/30}$ values of 24, 10 and 17 Gy, respectively. The LD$_{50/50}$ for adults was 18 Gy and for juveniles and tadpoles 0.1 Gy. The irradiated tadpoles failed to metamorphose (Landreth et al, 1974). In other studies, adult toads have shown LD$_{50/30}$ values of 22 Gy and LD$_{50/60}$ values of 20 Gy. Greater survival was observed after 15 Gy exposure

if toads were allowed to hibernate than if they were kept active. In contrast, a dose of 15 Gy to natural populations, as they emerge from hibernation in the spring, had little impact on breeding activity, feeding or preparation for hibernation the following autumn. However, there was a marked reduction in survival, independent of age and sex, in the population emerging from hibernation one year after irradiation (Tester et al., 1970).

(171) Although these LD_{50} values for amphibians are somewhat higher than those for mammals or birds, as noted, time may be an important relative factor. In one study, where four species of amphibians (dusky salamander; mudpuppy; 'congo eels' and rough skinned newts) were irradiated with 10 Gy, there was 100% short-term mortality (only one species showed an LD below 10 Gy) but extending the assay period to 200 days indicated that the LD_{50} value was in the range 0.8 to 7 Gy. (Sparrow et al., 1970). Similarly it has been shown that the LD_{50} values observed in frogs and salamanders for low LET radiation (2 to 22 Gy) are similar to those shown by mammals and birds, when the mean survival time is up to 190 days post-irradiation (Cosgrove, 1965; Conger and Clinton, 1973; Dana and Tinkle, 1965; Turner et al., 1967).

(172) More recent studies are those of Stark (2006) in which frog tadpoles (*Scaphiopus holbrooki, Bufo terrestris and Rana catesbeiana*) externally gamma irradiated with dose rates between 0.13 to 222 mGyd^{-1} (total doses from 0.0008 to 32 Gy) showed no reduced survival to metamorphosis when compared with controls.

Reference Trout (freshwater fish)

(173) There have been several studies on salmonid fish. Several studies using different salmon strains (Silver and Chinook salmon) have determined the LD_{50} for salmon embryos after acute X-ray irradiation in several embryonic stages. In silver salmon embryos the LD_{50} values at hatching varied between 0.3 and 18.7 Gy depending on the embryonic stage irradiated. Silver salmon embryos irradiated at the 1-cell stage have shown a rather variable radiosensitivity, with the very early part (0.17% of embryonic development) showing the lowest LD_{50} values (0.16 Gy) after 150 days post-fertilisation. At hatching the LD_{50} was 0.3 Gy (Bonham and Welander, 1961). In other studies with Chinook salmon exposed to X-rays, LD_{50} values for the survival of the larval fish to 107 days after fertilisation were 3.4, 2.9, 9.8 and 10.0 Gy when irradiation was performed at the 1-cell, 32-cell epiboly and eyed embryo stages, respectively (Wadley and Welander, 1971). Irradiation of Chinook salmon eyed embryos with 10 Gy X-rays, arrested the development of the hatched larvae and 50 % died in the 125 day post-hatch period. After doses of 2.5 or 5 Gy although the mortally was slightly higher in the irradiated group, the differences were not statistically significant (Welander et al., 1948).

(174) There are fewer data on trout, but it has been shown that irradiation of rainbow trout 'eye stage' embryos (*Salmo gairdnerii*) with up to 2.03 Gy X-rays had no effect on embryo survival (Welander et al., 1971). Irradiation with doses between 3.0 to 12.0 Gy (X-rays), did not significantly increase mortality of 3-month old rainbow trout fry (*Salmo irrideus*) in relation to control values (Kobayashi and Hirata, 1957).

(175) With regard to more chronic dose rates, beta (Sr-90) irradiation of salmon (*Salmo salar*) during artificial incubation of roe up to 66 days, with estimated total doses of only 0.16 mGy at 2.4 µGyd^{-1} produced an apparent 1.5-fold increase in mortality of salmon eggs and larvae in relation to controls. With lower dose rates of 0.83 µGyd^{-1} administered during 66 days (total dose of 0.055 mGy) the mortality of salmon eggs and larvae was 2.4 times higher than in the control (Fedorov et al., 1962).

(176) Other experiments have been more certain in their estimates of dose received. Results from the exposure of Chinook and Coho salmon developing embryos (*Oncorhynchus tshawytscha* and *O. kisutch*) to gamma-rays at a dose rate of about 4.8 mGy d^{-1} (accumulated total dose 0.33 to 0.4 Gy at hatching), demonstrated that there were no significant effects on the post-hatch survival up to about one year of age, when the parr were released to migrate to sea (Donaldson and Bonham, 1964). X-ray irradiation of silver salmon (*Oncorhynchus kisutch*) on day 5 post fertilisation at very high dose rates (1.4 Gy d^{-1}) with a total dose of 20 Gy, also had no significant effect on hatching success (Bonham and Welander, 1961; Egami and Hama, 1975).

(177) Factors such as temperature are also important. Irradiation of medaka fish (*O. latipes*) with 28 Gy (X-rays) produced 100% mortality when fish were maintained at 23 °C, whereas maintenance at 4°C provided apparent protection until the temperature was raised back to the normal 23°C (Egami, 1969; 1970). Similarly, X-rays doses of 80 Gy administered to goldfish (*C. auratus*) produced 100% mortality within 10 days when fish were maintained at 22°C, but had no effect on survival (up to 110 days) when fish were maintained at 4°C, although 75% subsequently died between 150 and 200 days post-irradiation compared with the control group (Hyodo, 1965a; 1965b).

(178) Although data on chronic irradiation are sparse, it is worth noting that beta irradiation of roach with 5.1 mGy d^{-1} produced a 2 to 2.8-fold increase in mortality compared with the control group (Fedorova, 1964). Exposure of guppy embryos (*Poecilia reticulata*) to gamma-rays at dose rates of 40.8; 96 and 304.8 mGy d^{-1} from fertilisation to birth (approximate accumulated doses of 1.1, 2.6 and 8.4 Gy, respectively) had no significant effects on their subsequent survival to maturity at approximately 3 months of age (Woodhead, 1977). And mosquito fish (*Gambusia affinis*) gamma irradiated with dose rates between 336 and 1,296 mGy d^{-1} for 40 days (total dose 12 to 50 Gy), at either 15 or 25 ºC, showed no increased mortality relative to the controls (Cosgrove and Blaylock, 1972).

Reference Flatfish (marine fish)

(179) X-ray exposure of plaice embryos (*Pleuronectes platessa*) 22 hours post-fertilisation (estimated time of maximum sensitivity), with doses between 0.3 and 1.5 Gy produced a clear sigmoid response curve for survival to larval metamorphosis (i.e. when the larvae transform to the "flat" morphology and adopt a benthic habit) with an estimated LD$_{50}$ of 0.9 Gy. Doses below 0.3 Gy had no significant effect on survival to metamorphosis. The LD$_{50}$ value obtained at hatching was higher than 1.5 Gy. Doses below 0.5 Gy had little effect on the mortality at hatching, but increased the incidence of abnormalities above control levels (Ward et al., 1970).

(180) Studies with juveniles have estimated LD values for a number of flatfish, but the time scales were short and thus not really comparable with higher vertebrate

values. Thus, for example, juvenile and post-larval individuals of 6 marine fish species (*Micropogon undulatus, Fundulus heteroclitus, Mugil cephalus, Paralichthys lethostigma, Lagodon rhomboides* and *Eucinostomus spp*) including one flatfish (*Paralichthys lethostigma*) have shown $LD_{50/30}$ values between 10.5 and 55.5 Gy. LD_{50} values for longer observation periods were lower, with $LD_{50/40}$ between 9.25 and 30.8 Gy in 6 species, and $LD_{50/50}$ between 10.8 and 22.5 Gy in 4 species. These results again show that the 30 day assessment period usually used for homeothermic mammals is not appropriate for the poikilothermic fish (White and Angelovic, 1966).

(181) It is also worth noting that gamma irradiation of two shark species (*Triakis scyllia* and *Heterodontus japonicus*) with 20 Gy produced mortality within 20 days due to intestinal and haematopoietic damage. The results suggest that radiosensitivity of sharks is similar to that of teleost fish (Egami et al., 1984).

Reference Bee (insects)

(182) There do not appear to be any precise data relating to the mortality of large insects, at any stage in their life cycle. Reviews have indicated that reported observations of LD_{50} values for adult insects vary from 20 to 3,000 Gy, sub-adult stages being more sensitive with LD_{50} values of 1 to 2 Gy for wasp, weevil, and fruit fly (Spirin, 1996; Woodhead, 1998).

Reference Crab (large marine crustaceans)

(183) Although data exist on doses relating to mortality for crabs, and other crustaceans, it is also evident that the time period post irradiation is important, as is the stage in the moulting cycle, and other factors such as temperature and salinity. Over short time periods, blue crabs (*Callinectes sapidus*) have shown $LD_{50/30}$ values of 510 Gy and $LD_{50/40}$ values of 420 Gy. But although gamma radiation dose rates of 768 and 1,752 mGyd^{-1} over a period of 70 days (53.76 to 122.64 Gy) had no effect on the cumulative mortality of young blue crabs (*Callinectes sapidus*), the proportion of total deaths at moulting was significantly higher than in the control group. Dose rates of 6,960 mGyd^{-1} resulted, after 50 days exposure (348 Gy), in 95% mortality with a smaller proportion of the total deaths associated with moulting (Engel, 1967). Other studies with fiddler crabs produced $LD_{50/40}$ values between 98 and 165 Gy. Gamma irradiation of fiddler crabs with doses of 80 Gy reduced the mean survival time to 80% the control value (Engel, 1973)].

(184) Data on other crustaceans give much lower values. Thus post-juvenile grass shrimp (*Palaemonetes pugio*) have been reported as having $LD_{50/30}$ values of 15 Gy (Ress, 1962).

Reference Earthworm (annelids)

(185) Studies with the earthworm *Lumbricus terrestris* give $LD_{50/30}$ values of 680 Gy for gamma radiation (Reiche et al., 1971; Heffner et al., 1971) and *Eisenia foetida* gave $LD_{50/30}$ values of 650 Gy for gamma radiation. The lowest dose producing observable mortality was estimated to be 390 Gy by Suzuki and Egami (1983). Other studies have produced lower values, such as those for adult annelids giving $LD_{50/30}$ values of 100 to 500 Gy (Harrison and Anderson, 1994).

(186) Some field data are also available. The population density of earthworms in an experimental plot in a birch forest irradiated with 26 Gy gamma rays decreased 5-fold some 4 months after exposure (Krivolutsky, 1987). And dose rates of 24 mGy d^{-1} have been described as reducing earthworm numbers (Krivolutsky 1987). In the Komi region (^{226}Ra, U), the number of *Lumbricidae* apparently sharply decreased after exposure to mainly alpha radiation at 24 μGy d^{-1} (0.3 specimens/m^2 compared with 2.05 in the control plot). Damage to the epithelium of earthworms was found. Amounts of mucous cells in epithelium and in middle intestine of earthworms were considerably higher compared with the control (Krivolutsky et al., 1983). In the Chernobyl 3 to 7 km zone, accumulated doses of 3.5 Gy produced a 4-fold decrease in the number of young earthworms. Total number of microfauna organisms completely recovered in 2 to 3 years after the accident (Krivolutsky et al., 1990).

Reference Pine tree (conifers)

(187) The effects of radiation on plants have been poorly studied in terms of what the actual physiological or biochemical effects leading to death actually are, and how they relate to their basic biology and life histories. It is also often less than clear as to what the actual dose to the plant was and how, in large plants such as trees, it varied with height and depth within the living tissues of the trunk, to the part of the tree above or below ground, or to specific organs such as leaf or flower buds, or to tissues within the soil, such as roots and root hairs. Time scales for trees are also rather different from those of most animals, given their long life span, and seasonal factors are also of relevance. All of the following data therefore need to be considered bearing these points in mind.

(188) Three year-old pine trees showed a LD$_{50}$ of 46 Gy at 124.8 mGy d^{-1}, with LD$_{50}$ for *Pinus rigida* of 74 Gy after 10 years of exposure (average dose rate of 30 mGyd^{-1}) (Sparrow et al., 1965). Eight years exposure to external gamma irradiation at an average dose rate of 31mGy d^{-1} (58 Gy) revealed that 50 % of the trees had been killed. A few trees, however, survived dose rates as high as 100 mGy d^{-1}. After an additional period of 2 years, 20% of the trees had been killed at a dose rate of 25 mGy d^{-1} (50 Gy) and after additional exposure to an average dose rate of 30 mGy d^{-1} 50% mortality occurred (Sparrow et al., 1965).

(189) Severe mortality of pine trees has also been observed after gamma irradiation with doses between 20 and 100 Gy (Woodwell, 1967). In a pine-birch forest (trees 24 to 26 years-old) gamma irradiation with doses of 26 Gy produced 100% mortality of the trees during 6 years following exposure (Tikhomirov and Fedotov, 1982).

(190) In a coniferous forest, exposure during 8 to 30 days to total doses of 10 to 20 Gy produced changes in species composition and diversity through selective mortality of more radiosensitive species. Doses above 20 Gy drastically changed the species composition by causing mortality of all, or nearly all, the higher plants (UNSCEAR, 1966).

(191) With regard to seasonal effects, autumn exposure of pine trees to gamma radiation over 16 to 18 days gave LD$_{50}$ values of 50 Gy after 2 years, and of 30 Gy

after 5 years. When pine trees were irradiated in spring, the LD_{50} was 30 Gy after 2 years. Although pine trees appear to be more resistant to acute irradiation in autumn, when the period over which radiation mortality is expressed is extended to 6 years after irradiation, the LD_{50} declines, approaching that shown by trees irradiated in spring. Dormant pine seeds showed LD_{50} values of 5 to 63 Gy for gamma radiation, while the vegetative phase of pines rendered LD_{50} values of 4.6 to 16 Gy (Karaban et al., 1980, Spirin et al, 1981; Sarapultsev and Geraskin, 1993).

(192) There do not appear to be any detailed studies on the effects of radiation on seeds in pines, but in ash trees *Fraxinus americana* (a deciduous tree), the sensitivity of seeds to acute gamma irradiation was found to be highly dependent on the seed's water content. Thus seeds with 3.4% of water content showed a dose-dependent reduction in germination at doses above 100 Gy; storage of the irradiated seeds for 3 years, or irradiation of 3-year-old seeds, further reduced germination rates but did not affect the pattern of dose dependence. Seeds with 40% water content showed increased germination rates at all doses up to 400 Gy, and substantial increase in survival at doses up to 200 Gy (Heaslip, 1971). More than 50% of one-year-old ash seedlings survived all doses up to 114 Gy when irradiated in the dormant state (late autumn). But exposure in the spring (at bud break) at doses higher than 56 Gy produced over 70% mortality. Over subsequent years, the seedlings irradiated in the dormant stage grew faster than those irradiated in the spring at all doses above 24 Gy − a dose that did not affect tree survival (Heaslip, 1971). In white spruce tree *Picea glauca* the pollen showed 50% reduction in seed yield and quality after acute doses between 60 and 90 Gy (Rudolph, 1971).

(193) Other data on pine trees record that, in a forest in the 4 km^2 zone of Chernobyl, complete death of pine trees and partial damage of deciduous trees was observed after external gamma radiation doses higher than 80 to 100 Gy (the dose rate on October 1st 1986 was >120 mGy d^{-1}, doses in needles >100 Gy) (UNSCEAR, 1996). And in 1990, in an area contaminated after the Chernobyl accident, 78% of the *Pinus sylvestris L.* died after receiving 3.4 mGy d^{-1}; only 2.9% of the pines were healthy. With dose rates of 1.5 mGy d^{-1}, 24.3% of pines died; 11.9% dried up; 30.8% were weakened and 30% of the pines were healthy (Pautov and Il'chukov, 1993). Other data indicate that, southeast of the area of the Urals accident, Sr-90 contamination of 6.3-7.4 MBq/m^2 were estimated as providing average doses in needles of 20 to 40 Gy and in bud meristem of 10 to 20 Gy, produced complete death of pines (LD100) (UNSCEAR, 1996).

Reference Wild Grass (grasses)

(194) The LD_{50} values for wheat, barley and oats have been calculated as being 20, 16 and 22 Gy, respectively (Sparrow and Sparrow, 1965). The major cereal crops show the highest radiosensitivity when the ears (seed heads) are developing. A reduction in yield of 50% (YD_{50}) of 4 to 16 Gy) has been recorded; rice being an exception with a (YD_{50}) of 75 Gy. At other stages of development the YD_{50} was of 20 to 60 Gy, with rice again being an exception at 160 Gy (Filipas et al., 1992). Pasture and forage crops, for which yield is related to vegetative mass rather than seed production, show YD_{50} values of 150-230 Gy. Legumes have shown an YD_{50} in the range 2 to 60 Gy for the vegetative stage and 1 to 4 Gy for flowering stages (Sparrow et al., 1971).

Reference Brown Seaweed (macro-algae)

(195) There are no mortality data for marine macroalgae.

5.3.3 Morbidity

Introduction

(196) Before discussing the effects of radiation on the ability of animals and plants to reproduce, it is useful briefly to consider some other aspects of radiation effects that can be simply grouped together under the heading of *morbidity*. In humans, such effects are termed late effects and they include tissue reactions and cancers, both of which may also lead to early mortality. In general, no tissues in humans express clinically relevant damage below 100 mGy of low or high LET radiation, either as an acute single dose or in protracted form. With regard to the induction of cancers, although there is considerable variation amongst different tissues and organs, it is assumed that cancer risk is proportional to dose at low and moderately low doses, (of the order of 100 mGy or less), and dose rates (less than 6 mGy per hour averaged over the first few hours). As a rough rule of thumb, the assumption is made that the risk of cancer induction is about 5% per Sv.

(197) Animals in the wild also develop cancer, although there has been no concerted effort to gather data on such occurrences, other than the now defunct Registry of Tumors in Lower Animals that has in the past collated information relating to reptiles, amphibians, fish, and some invertebrate animals in the USA. (Increased incidences of cancer in fish are quite common in some areas polluted by industry (eg Malins et al 1987) but not in relation to radiation.) There are, however, no equivalents to the epidemiological data available on humans. Cancer induction may therefore reasonably be considered as a form of morbidity, particularly for the mammals, and possibly for fish, but the extent to which this would affect early mortality, or reproductive success, is not clear. And for animals other than the mammals, there are no 'dose/risk' relationship data to draw upon. The following paragraphs therefore relate to a miscellany of forms of morbidity, as variously observed.

Reference Deer (large mammals)

(198) There are no morbidity data on deer, and most of the large mammal data (on dogs and from other 'laboratory animal' studies), have been directed at providing data for use in developing radiological protection criteria for humans. It is likely, however, that the same general conclusions with regard to the induction of 'tissue reactions' and possibly the risk of induction of cancers in relation to dose also apply, more or less, to other large mammals.

Reference Rat (small mammals)

(199) Again, most of the large amount of data available on rodents has been derived in order to aid the development of human radiological protection, but the following observations are of interest. No effect on rat body weight was seen after

gamma irradiation with doses from 0.01 to 0.1 Gy administered at 3, 6, 10, 13 or 17 days of age (Inouye and Kameyama, 1986; Canfi et al., 1990). Exposure on day 15 of gestation to 0.75 Gy gamma radiation reduced (by 10%) the body weight at 1, 21 days and 3 months of age, compared with the same-age controls, while doses of 1.5 Gy reduced the body weight to 77% of the control value of 6 day old offspring (Reyners et al., 1992; Norten et al., 1991). Gamma irradiation of rats with doses up to 0.8 Gy administered on day 9 or 17of gestation had no significant effect on postnatal growth rates, compared with control groups. Although exposure on day 17 caused prenatal growth retardation, this did not affect postnatal offspring growth rate (Jensh and Brent, 1988). A dose of 2.0 Gy at 9.5 days after conception was needed to significantly reduce the body weight of offspring 21.5 days post-exposure (Solomon et al., 1994). Mice gamma irradiated on day 20 of prenatal life showed a LOED for body weight reduction in males and females of 1.5 Gy (Zaman et al., 1997). Irradiation of mice on day 17 of gestation with doses from 0.3 to 1.5 Gy had no effect on brain weight/body weight ratio at 6 months after irradiation (Uma-Devi et al., 1999).

(200) In utero gamma irradiation of rats with 60 mGy d^{-1} (total dose 6.0 Gy) produced a 55% decrease in embryo weight and a 23% reduction of embryo length (Coppenger and Brown, 1967). And irradiation of rats during organogenesis (6 to 9 days after conception) with four daily doses of 0.01 Gy gamma rays produced significantly impaired learning capacity at 4 months of age, as deduced from behavioural tests in which performance requirements were gradually increased (Bornhausen et al., 1982).

(201) Gamma irradiation of adult mice with 384 μGy d^{-1} for up to 960 days (total dose 0.36 Gy), did not significantly affect body weight (Caratero et al., 1998). Adult rats gamma irradiated with up to 70 mGy d^{-1} for up to 90 days (total dose 6.3 Gy) showed a slightly slower growth rate than the control group (5% reduction), but the reduction in body weight was not statistically significant (Pinon-Lataillade et al., 1985).

(202) In pregnant mice exposed to tritium beta radiation on day 12.5 of gestation (organogenesis), at a concentration that gave cumulative doses during 7 days (until the end of gestation) to offspring of 0, 0.05, 0.10 or 0.30 Gy (dose rates of 7.13; 14.28 and 42.86 mGy d^{-1}, respectively), the LOEDR was 14.28 mGy d^{-1} (0.1 Gy) for the three endpoints of food labyrinth tests (mean time in finding food), learning and memory tests (hole board dipping test-number of holes dipped) and locomotor tests (open field test, latency to leave centre) studied at 21 days of age. However, the uncertainty was very high in the three parameters used. Analysis of the mistakes in the food labyrinth, water maze, avoidance acquisition and avoidance maintenance tests, indicated that the irradiated animals, especially those of the 14.28 and 42.86 mGy d^{-1} groups, had difficulties in both learning and memory retention for skill performance, though they showed hyperactivity in their young age period (Wang and Zhou, 1995).

Reference Duck (birds)

(203) There are very few data on birds, and no controlled experiments with ducks. But some experiments with other types of birds have been made. Thus in tree swallows, irradiation of the newly hatched nesting with 2.7 and 4.7 Gy produced

significant growth reduction, mainly in body mass. Irradiation also influenced the development time (Zach and Mayoh, 1984). Wild birds (tree swallow, eastern bluebird and house wren) showed progressively reduced growth after irradiation to hatchlings with 0.9 to 6 Gy. Exposure to doses of 4 and 6 Gy significantly reduced the body mass (10% and 13% reduction, respectively), and also reduced primary feather length and foot length. Doses of 0.9 Gy had little effect on initial growth and development (Zach and Mayoh, 1986). In domestic 2-day old fowl, doses higher than 6.7 Gy significantly reduced the growth rate over the subsequent 30 days (Brisbin, 1969).

(204) With regard to observations in contaminated areas, it has been reported that in ducks inhabiting the Chernobyl 5-km zone, exposure to 10 mGy d^{-1} (total dose 4.0 Gy) mixed radiation induced pathological changes in the liver, but had no effect in kidney, lungs or spleen. Two species of duck (*Anser anser L.*, *Anas boschas L.*) were included in this 1987 field study (Suvorova et al., 1993). In 1 day old mallards *(Anas platyrhynchos)* living in an area contaminated after the Chernobyl accident (Cs-137 and Sr-90 at 1 Bq kg^{-1} in soil) it has been reported that there was a 5-fold increase in basal metabolism and a small increase (1.2-fold) in respiratory coefficient. In 15 day-old birds the basal metabolism was 3 times higher than in controls, but no differences were seen in respiratory coefficients (Mikityuk and Ermakov, 1990).

(205) Other bird data relate to the Komi area of Russia, where in wood and black grouse exposed to alpha radiation (^{226}Ra, ^{210}Po, ^{238}U, ^{232}Th) estimated at 240 µGy d^{-1}, the average weights from irradiated populations were somewhat lower than the control group (80 and 85% the control value for males and females, respectively) (Maslov, 1972; Maslov and Maslova, 1972).

Reference Frog (amphibians)

(206) Gamma irradiation of frog tadpoles (*Scahiopus holbrooki, Bufo terrestris* and *Rana catesbeiana*) with dose rates between 0.13 and 222 mGy d^{-1} (total doses of 0.0008 to 32 Gy) had no effect on the body mass, body length, or body index (g/mm) at metamorphosis, nor on the age of metamorphosis (Stark, 2006).

Reference Trout and Flatfish (fish)

(207) There are some data on salmonids that are of interest. Thus it has been shown that exposure of developing embryos of Chinook and Coho salmon (*Oncorhynchus tshawytscha; O. kisutch*) to gamma rays at a dose rate of about 4.4 mGy d^{-1} (total dose 0.33 to 0.4 Gy) had no significant effects on growth as indicated by parr length. The weight of the Coho parr was not significantly different from the controls, but the exposed chinook parr were significantly heavier than the controls. In the exposed Coho salmon parr, individuals had significantly fewer vertebrae, and there was a significantly greater incidence of truncated operculae exposing the posterior edge of the gill filaments, as compared with the controls (Donaldson and Bonham, 1964).

(208) Gamma irradiation of rainbow trout fry (*Salmo irideus*) with 1.0 Gy significantly reduced their feeding activity during the period 3 to 7 days post-irradiation (Kobayashi and Hirata, 1957).

(209) A number of studies have been made in relation to immune responses. The exposure of rainbow trout (*Salmo gairdnerii*) during embryogenesis to tritium beta radiation (estimated dose rates of 50.4 and 504 mGy d^{-1} giving rise to total doses of 1.0 and 10.0 Gy) has been found to influence the immune response of juveniles and yearlings to a natural *Chondrococcus columnaris* infection. For the juveniles, the exposure to either dose rates significantly suppressed the immune response in the late summer, relative to the controls, but there was no significant difference between the irradiation levels; for the yearlings, the lower dose rate induced a significant suppression, again in the late summer (Strand et al., 1973).

(210) In a second study, a wider range of tritium dose rates was assayed (19.92; 199.2; 1,992 and 19,920 µGy d^{-1}; total doses of 0.0004, 0.004, 0.04 and 0.4 Gy) in order to determine the influence of tritium irradiation on the primary immune response in juvenile rainbow trout to a vaccination with heat-killed cells of *Flexobacter columnaris*. At 9 and 11 weeks post-vaccination there was significant variation between radiation treatments in the specific serum agglutinin titres. Irradiation with 19.92 µGy d^{-1} had no significant influence at either 9 or 11 weeks, and with 199.2 µGy d^{-1} had no effects at 11 weeks. In a continuation of this study, the response of yearlings to a second challenge of inactivated *F. columnaris* cells was investigated. At 7 and 10 weeks post-vaccination exposure to 19.92 µGy d^{-1} had no significant effect on the serum agglutinin titre; however, for dose rates of 199.2 µGy d^{-1} or higher there was a significant linear dependence of the immune response suppression (as % of control) on the logarithm of the dose (and dose rate) (Strand et al., 1977; 1982).

(211) In rainbow trout (*Oncorhynchus mykiss*) the influence of external gamma irradiation during embryonic development, and from fertilisation during 246 days, i.e. well into the juvenile period has been studied. In the first experiment the dose rates were 45.6, 88.8 and 216 mGy d^{-1} (total doses 0.83, 1.66 and 4.01 Gy). The immune response was tested at 5 months of age by means of an intra-peritoneal injection of dinitrophenol conjugated keyhole limpet haemocyanin (DNP-KLH) antigen. All groups raised antibodies to the antigen, and the response of the irradiated fish was not significantly different from the controls. In the second experiment, embryos were irradiated as before, and then the fish continued under irradiation (at lower mean dose rates: 23.76; 45.6 and 112 m Gy d^{-1}) for an additional 225 days (total accumulated doses: 5.43; 10.53 and 25.43 Gy). The immune response to the DNP-KLH antigen challenge was significantly depressed at the highest dose rate in relation to control values; no significant differences between the controls and the two lower dose rates were seen. The overall trend of the response appeared, however, to indicate suppression dependent on the total accumulated dose (and, therefore, the dose rate) from a threshold of around 2.5 mGy d^{-1} (Knowles, 1992).

(212) Other observations are that minor anomalies of growth, e.g. opercular defects in Coho salmon parr, were significantly increased at about 4.8 mGy d^{-1}, which could influence subsequent survival in the wild (Donaldson and Bonham, 1964). Pike exposed to mixed radiation at 2.7 mGy d^{-1} (total dose 1.2 Gy) showed no differences in growth compared with controls (Pitkyanen, 1978).

(213) And other fish data of interest are that in carp beta irradiated at 3 mGy d^{-1} (total dose 1.0 Gy), there was an increase in the concentrations of lipoperoxides in

liver and muscle (Storozhuk and Shekhanova, 1977). And carp beta irradiated at 6.6 mGy d^{-1} (total dose 0.082 Gy) the overall response to infection was lower in the irradiated carp compared with the control (decreased phagocytic activity of leokocytes) (Shleifer and Shekhanova, 1980).

(214) Paternal irradiation of an inbred line of guppy (*Poecilia reticulate*) with 5 Gy increased the incidence of spinal deformities in the F2 generation; 10 Gy administered to females and males increased the incidence in F1 and F2 generations, although the effects did not persist in the subsequent generations. X-rays irradiation of either male or female guppy of an hybrid line) with 10 Gy increased the incidence of neonatal deaths in the F2 generation, but no significant effects were seen in the F1 generation, or in an inbred line (Schroder, 1969).

(215) For male guppy (*Poecilia reticulata*) exposure to beta radiation (tritiated water) as developing embryos, at dose rates of 112.8 mGy d^{-1} (total dose 2 Gy) had no significant effect on body weight at either 16 or 43 weeks of age. Pooled data on the body weight at 14 weeks at higher dose rates (in the range 225.6 to 451.2 mGy d^{-1}) showed a significant reduction, but this had disappeared by 43 weeks; also exposed females showed no significant weight changes at 43 weeks. Fish irradiated as week-old juveniles were less sensitive. Irradiation as embryos with 9.4 mGy d^{-1} or as juveniles with 112.8 mGy d^{-1} did not affect the survival time of the guppies when exposed to a heat shock (Erickson, 1973).

(216) As to be expected, factors such as temperature, and salinity where relevant, are important in considering such effects in fish. But few studies have been made. The effects of radiation in combination with different levels of environmental temperature and salinity (a 33 factorial experimental design) have been investigated after exposure at the post-larval-juvenile stage of pinfish *Lagodon rhomboides*. In total, 8 body dimensions and the weight were measured after 45 days of exposure at 199,200 and 307,200 μGy d^{-1} (8.7 and 13.4 Gy). The analysis of variance showed that temperature significantly affected all 9 measures, with lesser influences for salinity and irradiation. There were significant first order interactions between radiation and temperature (8 measures) and between radiation and salinity (4 measures); the second order interaction between all 3 environmental variables affected 7 measures (White and Angelovic, 1966; 1968; Engel et al., 1966).

Reference Bee (insects)

(217) No data have been found on the effects of irradiation on the morbidity of bees, or on any large insects.

Reference Crab (large marine crustaceans)

(218) Juvenile (less than 1 year of age) blue crabs (*Callinectes sapidus*) exposed to gamma radiation at dose rates of 768 and 1,752 mGy d^{-1} did not show any significant increase of moulting frequency compared with controls; juvenile crabs exposed to 6,960 mGy d^{-1} moulted least, and none achieved a third moult. The growth rate (% increase in carapace width) of the crabs exposed to 768 mGy d^{-1} was significantly different from the control, but did not significantly change at 1,752 mGy d^{-1} (Engel, 1967; Engel et al., 1971).

Reference Earthworm (annelids)

(219) Young earthworm (*Eisenia foetida*) gamma irradiated with 100 Gy showed completely inhibited growth, and did not develop a clitellum (Suzuki and Egami, 1983). In the earthworm *Eisenia foetida,* posterior regeneration from the 50th segment (after cutting the animal) was blocked after a whole-body X-ray dose of 200 Gy. A general downward trend in the number of segments produced was observed in the range 20 to 100 Gy (Moment, 1972). Gamma-irradiation of earthworms (*Eisenia foetida*) with doses between 5 to 20 Gy decreased proliferation of epidermal cells (labelling indices of cells measured using 3H-thymidine autoradiography). Proliferation remained at a low level during 10 to 20 days after irradiation with 5 and 10 Gy, and the damage caused by 20 Gy did not appear to have been repaired even 40 days after irradiation (Suzuki, S., and Egami, 1983).

(220) The gamma irradiation of earthworms with 204 mGy d^{-1} has been reported to have had no effect on growth (Hingston et al., 2004).

Reference Pine tree (conifers)

(221) There are various data available on pine trees. Mature *Pinus rigida* gamma irradiated over 10 years at dose rates higher than 14.4 mGy d^{-1} showed reduced needle growth. Irradiation with dose rates of 9.6 to 48 mGy d^{-1} over 9 years produced a reduction in trunk growth (Woodwell and Miller, 1963; Sparrow et al., 1965). In one-year-old *Pinus sylvestris*, gamma irradiation with 168 mGy d^{-1} over a single growing season produced a substantial reduction of needle and stem length. Exposure to dose rates higher than 72 mGy d^{-1} for 3 to 4 years reduced needle growth (Sparrow et al., 1965). Two-year-old *Pinus banksiana* gamma irradiated over the growing season with dose-rates higher than 88.8 mGy d^{-1}, showed reduced stem growth (Amiro, 1986).

(222) Irradiation in the spring with doses higher than 5 Gy gamma radiation reduced photosynthetic activity of pine trees in the first year in a dose-dependent manner. This reduction, together with the loss of needles and growth points (apical and lateral meristems), lead to a reduction in primary production. Although photosynthesis recovered to above control values in the 2nd year after irradiation with doses below25Gy, and in the 3rd year with doses below 50Gy, this was insufficient to counterbalance the continuing loos of needles, and the overall productivity of the pines stands continued to decline (Karaban et al., 1980; Spirin et al., 1981).

(223) Irradiation of pines with 24 mGy d^{-1} reduced their photosynthetic capacity, resulting in modified leaf morphology which led to reduced growth and delayed maturation (Bostrack and Sparrow 1979). However, it has been suggested that net photosynthesis and CO_2 exchange in pines are poor indicators of damage from chronic irradiation at dose rates below 288 mGy d^{-1} (Bourdeau and Woodwell, 1964; Bostrack & Sparrow 1979).

(224) As gamma radiation doses increased above 0.5 Gy, there was a progressive reduction in needle length. After exposure of growing plants to 3.0 Gy or to 4.5 Gy to dormant plats, needle length was 10% the control value (Sparrow et al., 1963). Acute doses of 15Gy gamma radiation administered in spring were 100% lethal within 1

year for cell proliferation in the apical meristem, and for the processes of needle formation (Karaban et al., 1980; Spirin et al., 1981). In *Pinus taeda* and *Pinus elliottii* gamma irradiation with 12.5 Gy depressed the net rate of photosyntesis at 4 to 20 days after irradiation, and also depressed the rate of CO_2 evolution by stems (Hadley and Woodwell, 1966).

(225) As to be expected, there are many data relating to the contaminated area around Chernobyl. These are therefore not the results of controlled experiments, and need to be considered in that light, particularly in terms of dose received, and to what part of the plant, together with other uncontrolled (and possibly unknown) environmental variables.

(226) Irradiation leaves pine trees more susceptible to be attacked by xylophagous insects. In a pine-birch forest (trees 30-years old) exposed to gamma radiation (activity of Cs-137 in the source was 1.2E+15 Bq) the number of irradiated Scotch pine trees (*Pinus sylvestris L*) infested by xylophagous insects were 10% to 18% after receiving a dose of 30 Gy; 60% to 78% after doses of 100 Gy and 100% after doses of 230 Gy, compared with 5% in control trees (Spirin et al., 1985a; 1985b; Kozubov and Taskaev, 1994). Spruce trees exposed to mixed radiation (Chernobyl accident) at doses as low as 0.7 to 1 Gy, showed malformed needles, buds and shoot growth. Of the absorbed dose to critical parts of trees, 90% was due to beta radiation from the deposited radionuclides and 10% to gamma radiation (Kozubov and Taskaev, 1990).

(227) In an area contaminated after the Chernobyl accident, exposure of *Pinus silvestris* to doses higher than 1 Gy reduced growth rates and induced morphological damage. Doses below 0.1 Gy did not cause any visible damage to the trees. Of the absorbed dose to critical parts of trees, 90% was due to beta radiation from the deposited radionuclides and 10% to gamma radiation (Kozubov and Taskaev, 1994).

(228) In a forest of the Chernobyl zone of minor damage, the coniferous trees showed disturbances in growth and morphology as a result of irradiation with doses from external gamma-rays of 0.5 to 1.2 Gy (dose rate lower than 4.8 mGy d^{-1} the 1st of October 1986; dose in needles was estimated to be lower than 10 Gy) (UNSCEAR, 1996).

(229) In an area 4 km to the west of Chernobyl (contaminated with ^{144}Ce; ^{106}Ru; ^{95}Zr; ^{95}Nb; ^{134}Cs; ^{137}Cs; ^{90}Sr, etc.), exposure to cumulative doses of 6 Gy produced multi-buds in 25 to 35 years-old *Pinus sylvestris* (Kozubov and Taskaev, 1994b).

(230) In 1987, in an experimental plot of pine forest (35 years-old trees) in the 5 to 6 km zone from Chernobyl (contaminated with Chernobyl fallout and hot particles) all pine shoots generative organs and most part of sleep buds died after estimated cumulative doses of 20 Gy received at 4.3 mGy d^{-1}. Anatomic and morphological changes in the needle structure were also observed (form of needle section increased, density of resin duct decreased by 40%, number of conductive elements formed by cambium increased). After cumulative doses of 7Gy at 1.4 mGy d^{-1} oppression of growth of auxiblastes and needles of 1986 was observed. In the plot with the lowest density contamination (estimated cumulative dose of 2 Gy at 240 µGy d^{-1}) visible signs of radiation damage were not seen (Abaturov et al., 1991).

(231) In the 30-km zone of Chernobyl (contaminated with ^{137}Cs, ^{90}Sr and hot particles), 10 to 12 years-old *Pinus sylvestris L.* irradiated with 9 mGy d^{-1} showed, in 1987, morphological changes and growth of shoots was not observed. Some trees had short cactus-shaped and pineapple-shaped shoots of 1986. Needle were curved fleshy dark and hard. Sizes of buds were higher then those in the control (Sidorov, 1994). *Pinus sylvestris L* exposed to 0.5 Gy in the vegetation season of 1986 had an stimulatory effect, as manifested by additional growth of annual shoots. After cumulative doses of 5 Gy, a decrease of annual growth and morphological changes of vegetative organs were detected in the first two years after the accident. Cumulative doses of 10 Gy induced changes of morphogenesis of vegetative organs, changes in needle ultrastructure, depression of growth of meristematic tissues and short-cut shoots (Kalchenko and Fedotov, 2001).

(232) And in a forest in the 30 km^2 zone of Chernobyl, death of most growth points, partial dieback of coniferous trees and morphological changes in deciduous trees were seen after external gamma irradiation with doses of 10-20 Gy (the estimated dose rate on October 1st 1986 was 48-120 mGy d^{-1}; with doses in needles of 50-100 Gy). In the forest of the 120 km^2 zone of Chernobyl, pines showed desiccated needles, and morphological changes after external gamma irradiation of 4 to 5 Gy (the estimated dose rate on October 1st 1986 was 12-48 mGy d^{-1}, with doses in needles of 20-50 Gy) (UNSCEAR, 1996).

(233) In another area contaminated after the Chernobyl accident, exposure to 0.43 Gy produced a decrease in shooting increment of pine. Cessation of growth was seen after accumulated doses of 3.45 Gy. Morphological alterations in pine needles and undergrowth of deciduous trees were registered after cumulative doses of 13 Gy (dose rates of 24 mGy d^{-1}) (Sidorov, 1994).

(234) Common 50 to 60 years old spruce (*Pinus sylvestris L.*) in a zone contaminated after the Chernobyl accident, exposed to 25Gy at 68 mGy d^{-1} showed 100% mortality of central shoots and all needles. After accumulated doses of 5Gy at 14 mGy d^{-1}, needles on the pines were gigantic and the number of thilockoides in grains was 150% the control value. Exposure to 4 Gy at 11 mGy d^{-1} reduced the number of chloroplasts to 67% the control value, the mass of needles per one shoot to 55% the control value and the length of needles to 25% the control. Exposure to 1 Gy at 2.7 mGy d^{-1} produced stimulation of needles growth in 1987, but two years after the accident differences of needle length were statistically unreliable (Ladanova, 1994).

(235) In 55% of scotch pines (*Pinus sylvestris L.*) exposed to 9.6 mGy d^{-1} in a zone contaminated after the Chernobyl accident, the leading shoots of 1986 were short. In 33% of the samples the leading shoot of 1986 died, and in 44% the lateral shoots of 1986 in the upper crown part were short. 55% of the samples did not have the lateral shoot of 1986. In 78% of the samples all needles of 1984 and 1985 on the growth of 1987 were fully yellow. After 3.6 mGy d^{-1} in 7% of the samples the needles of 1984 and 1985 in the crown were yellow. In 46% of the samples the needles of 1984 and 1985 on the growth of 1987 in the middle crown part were fully yellow, and in 40% of the samples the needles in the crown were fully yellow. After 1.7 mGy d^{-1} in 61% of the samples the leading shoot of 1986 was short. In 46% of the samples the lateral shoots of 1986 in the upper and middle crown part were short (Abaturov et al., 1996).

(236) In the Southeast area of the Urals accident (^{90}Sr contamination at 1.5 to 1.8 MBq/m^2) desiccation of needles in the lower part of the crown, and reduction in growth increment was seen in pines (average doses in needles of 5 to 10 Gy and in bud meristem of 2 to 4 Gy). In areas with 3.7 to 4.4 MBq/m^2 of ^{90}Sr (average doses in needles of 10 to 20 Gy and in bud meristem of 5 to 10Gy) there was a desiccation of 95% of the crown and growth retardation (UNSCEAR, 1996).

Reference Wild Grass (grasses)

(237) In an area contaminated as a result of the Chernobyl accident (1986-1988), seeds of timothy-grass (*Phleum pratense L.*) were additionally exposed to probing acute gamma-radiation in different doses. After 20Gy (5 µGy d^{-1}) and 80Gy (240 µGy d^{-1}) stimulation of growth processes was observed (Frolova et al., 1991).

Reference Seaweed (macro-algae)

(238) There are no data available.

5.3.3   Reduced reproductive success

Introduction

(239) In considering the effects of radiation in an environmental context, effects relating to reproductive ability are clearly of great importance. Reduced reproductive success can result from many factors: reduced fertility of either male or female, including the periods over which such effects may last; reduced fecundity, in terms of litter size, sex ratio, deformed embryos, and so on; or even changes in behaviour or distribution that may reduce the success of effective mating. Here again, some data in relation to the human being may help to place such information into perspective.

(240) Temporary sterility in human males appears to have a threshold of about 0.15 Gy if given as a single exposure, or about 0.4 Gy per year over an extended period of time. Permanent sterility can result from somewhere in the range of 3.5 to 6 Gy in a single brief exposure, or about 2 Gy per year over an extended period of time. For females, sterility (effect on the ovaries) can result from about 2.5 to 6 Gy received in a single brief exposure, or from a dose of about 0.2 or more Gy per year over an extended period of time.

(241) With regard to effects on the developing foetus, based on both human and animal data, there appears to be a dose threshold of about 100 mGy for the induction of malformations, and a threshold of about 300 mGy in the most sensitive pre-natal period (8 to 15 weeks post-conception) for any mental retardation effects. It is also generally observed that the effects of acute irradiation on reproductive capacity (fecundity and fertility) are highly dependent on the time of development or age of the animal when they are irradiated.

Reference Deer (large mammals)

(242) There have been no direct studies on deer and, apart from the data available on human beings, some of the most complete data sets on 'large' mammals are those

relating to pigs. The human data relating to sterility of males and females probably apply equally well to large mammals such as deer. In bulls that were gamma irradiated with doses between 0.38 and 2.20 Gy, the number of germ cells in the seminiferous tubules were significantly reduced (10% the control value) at 30 and 60 days of age respectively (Erickson et al., 1972).) Adult beagle dogs irradiated with 4.32 mGy d^{-1} showed progressive germ cell depletion and sterility within a few months, but exposure at 864 µGy d^{-1} over the whole life produced no apparent damage in fertility (Committee on Biological Effects of Ionizing Radiation (BEIR III, 1980).

(243) The exposure of pig embryos to gamma rays at 10 mGy d^{-1} for 108 days during gestation (total gestation, 112) reduced the gonad's weight in offspring, and at 31.2 mGy d^{-1} (3.36 Gy) both female and male offspring were rendered sterile (Erickson and Martin, 1976). Continuous irradiation of pigs between days 0 and 108 of gestation, with dose rates of up to 10 mGy d^{-1} of gamma rays (total doses of 1.08 Gy), produced no increase in dead piglets or dead foetuses in first and second pregnancies, respectively. The lower dose rate that produced a significant reduction in number of primitive stem germ cells per cross section of seminiferous tubules (41% the control value) was 2.5 mGy d^{-1}. After exposure to 10 mGy d^{-1}, 40% of the pigs were infertile. Irradiation apparently did not alter either age at or regularity of oestrus. For their first pregnancy, the groups did not significatively differ in either infertility incidence or number of offspring farrowed. Irradiation had no apparent effect on piglet birth weight, or survival to weaning or weight at weaning. The nurturing ability of the sows was also unaffected (Erickson and Martin, 1984). In pigs gamma irradiated between days 0 and 108 of gestation, the lower dose rate that induced significant effects (LOEDR) in a variety of characteristics of the piglets was determined. Thus the LOEDR for reduced body weight was 70.4 mGyd^{-1} (total dose 7.56 Gy); for reduced brain weight it was 29.9 mGy d^{-1} (total dose 3.24 Gy); for reduced ovary and testis weight (55% reduction) it was 9.9 mGy d^{-1} (total dose 1.08 Gy); and for reduction in germ cells in females and males (57% and 89% reduction, respectively) it was 5.10 mGy d^{-1} (total dose 0.54 Gy). After irradiation with 10.1 mGy d^{-1} during gestation (total dose 1.1 Gy), germ cell numbers in pigs were reduced to 1 and 5% the control value in males and females, respectively (UNSCEAR 1986).

(244) The main induction period of externally detectable malformations has been determined for several large mammals after in utero irradiation. The induction period and the dose needed to produce the effect, varied depending on the malformation and the mammal studied. The main induction period of externally detectable malformations in trunk was until 32 days after conception, at doses higher than 1.0 Gy for cattle; 8 to 12 days after conception, with doses higher than 2.5 Gy for monkey and until 23 days after conception, with mean doses higher than 1.0 Gy (Lowest response dose to cause effect >1.0 Gy) for sheep. In dogs, the main induction period of externally detectable malformations in extremities was 25 to 28 days after conception, with doses higher than 1.3 Gy (CRP, 1989).

Reference Rat (small mammals)

(245) Rats and mice have been used extensively to study reproductive effects of irradiation in mammals. First of all, with regard to fertility, gamma irradiation of rats on days 10 to 12 after conception with 1.5 Gy caused germ cell killing in male

offspring. A slight reduction in testis weight was observed when this dose was administered on day 15 of gestation, with the peak reduction for exposures between 18 days after conception and 3 days after birth. The reduction in weight was the consequence of spermatogenic cell loss in the tubules, but no effects were seen in the endocrine function of the testis (Coffigny and Pasquier, 1976). Male rats gamma irradiated on day 15 of gestation with 0.95 Gy, showed decreased total number of germ cells and testes weight (Erickson and Martin, 1972; Pujol et al., 1996). Male rats 2 or 12 days-old gamma irradiated with 2.85 Gy showed permanent reduction in the stem spermatogonial population (analysis done from days 5 to 120 post irradiation). The loss of testicular weight observed 24 days after exposure was a consequence of the loss of spermatocytes through mature depletion. By 40 days post irradiation, much of the spermatocyte population was restored, but the pre-irradiation stock of spermatids had matured and flowed from the testis, resulting in losses of testicular weights. Irradiation produced a permanent decrement in the stem spermatogonial population that was age dependent. Long-term damage to the reproductive system of male rats has also been described after whole body exposure to an acute dose of 0.1 Gy gamma radiation (Erickson and Martin, 1973; Canfi et al., 1990).

(246) Male rats irradiated with dose rates of 70.05 mGy d^{-1} gamma rays, up to 92 days, produced a 59% reduction in the numbers of spermatogonia per testis after cumulative doses of 0.6 Gy. After 92 days of exposure all cell types were reduced to 10 % the control value. No effects were seen on seminal vesicle or ventral prostate weight. Growth rate was only slightly slower in irradiated rats when compared to controls. No significant changes were observed in testosterone concentrations, weight of testosterone-dependent accessory organs and LH plasma concentrations in the irradiated groups (Pinon-Lataillade et al., 1985).

(247) Male rats irradiated with gamma radiation at 10.1 mGy d^{-1} during 1 to 6 months, showed a 50% reduction in numbers of A1 spermatogonia, while no effect was seen on A4 spermatogonia. Irradiation during 1 to 6 months with dose rates of 30.24 mGy d^{-1} or higher reduced (40%) the numbers of A4 spermatogonia and testis weight (Erickson, 1978). Gamma irradiation of adult rats during 180 days with 50 mGy d^{-1} increased 27% the number of tubules devoid of germ cells. Exposure during 12.6 days at the same dose rate (total dose 0.6 Gy) decreased type A spermatogonia to 55% the control value. The content of preleptotene spermatocytes decreased to 35% the control value after 25.6 days of exposure (total dose 1.3 Gy). Numbers of A spermatogonia per testes and preleptotene spermatocytes per testes, remained less than the control values even 33 weeks after irradiation. Cumulative doses of 3.5 Gy, produced a 25% decrease in male fertility and a 50% reduction in testes weight (LOEDR) (Pinon-Lataillade and Maas, 1985).

(248) In experiments with mice, again at high doses, after gamma irradiation with 6 or 8 Gy, male mice showed mean times of return to fertility of 81.0 ± 4.1 days and 104.8 ± 7.8 days, respectively. Fractionation of the dose (2 fractions) had no effect in the time needed to return to fertility. When mating with control females, all irradiated groups gave higher rates of intrauterine death and lower implantation rates than control non-irradiated pairs (Sheridan, 1971). Adults exposed to gamma radiation showed LD_{50} values for late type A, intermediate and early type B spermatogonia between 0.20 and 0.24 Gy, showing all cell types had a similar radiosensitivity. LD_{50} for spermatozoa and spermatids (28 days after irradiation) was 0.64 Gy. Testes weight

28 days after irradiation was reduced to 50% the control value after 3.62 Gy (Gasinska et al., 1987; Gasinska, 1985; Oakberg, 1957).

(249) With regard to males and females, gamma irradiation of rats with 10 mGy d^{-1} during gestation (22 days; total dose 0.21Gy) reduced the number of germ cells in males (50%) and females (90% reduction) (UNSCEAR 1986). After irradiation with 32.64 mGy d^{-1} (total dose 0.6 Gy) on days 0 to 21 of gestation, a significant reduction of female and male germ cells was observed (45 and 17% reduction, respectively; LOEDR) (Erickson et al., 1976)

(250) The numbers of primary oocytes in 21-day-old F1 and F2 offspring rats exposed since conception at a dose rate of 1,848 µGy d^{-1} of tritiated water or food were no different from control (both in F1 and F2, independently of the exposure regimen: food or water) (UNSCEAR 1996). A significant reduction in number of primary oocytes was observed in 21-day-old F1 offspring exposed to 14,640 µGy d^{-1} from tritiated water and to 4,800 µGy d^{-1} from tritiated food (organically bound tritium) (Pietrzak-Flis and Wasilewska-Gomulka, 1984). Exposure of adult rats to beta radiation (tritium) at dose rates of 4,800 µGy d^{-1} (total dose 0.2 Gy) produced a moderate effect in female reproductive organs (30% reduction in number of oocytes) (Pietrzak-Flis and Wasilewska-Gomulka, 1984).
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(251) The exposure of rats on days 13 to 20 after conception to 432 mGy d^{-1} gamma radiation (total dose 3.0 Gy) resulted in offspring with smaller ovaries, and an absence of follicles and corpora lutea, while the same dose-rate had no effect on these parameters when administered on day 18 after conception (Ershoff, 1960).

(252) And with regard to mice, gamma irradiation with 130 mGy d^{-1} (total dose 0.44 Gy) produced a 70% reduction of stage 1 oocytes. The results showed that early oocytes stages in 10 days-old mice are more sensitive to chronic irradiation than similar stages in the adult (Oakberg, 1962). Continuous irradiation with 12 to 24 mGy d^{-1} for at least 10 generations did not affect the fertility of pairs of mice from 4 different strains, as indicated by the average size of the 1st litter (Stadler and Gowen, 1964).

(253) Fecundity is a different measure of reproductive success. Gamma irradiation of 8 day-old rats with 0.06 Gy produced a reduction in litter size, as a consequence of a 5-fold increase in embryos death rate (Freud et al., 1990). Doses of 0.05 Gy gamma radiation to rats in the pre-implantation period resulted in foetal mortality, while a dose of 0.1 Gy produced both embryonic and foetal mortality, with the latter being greater (UNSCEAR 1977; 1986). Gamma irradiation of several species of rodents in the early stages of organogenesis gave an LD$_{50}$ lower than 1.5 Gy for embryo survival; LD$_{50}$ values increased with development until the foetal stage (UNSCEAR, 1996)

(254) Rats gamma irradiated on day 9.5 of gestation with 1.5 Gy (at what were very high dose rates, equivalent to 17.3 to 1440 Gy day^{-1}) showed an increase in embryo re-sorption rate (48.3 to 60.7% compared with 2.84% in controls), and in mean re-sorptions per litter (5.1 to 7.8% compared with 0.3% in controls). A decrease in percentage of live foetuses at term was also observed (39.0 to 51.6 % compared with 94.3% in controls) (Brent, 1971). The same gamma doses (1.5 Gy), given 15

days post conception, reduced the number of pups per litter to 63% the control value. No significant effects were seen in the number of pups per mated female (Mazaud et al., 2002). Regarding the effect of irradiation on the subsequent growth of embryos, exposure of 8 day-old rats to 0.06 Gy gamma rays led to a reduction in the body weight of pups on the weaning day (85% the control value) (Freud et al., 1990).

(255) Pregnant rats exposed to 70.05 mGy d^{-1} gamma radiation showed no alterations on average litter size (Hossain and Uma Devi, 2000). Rats gamma irradiated during the gestation period (from day 0 to day 12, 13, 14, 15, 16, 17, 18, or 19 of gestation) with dose rates of 60 mGy d^{-1}, had embryos of reduced length and weight, and increased percentage of mortality was observed (total resorptions+dead embryos or foetuses+viable embryos but reduced in size/total implantation). In 20-day irradiated embryos, a statistically significant reduction in liver/body weight, spleen/body weight and kidney/body weight was observed. Irradiation with 600 mGy d^{-1} (total dose 6.0 Gy) produced a severe decrease in fecundity (75% reduction in embryo survival) (Coppenger and Brown, 1967).

(256) No effects on litter size have been observed after gamma irradiation of rats at 50.04 mGy d^{-1} for up to 180 days (total dose up to 9.0 Gy). There was diminished fertility on week 1 and 9 post-irradiation, but fertility recovered to 75% the control value 25 weeks after irradiation (Ershoff, 1960). Exposure to 432 mGy d^{-1} on days 13 to 20 after conception produced offspring with smaller ovaries, absence of follicles and corpora lutea, while the same dose-rate had no effect in these parameters when administered on day 18 after conception. No effects were seen in weight at weaning and weight at young after exposure to 432 mGy d^{-1} gamma rays, during 7 or 21 days (Ershoff, 1960).

(257) Doses due to internal exposure are more difficult to determine, but exposure of rats from the first day of pregnancy or birth to 30 mGy d^{-1} tritium beta radiation (total dose 1.3 Gy), produced a 77% reduction in testis weight and sperm content. No effects in ovary weight were seen. But the same dose rates produced a severe decrease in fecundity of the F2,3 litters (70% reduction in embryo survival) . Exposure of rats to tritium beta radiation from conception during 42 days, to 30 mGy d^{-1} (1.26 Gy) produced a 3.6-fold increase in the percentage of resorptions of the F2, 3 litters. Rats exposed from first day of pregnancy were considered to be more sensitive to the effects of chronic beta irradiation than adult rats (Laskey and Bursian, 1976). After administration of ^{3}H-water throughout development at 60 mGy d^{-1} ovaries were seriously reduced or absent (Cahill and Yuile, 1970).

(258) In rats receiving tritiated water during F0 and F1 at dose rates of 0.03, 0.3, 3 and 30 mGy d^{-1}, (giving cumulative doses from conception to delivery of F2 between 0.0046 and 4.6 Gy), the offspring of F1 and F2 were morphological normal regardless of the dose rate. Administration of tritiated water during 22 days, at any dose rate assayed, had no effect on pre-implantation death, lungs, heart, thymus, liver, spleen and kidney weight. Exposure to 30 mGy d^{-1} for 22 days, increased 2.6 times the number of resorptions (Laskey et al., 1973). A significant reduction in birth weight of female and male rat offspring was observed after tritiated water administration (60 mGy d^{-1}) during gestation. (Cahill and Yuile, 1970).

(259) There have been many experiments with mice, and it is also worth noting that there appears to be a close relationship between cell killing and ovarian cancer in some strains of mice; and that because mouse oocytes are particularly sensitive to radiation (LD_{50} for oocyte killing of 50mGy), ovarian tumours are frequently observed at very low dose rates (ICRP 99).

(260) Adult female mice gamma irradiated with 5 Gy showed a reduced number of implantation sites (81% the control value). No reduction was seen in the number of pregnant mice. The LOED for reduced survival of embryos to day 16 of age was 2.5 Gy (survival of 87% the control value) (Friedberg et al., 1998). Gamma irradiation of male mice with 3 Gy (mated with non-irradiated females), did not reduce the life span of F1 (females and males), but decreased mean litter size (49 compared with 71 in controls). Sex ratio was not affected after 3 Gy exposure (Iwasaki et al., 1996).

(261) In mice gamma irradiated 7 hours after presumed fertilisation, the LOED on day 19 of gestation for an increase in early resorptions and reduced embryos alive was 0.5 Gy (3-fold increase and 1.6-fold decrease, respectively). The LOED for increased number of foetus with external malformations was 0.1 Gy (8-fold increase). No effects on foetal resorptions were seen at any of the doses assayed (Jacquet et al., 1995). Mice gamma irradiated 2 hours after mating with 1.5 or 2.0 Gy, showed increased number of abnormal foetuses alive (3 and 5-fold increase, respectively), and decreased numbers of implants per female (2 to 3 fold decrease, respectively) (Rutledge et al., 1992). Exposure of mice with doses between 0.05 and 2 Gy of gamma radiation produced a dose dependent increase in late post-implantation death, pre-implantation death and percentage of malformed foetuses, and a dose-dependent decrease in surviving foetuses (Pampfer and Streffer, 1988).

(262) Gamma irradiation of mice on gestation days 3.5 (pre-implantation), 6.5 (early organogenesis) or 11.5 (late organogenesis) with doses of 0.009 or 0.05 Gy, had no effects on litter size and sex ratio, regardless of the dose or the day of irradiation. The LOED for increased postnatal mortality in mice irradiated on day 6.5 of gestation was 0.05 Gy (16.1% compared with 10% in controls), while no effect was seen when the same dose was administered on day 3.5 of gestation (Hande et al., 1990).

(263) In a study using more than 30,000 mice, the effects of irradiation during 3 consecutive generations were determined (each generation was exposed during 80 days with a cumulative dose 0.344 Gy/generation). The 4th generation (not irradiated) was mated to generate the F1 and this one mated again to generate the F2. Exposure during three consecutive generations to 4.7 mGy d^{-1} had no effect on mean litter size of F1 and F2, but increased the percentage of early deaths both in F1 and F2 (two-fold increase in both). No deleterious effects of radiation in the F1 and F2 individuals, including foetuses, were observed concerning the growth and fertility. Exposures at dose rates of 24.8 and 33 mGy d^{-1}, had no effects in the two first generations (mean litter size and sterility), but decrease litter size and increased sterility in the 3rd and 4th generation (Muramatsu et al, 1963;1965).

(264) In mice gamma irradiated on day 7.5 of gestation, the LOED for increased prenatal mortality up to 18 days post coitus was 1.2 Gy (Di Majo et al., 1981). Gamma irradiation of mice during the pronuclear zygote stage of development not only increased the prenatal mortality in a dose dependent manner (doses from 0.1 to

1.0 Gy), but embryos also died earlier in development. With all the doses assayed, radiation-induced deaths occurred before day 11 of gestation, since as a result of irradiation the early pronuclear zygote cannot progress to a less radiosensitive phase (Friedberg et al., 1973). In mice gamma irradiated on day 2 of gestation, the LOED was 1.0 Gy for increased pre-implantation death on day 19 of gestation (11% compared with 5% in controls) and for decreased surviving foetuses at the same day (78% compared with 87% in controls). The number of surviving foetuses was strongly dependent on the gestation day when the irradiation was performed, with day 1 showing the highest and day 6 the lowest effect on survival. On day 1, the major contribution to prenatal mortality was the pre-implantation death, whereas the contribution of early resorptions gained more significance when the radiation exposure was done at later stages within the pre-implantation period. Significant increases in the number of malformations were seen when 1 Gy was administered 1 or 3 hours after conception, but no effect was seen after irradiation at 6 or 12 hours after conception. Irradiation on day 8 of gestation with 1 Gy did not reduce survival but 7.4 % of the foetuses showed a macroscopically visible malformation, mainly gastroschisis and exencephaly. A high number of whole resorptions (90%) was only seen after 3 Gy administered on day 8 of gestation (Muller and Streffer, 1990; Muller et all., 1999).

(265) In another experiment, adult male mice were gamma irradiated, either with a single dose of 2.75 Gy, or with a daily dose of 0.05 Gy for 55 days, and then kept celibate for 70 days after irradiation before being mated with control females. Exposure to single doses of 2.75 Gy increased the number of lost litters by F1 females (73 compared with 56 in controls) and the percentage of dead implants (10.75 compared with 7.70 in controls). A decrease in the percentage of pregnant females after mating with irradiated males was also observed (54.49 compared with 59.35 in controls). No effect was seen in percentage survival in weaned litters (80.10 compared with 81.44 in controls). The F1 females from the irradiated groups showed no significant effects on productivity or fertility when compared to the control group. Fractionation of the dose led to no significant effects on any of the parameters assayed (Sheridan, 1968).

(266) The effects of in utero irradiation on induction of malformations in embryos mainly depends on the day of gestation when the irradiation takes place, and to a lesser extent on the dose within the range of 0.25 to 2.5 Gy for gamma rays. Doses of 1.5 to 2.0 Gy on day 9.5 after conception significantly increased the percentage of malformed offspring 21.5 days after exposure (Brent, 1971; Solomon et al., 1994; Schmitz et al., 2002). Central nervous system malformations were primarily induced with doses of 1.0 to 2.0 Gy on 9 to 14 days post conception (LOED of 0.50 Gy). Eye malformations were primarily induced after irradiation on day 9 to 10 post conception with doses of 1.0 to 2.0 Gy (LOED of 0.25 Gy). Skull malformations were mainly detected after irradiation with doses of 1.5 to 2.5 Gy on day 9 to 12 of gestation (LOED of 1.0 Gy). Finally, extremity malformations were mainly induced after exposure to doses higher than 2.0 Gy after day 9 of gestation (UNSCEAR, 1986)

(267) Gamma irradiation of mice with 0.015 Gy just after mating (fertilised mouse eggs prior to cleavage) increased the percentage of abnormal early embryos at 6 and 24 hours after exposure. Exposure to this low dose produced delay of first cleavage and an 8-fold increase in the number of abnormal in the irradiated group. The

anomalies included cytoplasmic damage appearing as a wave of necrosis over the egg, hyperchromaticity of both cytoplasm and nucleus, exudation of cytoplasm through ruptured cell membranes, pyknosis of nuclei and congealing chromosomes. These anomalies are rarely, if ever, found in the controls. On the basis of this and other recent studies it is believed that the newly fertilised egg is probably the most radiosensitive cell in the mouse, except possibly the germ cell (Rugh and Grupp, 1961).

(268) In mice exposed to 2.4 mGy d^{-1} gamma radiation during 4 to 6 months (total dose 0.15 Gy), there was a moderate decrease in fecundity (35% reduction in number of offspring sired and weaned; LOEDR) and after total doses of 0.6 Gy a major decrease of male fertility (50% reduction of fertile pairs after male irradiation; LOEDR) (Leonard et al., 1985) Exposure of mice to gamma radiation at dose rates of 100.8 or 201.6 mGy d^{-1} (during 24 or 16 weeks, respectively) had no effect on mean litter size of females surviving sterility and on mortality between birth and weaning of the offspring. The LOEDR for mean number of litters per female was 100.8 mGy d^{-1} (24 weeks of exposure; 2.2 Gy), which reduced the number of litters to 35% the control value (Searle et al., 1980). Adult female mice gamma irradiated during 40 days with 84.5 mGy d^{-1} (total dose 3.38 Gy) showed reduced fertility (Rönnbäck, 1965). Gamma irradiation of mice, from day 19 post coitus to day 2 after birth, with 227.5 mGy d^{-1} had no effect on litter size. After exposures of 50 mGy d^{-1} or higher, a decrease in the number of litters per fertile female during 245 days after exposure was observed (48% the control value). The LOEDR for reduced germ cells per ovary (quantified at 165 days of age) was 227.5 mGy d^{-1} (Rönnbäck, 1983). Mice gamma irradiated with 22.5 mGy d^{-1} (total dose 0,09 Gy) showed a 30% reduction in number of litters per fertile female, and a 39% reduction in female fertility span (Rönnbäck, 1983). Gamma irradiation of mice with 84 mGy d^{-1} (3.4 Gy) had no effects in litter size (Searle et al., 1980; Rönnbäck, 1983).

(269) The impact of chronic exposure from internal radiation (tritiated water) and external gamma radiation on pre-implantation mouse embryos maintained in culture has also been studied. Irradiation at the pronuclear, early two-cell and late two-cell stages, and survival to the expanded blastocyst stage was used as the criterion of damage. Exposure from the pronuclear stage showed the greatest radiosensitivity, with 50% survival at an estimated dose rate of 240 mGy d^{-1} (4.4 MBq/ml) (Yamada et al, 1982). In mice, cumulative doses of 0.9 Gy beta radiation (^{90}Sr-^{90}Y) reduced their fertility. Irradiation at a dose rate of 79.2 mGy d^{-1} during the period 20 to 40 days after conception (total dose 1.6 Gy) produced complete sterility (Rönnbäck, 1965). Similarly, in mice beta radiated (^{90}Sr-^{90}Y) with 60 mGy d^{-1} (total dose 12 Gy) produced a moderate decrease in fecundity (28% reduction in number of embryos per female) (Ilyenko and Krapivko, 1993).

(270) With regard to 'field studies', made in a contaminated area of Chernobyl, exposures to mixed radiation at 15 mGy d^{-1} (total dose 2.7 Gy), produced no damage in male reproductive organs (frequency of abnormal sperm heads) in mice. Dose rates of 23 mGy d^{-1} (total dose 3.0 Gy) produced a moderate effect in male reproductive organs (35% reduction in testes mass), and 100% of mice temporary sterile (30 to 40 days) (Shevchenko et al., 1991).

(271) It is also worth noting that in a field study made in Rock Valley (Nevada), desert rats received a gamma irradiation of 2.11 to 3.60 Gy per year (5.8 to 9.8 mGy d^{-1}) from April to May 1963, to May to June 1968. Although effects on fertility could not be measured in the study, from the data of birth and death rate, a 40% reduction in the multiplication rate per generation could be estimated. The results showed that the response of field rat populations to chronic gamma radiation was similar to that observed in laboratory rats. The authors conclude that chronic exposure to dose rates of 5.8 to 9.8 mGy d^{-1} for up to 5 years gamma radiation is clearly detrimental for a population of desert rodents (increased mortality, reduced reproductive capacity) (French et al., 1974).

Reference Duck (birds)

(272) Surprisingly, there are few data of value with regard to birds. It is reported that chronic dose rates of 192 to 240 mGy d^{-1} cause effects on embryonic development in birds. However, the minimum dose rates that may cause other clearly evident effects have not been described (UNSCEAR,1996). Gamma irradiation with 4 mGy d^{-1} (total dose 4.0 Gy) decreased hatching success in several bird species (American robin; Brown-headed cowbird; Red-eyed vireo; Hermit thrush; Ovenbird; Common flicker) (Buech, 1976). And dose rates of 240 mGy d^{-1} gamma radiation to developing chicken embryos (Barred Rock), until hatching, have been reported as effectively sterilizing both sexes (Mraz and Woody, 1972).

(273) There are a number of data relating to tree swallows. Birds irradiated at 7 to 8 days of development with doses up to 3.4 Gy, and incubated naturally, showed no significant differences with the control group in hatching or fledging success, but the time to hatching increased and growth was depressed after irradiation with doses greater than 1.6 Gy (Zach and Mayoh, 1986). Doses between 0.9 to 6.0 Gy administered to young wild birds (tree swallow, eastern bluebird and house wren) have been reported to have had no effect on mortality during the nesting period (Zach and Mayoh, 1986b). Gamma radiation exposure at 720 to 6,240 µGy d^{-1} did not produce significant differences on breeding success of tree swallows as measured by clutch size, hatching success, fledging number, incubation time and nestling time (Zach and Mayoh, 1982).

Reference Frog (amphibians)

(274) Again, there are few data of value. It has been reported that the paternal exposure of toads to 3 to 20 Gy reduced survival of offspring, increasing the induction of abnormalities in live offspring (Blair, 1960). Gamma irradiation of frog tadpoles (*Scaphiopus holbrooki, Bufo terrestris and Rana catesbeiana*) with dose rates between 0.13 to 222 mGyd^{-1} (total doses from 0.0008 to 32 Gy) had no effect on hatching success of eggs (Stark, 2006).

(275) The closest other relevant data are probably those for lizards. Adult female lizards exposed to gamma radiation became sterile after total doses of 15 Gy at dose rates of 60 mGy d^{-1} (Turner et al., 1971). Gamma irradiation with 11 to 13.7 mGy d^{-1} during 3.5 years (total dose 14 to 22 Gy) produced a lack of reproduction of lizards (*Crotaphytus wislizenii*). In lizard *Cnemidophorus tigris*, after 5.5 years of exposure to 5.5 mGy d^{-1} (total dose 11 Gy), the ovaries had regressed completely, leading to

female sterility. At this time 1 of 3 irradiated males was found to be sterile. Control males and females of the same age were reproductively normal. Similar responses became apparent in *Cnemidophorus* some 2 years later than for *Crotaphytus* (the delay reflects the lower dose rate received) (Turner et al., 1971;UNSCEAR, 1996).

(276) And in natural populations of male and female adult lizards, irradiation of the gonads with 4.5 Gy (head and thorax shielded) resulted, after release, in a substantial reduction in the production of offspring in the year of irradiation. This in turn reduced the density of adults in the following year, but by the 2nd year both natality and population density were recovering to control values (Tinkle, 1965).

(277) In a contaminated area as a result of the Chernobyl accident, the only effect that could be unambiguously attributed to the radiation exposure in male brown frogs (*Rana arvalis*) was the decreased fertility. In the spring of 1987, more than 33% of the eggs clusters deposited were wholly or partially infertile. In eggs that were fertile, so-called partial division was observed as a consequence of the anomalous behaviour of the male pronucleous and/or the anomalous replication of the chromosomes. In 1988 the proportion of partially or incompletely infertile egg clusters remained high (27%), but declined to a stable incidence of 3% from 1989 onwards. In control populations the proportion of clusters with infertile eggs was less than 1.5%. No effects were seen in the processes of ovogenesis or embryonic development (Cherdantsev et al., 1993).

(278) In an area contaminated after the Kyshtym accident (^{90}Sr; 1Bq/Kg), the brown frog reproduction success was 45 to 90% of the control values. The volume of eggs laid per female inhabiting the contaminated area was reduced to 48% the control value. In the contaminated areas frogs developed more rapidly than in the control ones, and showed a 9-fold increase in morphological abnormalities (Pyastolova et al., 1996).

Reference Trout (freshwater fish)

(279) Acute dose information is inconsistent. Irradiation of rainbow trout 'eyed' embryos (*Salmo gairdnerii*) with doses up to 2.03 Gy (X-rays) had no detrimental effect on their subsequent fecundity, or on their growth over a two-year period (Welander et al., 1971). And irradiation of both parents of rainbow trout (*Salmo irrideus*) with 1.0 Gy of X-rays had no significant effect on cumulative mortality of eggs, but significantly increased the subsequent mortality of the fry when doses of 0.5 Gy or higher were administered (Foster et al., 1949). Irradiation 5 days post fertilisation of silver salmon (*Oncorhynchus kisutch*) with 20 Gy X-rays had no significant effect on hatching success (Bonham and Welander, 1961).

(280) After gamma irradiation of rainbow trout late in embryonic development with 6.0 or 8.0 Gy, more than 50% were sterile (Konno, 1980). Exposure of 4-month old rainbow trout fry to 1.0 and 5.0 Gy X-rays produced a dose-dependent increase in the incidence of necrotic cells in the developing testes, but the organ recovered and the irradiated fish tended to mature earlier than the controls. In females, both doses produced a significant decrease in ovary weight 4 and 6 months after exposure, but after 1.0 Gy ovary weight recovered to that of the control values within 9 months (Niiyama, 1957; Kobayashi and Mogami, 1958).

(281) Gamma irradiation of rainbow trout sperm (*Salmo gairdnerii*) with 0.25 or 0.5 Gy increased the fertilisation rate of eggs and the survival of the resulting embryos, but the number of abnormal embryos also increased (Newcombe and McGregor, 1972; 1973; McGregor and Newcombe, 1972a; 1972b).

(282) A large study on the effects of chronic irradiation involved Chinook and Coho salmon (*Oncorhyncus tsawytscha* and *O. kisutch*) embryos irradiated with gamma- rays through their 80 days of development, at dose rates of 5; 13; 28.8; 50.4; 100.8; 199.2; 170.4 and 504 mGy d^{-1}. Deleterious effects on the first generation individuals were consistently observed after dose rates above 50.4 mGy d^{-1} (reduced relative fecundity, ratio of egg weight to body weight of returning females). When adult males and females that had been irradiated at 5 mGy d^{-1} as embryos returned, they were mated together and, if not further exposed, the offspring generally outperformed the corresponding controls; if, however, the developing embryos from irradiated parents were given additional exposure at the same dose rate, there was some evidence of cumulative damage relative to the controls (Hershberger et al., 1978; Woodhead, 1984).

(283) Chinook salmon gamma irradiated with 5 mGy d^{-1} (total dose 0.41 Gy) showed retardation of gonadal differentiation (Bonham and Donaldson, 1972) but in salmon gamma irradiated at 170 µGy d^{-1} (0.04Gy), the amount of primary sex cells in embryos was 1.5-1.8 times higher than in the control (Kasatkina et al., 1973).

(284) In artificial incubated rainbow trout roe (*Salmo irideus Gibbans*) for up to 52 days, gamma irradiation produced an increase in early death of fore-larvae, although there was no clear dose-response relationship. Dose rates of 10.5 and 32 mGy d^{-1} (0.55 and 1.7 Gy) induced a 3-fold increase; while dose rates of 130 and 330 mGy d^{-1} (6.9 and 17.0 Gy) produced a 5 to 6-fold increase. After dose rates of 130 µGy d^{-1} (0.007 Gy) no statistical differences in the number of fish egg death before hatching compared with the control group were seen (Lyapin et al., 1971).

(285) Some other studies are of interest. Brown trout eggs (*Salmo trutta*) exposed to ^{90}Sr/^{90}Y at estimated dose rates of 690; 6,910 and 31,200 µGy d^{-1} showed significant variation in the hatch rate, with 696 and 6,720 µGy d^{-1} producing a significant decrease and increase in hatch rate relative to the control, respectively. At dose rates of 31,200 µGy d^{-1} fry were smaller than controls. The proportions of abnormal embryos were also variable with no significant differences from the controls at any dose rate assayed (Templeton, 1970; Brown and Templeton, 1964b). And in salmon exposed to beta radiation (^{144}Ce) at 1 mGy d^{-1} (total dose 0.23Gy), hatching started 2 to 3 days earlier than in the control and was more prolonged in time (Kasatkina et al, 1973).

(286) There are a lot of data on the effects of acute irradiation in a freshwater fish called the medaka. However, different laboratory strains of the medaka have been shown to have differing radiosensitivities in terms of effects on both fertility and fecundity (Egami et al., 1983). Some of the more interesting data are summarised below.

(287) Irradiation of reproductively active male and female medaka (*Oryzias latipes*) with 5 Gy increased the number of deformed and dead embryos resulting

from subsequent matings. The process of spermatogenesis was seen to be 3 to 4 times more radiosensitive than oocyte maturation, and took twice as long time to recover to normal levels. The loss of male fertility after exposure to 5 Gy has been shown to be due to the radiation-induced reduction in the numbers of the differentiating spermatogonia and the spermatocytes, and that the recovery is due to the compensating activation of the more radio-resistant primary spermatogonia. The sterility induced after 5 and 10 Gy was temporary and recovery was well established at 60 days after irradiation. Doses of 1 Gy caused temporary reduction in testes weight and slight effects on spermatogonial proliferation, and 2.5 Gy to either the male or female can temporarily reduce the hatchability of the eggs laid (Egami et al., 1983; Konno and Egami, 1966; Michibata, 1976; Egami, 1955; Egami et al., 1967; Egami and Hyodo-Taguchi, 1969).

(288) Irradiation of female medaka with 20 Gy altered the normal process of oocyte maturation (ovarian growth) when the fish are transferred from water at 10 °C where they are sexually inactive to water at 26 °C. A radiation dose of 10 Gy had no effects (Egami, 1955; Egami and Hyodo-Taguchi, 1965).

(289) Irradiation of medaka embryos 3 days after fertilisation with 20 Gy, interrupts the normal development of the gonads. Ovary appears to resume normal development in terms of cell numbers at about 5 days post-hatching, while the testes do not resume development (Shimada and Egami, 1982). Irradiation of the meiotic oocytes in 3-day old medaka fry with 10 Gy produces cell death and since there are not oogonia remaining in the earlier mitotic stage of development, no regeneration of the ovary is possible (Hamoguchi, 1976). Irradiation of the medaka ovary with 20 Gy X-ray, had no effect on the subsequent egg-laying activity of females, but the same dose to the whole body, or with just the ovary shielded, resulted in a substantial reduction in egg-laying from 5 days post-irradiation (Egami and Hyodo-Taguchi, 1965).

(290) Irradiation of female medaka followed by immediate mating with unirradiated males, produces a dose-dependent reduction in the hatching success (i.e. the increased induction of dominant lethal mutations) for eggs produced 1 - 4 days post-irradiation, i.e. there is no threshold for effect above 2.5 Gy of X-rays. For eggs produced 6 to 10 days post-irradiation, there was some evidence for a threshold extending up to 10 Gy and some recovery from the exposure. The mating of irradiated males with unirradiated females showed greater reductions (as compared with the response of irradiated females) in hatching success at a given dose for eggs fertilised with sperm irradiated as sperm or late spermatids; the early spermatids and spermatocytes showed somewhat lesser radiosensitivity (Egami et al, 1983; Shima and Shimada, 1991).

(291) Irradiation of medaka with gamma-rays at dose rates above 530 mGy d^{-1} during embryonic and early post-natal development, produced slight quantitative changes in the numbers of male and female germ cells over the period of irradiation, but in the surviving adults there were no significant differences, compared with the controls, in the gonadosomatic indices (GSI) for either the males or the females (Egami and Hama-Furukawa, 1981).

(292) In medaka, the subsequent fertility and fecundity of fish irradiated as embryos with tritium and gamma-rays has also been determined. When irradiated females were mated with unirradiated males, the total number of ovipositions and number of eggs per female decreased with increasing dose rate (i.e. the accumulated dose during embryogenesis) with 50% reductions at approx. 4 Gy (408 mGy d^{-1}) and 15 Gy (1,512 mGy d^{-1}) for beta and gamma irradiation, respectively (an implied RBE of aprox 3.8). For irradiated males mated with unirradiated females, the number of ovipositions was hardly affected, but the number of fertilised eggs declined with increasing dose rate; there was no significant difference in the degree of response between the beta and gamma radiation. Both radiation types produced a 50% reduction in reproductive capacity at approximately 5 Gy (504 mGy d^{-1}) (Etoh and Hyodo-Taguchi, 1983; Hyodo-Taguhi and Etoh, 1985;1986).

(293) Adult medaka males exposed to tritiated water, showed dose rate dependent reductions in the number of spermatogonia 1b at tritium dose-rates above 10.1 mGy d^{-1}, but recovery was under way by 30 days at dose rates less than 20.16 mGy d^{-1}, and essentially complete (i.e. not significantly different from the controls) at 120 days(Hyodo-Taguchi and Egami, 1977; Hyodo-Taguchi et al., 1982). In medaka embryos, exposure to tritiated water or external gamma-rays an average of 9.1 days (from 3 hours after fertilization to hatching) at dose rates between 432 and 1,896 mGy d^{-1}, had little effect on hatching rate. Larval survival to 1 month of age was, however, consistently and significantly decreased at dose rates above 840 mGy d^{-1} for tritium beta particles and at the highest dose rate for gamma radiation. The incidence of vertebral anomalies was increased for all dose rates gamma radiation assayed (>432 mGy d^{-1}) but only at dose rates > 840 mGy d^{-1} for tritium radiation (Hyodo-Taguchi and Etoh, 1993).

Reference Flatfish (marine fish)

(294) The only data available for marine flatfish are those relating to the plaice (Pleuronectes platessa). Male plaice gamma irradiated 6, 12 and 28.8 mGy d^{-1} for 73 days (total doses 1.1 to 2.1 Gy), showed no significant effects on the gonado-somatic index (GSI) at any dose rate assayed; the relative proportions of cells at the different stages of spermatogenesis were, however, significantly affected at all dose rates. A second, longer experiment (exposure during 197 days) showed that the testis weight, normalised for body weight, was significantly reduced at a dose rate of 5.76 mGy d^{-1} (total dose 1.1 Gy) and that there would have been some effect of irradiation at lower dose rates; the dose rate at which this effect would have become insignificant could not, however, be determined (Brown and Templeton, 1964; Templeton, 1970).

Reference Bee (insects)

(295) There are no data available for bees, but gamma irradiation of wasps with 0.576 Gy d^{-1} (total dose 2.5 Gy) produced an increase in the number of disintegrating oocytes in females. Dose rates of 1.15 Gy d^{-1} (total dose 5.0 Gy) further increased the number of disintegrating oocytes in females and decline in offspring number observed (Baldwin, 1968). And in moths, exposure of mature pupae or adult codling moths to 300 to 400 Gy completely sterilized the females and reduced the male fertility to less than 10% (Proverbs, 1982).

(296) One set of studies with other insects is of interest. In bark beetle population studies, after irradiation with more than 4,800 mGyd^{-1}, it was seen that adults attacked the trees and began excavating galleries but were killed before they could finish the preparation of the gallery for laying eggs; after exposure to 960 to 4,800 mGy d^{-1} the egg cavities were completed but there was no egg hatch, owing either to infertility or damage to the developing embryos; with dose rates of 720 to 960 mGy d^{-1} eggs hatched but there was total larval mortality; After 480 to 720 mGy d^{-1} there was low larval mortality but all the pupae died; after exposure to 240 to 480 mGy d^{-1} there was some pupal mortality and some adult emergence, and with dose rates lower than 240 mGy d^{-1} adult emergence was as high as, or higher than, normal (Smith, 1970).

Reference Crab (large marine crustaceans)

(297) There are no data available on crabs or any large crustaceans. With regard to acute doses, studies with amphipods (*Gammarus duebeni*) have shown that the long-term (20 weeks) fertility and fecundity of irradiated females mated to non irradiated males was affected after 2.2 Gy, but not after 1.5 Gy (Hoppenheit, 1972). Irradiation of calanoid copepods (*Diaptomus clavipes*) with 5 Gy significantly reduced the percentage hatch of egg clutches carried by irradiated ovigerous female. No effects were ween after exposure to doses of 1 Gy (Bardill et al., 1977).

(298) Many studies have been made with water fleas, which have a very different biology from crabs. In populations of water fleas (*D. pulex*) maintained with a constant per capita supply of food, irradiation at all dose rates assayed (> 5Gy d^{-1}) had a profound impact on the age-specific fertility rate, mx (the number of female offspring produced per female in a given age interval, x) was reduced at all ages and the reproductive life span was truncated. In total, these effects resulted in monotonic declines with increasing dose rates in both the population birth rate and the intrinsic rate of natural increase. At the highest dose rates (~ 17 Gy d^{-1}) the intrinsic rate of natural increase was around zero and the populations would have had no reserve reproductive capacity to survive additional environmental stress; the maximum dose rate that the populations could tolerate under these conditions was about 13 Gy d^{-1}. The cumulative dose at which the average female ceased reproduction, approximately 100 Gy, was independent of dose rate (Marshall, 1962).

(299) In populations of water fleas (*Daphnia pulex*) in competition (constant total food suply), after gamma irradiation at 4.32 Gy d^{-1} (98.2 Gy) fecundity appears to increase very slightly, although overall population size declined with increasing dose rate up to 4.3 2Gy d^{-1}. This was the maximum dose rate at which population appear to be able to maintain themselves indefinitely, and it was concluded that the slight increase in fecundity was due to the increased food available to each individual and that this partly balanced the radiation damage. In populations not competing for food, exposure to 5.28 Gy d^{-1} (120 Gy) reduction in fecundity was considered to be the cause of progressive reductions in population birth rate (Marshall, 1962; 1966). From these and other studies it has been shown that environmental variables, including chronic irradiation, interact with the demographic properties of the exposed population in a complex way, and that the other environmental stresses reduce the population tolerance to irradiation.

Reference Earthworm (annelids)

(300) With regard to acute doses, the hatchability of cocoons of *Eisenia foetida* irradiated at various developmental stages was affected after gamma radiation doses higher than 20 Gy. Exposure during early embryogenesis of earthworms to 20Gy reduced hatching success of embryos, whilst 20 Gy to mature adults affects hatchability of eggs laid post irradiation (Suzuki and Egami, 1983). Gamma-irradiation of *Eisenia foetida* with 5 to 20 Gy reduced testicular cells. The number of testicular cells recovered to control values in about 10 days after 5 and 10 Gy, whereas after 20 Gy the recovery occurred after 40 days or more (Suzuki and Egami, 1983).

(301) In another laboratory study, it was seen that external gamma irradiation with dose rates up to 204 mGy d^{-1} had no effects up to week 16 of age on: mean weight of worms; histopathology of worms; number of cocoons/tank. Dose rates of 213.6 mGy d^{-1} slightly increased the cumulative number of mortalities (1.6-fold) and reduced to 50% the control value the mean number of offspring per tank (Hingston et al., 2004).

(302) The continuous exposure (13 weeks) of *Eisenia fetida* to ^{60}Co over two generations has shown reduced reproductive capacity, the lowest dose rates producing a significant effect being 96 mGy d^{-1} and 264 mGy d^{-1} for the F1 and F2 generations respectively (Hertel-Aas et al 2000?).

(303) With regard to 'field' observations, population studies of soil invertebrates living in areas contaminated with several radionuclides (^{90}Sr, ^{137}Cs, ^{95}Zr-^{95}Nb, ^{106}Ru, ^{239}Pu and ^{226}Ra), showed reduced numbers of individuals at dose rates between 10.1 to 1,008 mGy d^{-1}. However, some effects were observed at dose rates of 2.4 mGy d^{-1}. The most sensitive organism observed was the common earthworm (Krivolutsky, 1987). Soil with elevated natural background levels of ^{226}Ra (24 to 48 µGy d^{-1}) contained less earthworms (*Eisenia nordenskioldi, Dendrobaena octaedra, Octolasium lacteum*) and insect larvae (*Dipterea, Elateridae*) than control areas. Earthworms, especially, proved sensitive to increased radium levels, possibly due to their close contact with soil. In the contaminated plots, earthworms were also smaller in size and showed reproductive disturbances; histological changes in the epithelium of integuments and mid-gut were also observed (Krivolutsky, 1980; Krivolutsky et al., 1982).

(304) Studies with marine polychaetes are also of interest. In marine polychaete worm *Ophryotrocha diadema*, which is hermaphroditic but not self-fertile, dose rates of 40.8; 76.8; 184.8 and 336 mGy d^{-1} gamma-rays were administered during 7 generations and the breeding performance recorded. Reproductive performance was affected in all generations. In generation 1, the number of egg sacs, eggs and larvae produced were only reduced at the highest dose rate, but in generations 2 and 3 the reductions were dose-rate-dependent; by generation 7 there was a clear tendency towards recovery at the 3 lower dose rates (the populations at the highest dose rate went to extinction in generation 3). The lowest dose rate to produce a significant effect, reduction of larvae in generation 2, was 76.8 mGy d^{-1} (decrease n° of egg sacs, eggs and larvae produced) (Knowles and Greenwood, 1994).

(305) Beta irradiation of marine polychaete worm (*Ophryotrocha diadema*) at 175.2 mGy d^{-1} reduced the number of eggs surviving to the larvae stage but did not

affect egg production. This is in contrast to previous reported effects for gamma radiation, where egg production is reduced but not the number becoming larvae (Knowles and Greenwood, 1997). In the marine polychaete worm (*Neanthes rarenaceodentata*) significant effects on reproduction in generation 1 at dose rates of 408 mGy d^{-1} were seen (reduced number of embryos). Dose rate of 76.8 mGy d^{-1} reduced the percentage of live embryos and increased the number of abnormal embryos in the broods (Harrison and Anderson, 1989).

Reference Pine tree (conifers)

(306) There have been many studies with pine trees. Irradiation during 9 years with a dose rate of about 36 mGy d^{-1} reduced the number of seeds in P*inus rigida* cones to 10% the control value. No cones with mature seed were found after accumulated doses greater than 74 Gy (Sparrow et al., 1965). Gamma irradiation with 0.3 to 22 Gy over 16 days in autumn, when the early stages of pollen (male gametes) formation takes place, produced damage in pine trees. In the spring following exposure, vegetative growth and the production of male cones occurred in trees that received doses lower than 12 Gy; but in the following year all the experimental trees receiving doses up to 22 Gy were productive (Tikhomirov et al., 1978).

(307) Gamma irradiation with doses higher than 3.0 Gy produced a significant reduction in fertility and viability of pollen produced by pine trees; viability recovered in the 2nd year and in the 3rd year pollen fertility and viability were not different to control values in those trees exposed to doses bellow 22Gy. Gamma doses higher than 0.7 Gy produced changes in size and pollen production rate in the male cones, that persisted in the 2nd year, but by 3rd year recovery to control values was apparent after dose of up to 12 Gy (Tikhomirov et al., 1978).

(308) A pine-birch forest (24-26 years-old trees) was irradiated with a gamma source of 1.0E+15 Bq, and studied during 6 years after the exposure. In the first vegetative season the mass of pine pollen was 47-28% of the control after 12 Gy and 5% of the control after 22 Gy. In the fifth vegetative period the mass of pine pollen was 25% of the control after 22 Gy (Tikhomirov and Fedotov, 1982). It has been determined that complete recovery to the pre-irradiation stage of a pine-birch forest after irradiation with doses of 25 Gy gamma radiation, would require more than 50 years (Spiridonov et al., 1989).

(309) In a pine forest (*Pinus sylvestris L*) contaminated after the Chernobyl accident (^{137}Cs, ^{90}Sr and hot particles), the average number of seeds in one cone decreased 2 and 3-fold after estimated total doses of 8 and 10Gy, respectively. Differences seen in 1988 were not statistically significant. Doses of 1.2 Gy slightly reduced the average number of seeds in one cone and had no effects on germination of seeds, while 8 Gy produced a 2.7–fold decrease in germination of seeds. Since 1988 differences were statistically unreliable. Doses below 0.1 Gy did not cause any visible damage to the trees. Of the absorbed dose to critical parts of trees, 90% was due to beta radiation from the deposited radionuclides and 10% to gamma radiation (Kozubov and Taskaev, 1994).

(310) As to be expected, most of the data on the effects of chronic irradiation in pine trees have been obtained from territories contaminated after the Chernobyl

accident. In a forest in the zone of minor damage of Chernobyl, coniferous trees showed disturbances in reproduction after cumulative doses from external gamma radiation of 0.5-1.2 Gy (the dose rate on October 1st 1986 was <4.8 mGy d^{-1}, and doses in needles <10 Gy) (UNSCEAR, 1996). In an experimental plot of pine forest (50 to 60 years old *Pinus sylvestris L.*) in the zone 1.2 to 1.5 km of the Chernobyl accident (^{137}Cs, ^{90}Sr and hot particles) exposure to 2.4 mGy d^{-1} from October 1986 led to a reduction of pollen viability (77 and 65% the control value in 1987 and 1988, respectively). After exposure to 5 mGy d^{-1} the pollen viability was 93% and 91% the control value in 1987 and 1988, respectively. In 1989 pollen viability it was slightly higher (1.13 times) than in control (Kozubov and Taskaev, 1994b).

(311) In the zone at 4 km from Chernobyl (again ^{137}Cs, ^{90}Sr and hot particles) in October 1987 about 5% of the seed-buds of *Pinus sylvestris L.* were showing signs of necrosis (cumulative doses of 0.7Gy at 700 mGy d^{-1}). In 1987, at the beginning of formation of female gametophytes, 30% of seed-buds were in a deteriorated state by the end of meiosis. In 1988, after accumulated doses of 3Gy (2,500 mGy d^{-1}) 20% of the seed-buds were showing signs of necrosis and, in the second year of growth, this had increased to 75% (Kozubov and Taskaev, 1994b).

(312) In the forest of the 120 km^2 zone from Chernobyl, pines showed suppressed reproductive ability after cumulative doses from external gamma radiation of 4 to 5 Gy (the dose rate on October 1st 1986 was 12 to 48 mGy d^{-1} with doses in needles 20 to 50 Gy) (UNSCEAR, 1996). In another area, Scotch pines (*Pinus sylvestris L.*) irradiated with 1.2 Gy at 2.6 mGy d^{-1} showed a 56% increase in numbers of branching pollen tubes. Exposure to 3.5 Gy at 840 µGy d^{-1} produced 53 % increase in numbers of branching pollen tubes. In 1990 and 1991, after pines receiving an accumulated dose of 8 or 25 Gy respectively, (2.6 mGy d^{-1}) pollen viability was 75% (Surso, 1993). And elsewhere as a result of the Chernobyl accident (again ^{137}Cs, ^{90}Sr and hot particles) cumulative doses of 15 Gy produced changes in the generative organs of *Pinus sylvestris L.*, manifested as decrease of male flowers, decrease in the numbers of seeds in cones and decrease of seed germination (Kalchenko and Fedotov, 2001).

Reference Grass (grasses)

(313) Grassland populations irradiated during 8 to 30 days with total doses of 80 to 100 Gy showed changes in productivity and reproduction, from which rapid recovery would be expected after the radiation stress has been removed. Dose range may be 2-4 times less for more acute exposures (UNSCEAR, 1996).

(314) The lowest dose level at which effects on these types of plants have been registered are on externally irradiated barley seedlings, in which an increase in the yield of aberrant cells was noticed after a dose of 0.01 Gy (Evseeva and Geraskin, 2000). A lack of a linear dose-response relationship has been observed for structural aberrations in the root meristem of barley seeds, in the dose range 0-10 Gy. In the region of dose independence (0.010 to 0.5 Gy and 1 to 10 Gy), the rate of aberrant cells significantly exceeded the spontaneous level. Similar findings were achieved for barley seedling systems in the dose range 0.05 to 0.3 Gy (Geras'kin et al, 1996; 1999).

(315) It is reported that the threshold for change diversity in old communities of grass in Colorado, USA was less than 480 mGy d^{-1} and the dose rate to produce 50%

reduction in the diversity of a plains short grass community declined with extended exposure to about 24 mGy d^{-1} (Woodwell and Oosting, 1965; Fraley and Whicker, 1971).

(316) Winter rye-weed community showed little change in composition below 960 mGy d^{-1} although the rye standing crop and reproductive capacity was reduced at dose rates of 240 mGy d^{-1} and the production of fertile rye seed was reduced at dose rates above 24 mGy d^{-1} (Holt and Bottino, 1972).

Reference Seaweed (macro-algae)

(317) There are no data on reproductive effects in seaweeds.

5.3.4 Chromosomal damage

Introduction

(318) In addition to the effects discussed above, a fourth category of interest is that of observable chromosomal damage that is dose related, even though the biological consequences of such cellular damage are not known. A number of data, for some types of Reference Animals and Plants, are available, as discussed below.

Reference Deer and Reference Rat (mammals)

(319) Experimental data for mammals have not been examined in detail here, but it is perhaps worth noting that a reciprocal translocation induction rate of 0.01 to 0.078 Gy^{-1} has been described for primates irradiated with doses of up to 1.0 Gy (Matsuda et al., 1985). And that in several species of rodents the induction rate of reciprocal translocations in stem cell spermatogonia has been determined to be 0.01 to 0.03 Gy^{-1} at total doses up to 3 Gy of low LET radiation (UNSCEAR, 1996). Irradiation of female mice with doses of 0.02 to 0.16 Gy produced no changes in the incidence of either aneuploidy or polyploidy.

Reference Duck and Reference Frog (birds and amphibians)

(320) No data available

Reference Trout and Reference Flatfish (fish)

(321) Irradiation of rainbow trout ova or sperm (*Salmo gairdnerii*) with 2.0 Gy X-rays produced a significant increase in the number of anomalous embryos surviving. It was suggested that this outcome was the consequence of dominant lethal mutations involving the loss of chromosomal material in the irradiated gametes and the resulting aneuploidy in the zygote. It was estimated that the doubling dose for the induction of dominant lethal mutations was about 0.26 Gy, considering a linear dose response relationship and taking into account the spontaneous incidence of anomalies in the control eggs (Newcombe and McGregor, 1967).

(322) X-irradiation of male and female guppy (*Poecilia reticulata*) with doses of 10 and 20 Gy confirmed the possibility of mutations at Y-linked genes for specific

body colour patterns (the colour pattern polymorphism complex). Exposure of the male partner in an inbred line to 5 Gy, and both partners to 10 Gy, showed on increase in anomalous individuals in the F1 and F2 generations - and indication of recessive mutations. In specific locus tests, the phenotypic segregation ratios in the F2 generation after exposure of wild-type parental generation stem cell spermatogonia or oogonia, or spermatozoa (to 10, 10 and 2 x 5 Gy of Xrays, respectively) were significantly altered from the control values (also significantly different from the theoretical Mendelian expectation). It was concluded that heterozygosity for radiation-induced recessive mutations in the wild-type gene constitution were having differential deleterious effects on the viability of the F2 offspring depending on the particular complement of test alleles present (Purdom and Woodhead, 1973; Schroder, 1969; Schroder, 1969d; Schroder and Holzberg, 1972; Purdom, 1966). A 10 Gy X-ray exposure of female and male guppy as neonates, produced mutagenic effects in F1 and F2 offspring on quantitative traits that are controlled by a polygenic system (number of vertebrae and relative body proportions) (Schroder, 1969; Schroder 1969b).

(323) X-irradiation of neonatal male guppies (stem cell spermatogonia) with 10 Gy increased the incidence of exchanges of chromosomal material between the X and Y chromosomes as revealed by the resultant appearance of specific, sex-linked, colour patterns in the offspring derived from breeding tests with unirradiated females. The later stages of differentiating spermatogonia did not show this response (Schroder, 1969c).

(324) Gamma irradiation of sperm medaka (*Oryzias latipes*) with 0.64 Gy produced a 10-fold increase in the incidence of specific locus mutations in relation to control values. The induction of specific locus mutations in the developing gametes of the male medaka was found to increase from spermatogonia through spermatids and be greatest in the mature sperm (Shima and Shimada, 1991).

(325) In gamma irradiated zebra fish (*Brachydanio rerio*), the specific locus mutations rate was estimated to be 4×10^{-3} Gy^{-1}. Quantifying the embryo viability in eggs fertilised with UV-inactivated sperm and then made homozygous through the application of a heat-shock, the recessive lethal mutation rate was estimated to be 4×10^{-1} Gy^{-1}. Later studies showed that specific locus and recessive lethal mutations could be induced in the pregonial cells in early cleaving embryos and recovered in subsequent offspring (Chakrabarti et al., 1983; Walker and Streisinger, 1983).

(326) It has previously been concluded that the data available show that the sensitivity of fish is similar to that shown by mice, and most often lower (Purdom and Woodhead, 1973; Schroder, 1969; Shima and Shimada, 1991; Purdom, 1966); there is only one example for specific locus mutations induced in maedaka sperm showing apparently greater sensitivity (Shima and Shimada, 1991).

Reference Bee (insects)

(327) Experiments considering mutation frequencies in females, percentage of parasite host cocoons, and frequencies of eye colour mutations have shown that gamma radiation of wasps with 2.5 Gy produced a 8-fold increase in mutation

frequencies (Baldwin, 1962; 1968; 1970). In wasp, after 4 days exposure to gamma radiation, a mutation rate of 90×10^{-6}/Gy/locus was estimated (Baldwin, 1970)

Reference Crab and Reference Earthworm (other invertebrates)

(328) No data available.

Reference Pine tree (conifers)

(329) In a pine-birch forest (trees 24 to 26 years-old) gamma irradiated with a 1.0E+15 Bq source, a 5-fold increase in the frequency of chromosomal aberrations was observed in the first years after irradiation with 12 Gy (autumn irradiation). A 17.6-fold increased was seen after spring irradiation with 5 Gy (Tikhomirov and Fedotov, 1982).

(330) In an area contaminated after the Chernobyl accident, exposure of *Pinus silvestris* to 0.5 Gy apparently caused detectable cytogenetic damage. Doses below 0.1 Gy did not cause any visible damage to the trees. Of the absorbed dose to critical parts of trees, 90% was due to beta radiation from the deposited radionuclides and 10% to gamma-rays. In another area, Scotch pines (*Pinus sylvestris L.*) gamma irradiated with 10 Gy showed a mutation frequency in isozyme locus of 6.1×10^{-3} per locus. The rate of natural mutagenesis of isozyme locus is $(6.0\text{-}6.8) \times 10^{-4}$ mutations per gene (Kalchenko et al., 1995).

Reference Wild Grass (grasses)

(331) Studies using the pollen test have shown a linear dose-response relationship after acute gamma-irradiation of homozygous non-waxy maize plants during meiosis at doses up to 1 Gy . Higher mutation rates per unit dose were achieved at the lowest doses (0.03 to 0.25 Gy) compared with medium doses (>0.5 Gy). The study also confirmed that the induced mutations could be transferred to the subsequent diploid generation (Ehrenberg and Eriksson, 1966).

(332) Cultivars of the same species having similar nuclear volumes in interphase would be expected to display similar radiosensitivities. However, a comparative analysis of 172 cultivars of hexaploid wheat revealed a 2 to 5 fold variation in the radiosensitivity of the seeds as indicated by changes in morphometric characters in the seedlings. It was shown that increased radiosensitivity correlated with the degree of biochemical polymorphism i.e. the differentiation of the genome, in the cultivars (Sarapultsev ad Geraskin, 1993).

(333) Barley plants, internally irradiated with 90Sr showed that the lower daily doses 0.0001 to 0.0011 Gy (100 to 1,100 μGy d^{-1}) gave higher rates of mutational events (pollen test) per dose unit than the highest daily doses (>0.0025 Gy; 2,500 μGy d^{-1}). The lowest dose rate producing mutation rates significantly higher than the spontaneous rate was 300 μGy d^{-1}, corresponding to a total dose between 0.001 and 0.01Gy (Ehrenberg and Eriksson, 1966). And wheat grown for one generation on contaminated soil (27 MBq per m²) near Chernobyl zone showed an increase in microsatellite mutations as compared with wheat grown on uncontaminated soil. The mutation rate was estimated to increase from 1.03×10^{-3} to 6.63×10^{-3} per locus over

one generation. The total dose to the wheat plants was estimated to be about 0.3 Gy (Kovalchuk et al., 2000).

Reference Brown seaweed (macro-algae)

(334) Study of nuclear division in the spermatogenous filaments of treated antheridia of *Nitella flagelliformis* (green filamentous algae) revealed chromosome fragments at both metaphase and anaphase, formation of rings, anaphase bridges and, rarely, of micronuclei. A linear increase in the number of cells showing chromosomal aberrations with increasing dose ranging from 1 to 5 Gy was observed (Sarma and Singh, 1974).

5.4 Discussion

(335) As stated in the introduction, there are many data to refer to, but little guidance with respect to their reliability, consistency, interpretability, or utility. There are many data on some types of organisms - such as small mammals, some fish, and on pine trees – that have been gathered for various reasons, in various ways, for many years. But for some types of animals, such as birds, there appears to be a surprising lack of data. And again, for some types of both animals and plants, the information covers a wide range of dose rates, and thus both 'chronic' and 'acute' exposures, but in other cases the data would appear to be largely derived from the latter type of experiment, and thus of limited value in most environmental situations. Reviews of data are also often difficult to use because the original experimental data are usually reported for dose rates averaged over periods of hours, days, or years. Summaries of the data are therefore often arbitrarily organised into such bands of dose rates. They are also often reviewed collectively with respect to their environment, and thus primarily with respect to their pathways of exposure (such as aquatic) rather than with respect to the effects of radiation in relation to their phylogeny, or to some specific feature of their biology.

(336) Reviewers have also, explicitly and understandably, usually omitted the large amount of data that have been derived from laboratory studies of mammals for the purposes of improving the radiological protection of humans, particularly with regard to stochastic effects. As a consequence, none of this data base has been examined with respect to the potential risk and consequences for the same species in the wild. Such an evaluation needs to be done.

(337) So one is thus, in effect, dealing with a miscellany of isolated pieces of information. Nevertheless, some broad conclusions may be drawn. For the higher vertebrates, there is little difference in response across a range of dose rates for mammals, and this may well also apply to birds (because they are also 'warm blooded' vertebrates with high metabolic rates), but there are insufficient data to draw firm conclusions. For the lower vertebrates, generalisations are difficult because their lower metabolic rates – that are also temperature dependent – are seldom taken into account in studies on radiation effects. The inference is, however, that if allowances for such differences were made (essentially by allowing more time for the effects to appear, and not by drawing comparisons over such short time periods as 30 days, which are only relevant for mammals) then the differences between higher and lower vertebrates may be less than it appears to be.

(338) For invertebrates, however, it is difficult to generalise across different animal types at any dose rates, except to note that they often appear to be more resistant than vertebrates. Why this should be the case is unclear: there is no theoretical concept to draw upon. A generalisation that can be drawn, however, is that eggs and larvae have usually been found to be more radiosensitive, in terms of mortality, than adults; thus in terms of assessing the potential for overall reduced reproductive success, such factors (and thus exposure situations relevant to such stages in the life cycle) are important.

(339) With regard to trees, it is again necessary to note the very long time scales involved with respect to relating exposure to dose, and dose to effect. Equally, however, it is disappointing that so few controlled radiation experiments have been made; although an issue of importance here, and one which has already arisen in Chapter 4, is that of accurately assessing the dose received, what tissue received the dose, and whether it was above or below ground. Indeed, there seems to be no clear understanding as to what the basic differences are (if any) between the effects of radiation on plants and animals at a cellular level, nor is there any clear understanding of how effects at a cellular level in plants are subsequently manifested at the level of tissues, or groups of tissues, for the whole plant.

(340) Finally, the question arises as to what can usefully be done with such information, allowing fully for its obvious limitations, and what can be done in a positive way? This issue is addressed in the next chapter, but all of the points made in the discussion above need constantly to be borne in mind.

6   ASSESSING EFFECTS IN TERMS OF DERIVED CONSIDERATION LEVELS

6.1 Introduction

(341) Some form of practical means is obviously required in order to make environmental management decisions and judgements based on our current knowledge of the effects of radiation on different types of animals and plants. But the task is clearly not easy, because although there is a reasonable amount of information

relating to various types of radiation effects, as discussed in the previous chapter, this is almost entirely in relation to relatively high dose rates and total doses. And because such effects are primarily of a non-stochastic nature (with the exception of data derived from small mammalian studies on cancer induction) it is difficult, in the absence of any form of 'sliding scale' against which to apply some form of 'risk related' criteria, to make assessments or judgements at lower dose rates.

(342) It has therefore been suggested that the only other useful comparator might be that of the natural background radiation dose rate normally experienced by such animals and plants (Pentreath, 1999, 2002a). Additional doses that were but fractions, or small multiples, of the normal background dose rates might therefore be unlikely to be the cause of any environmental managerial concern, particularly when considered against those multiples of background dose rates that were known to have specific effects; whereas dose rates that were very much higher, and in the region of known or expected effects, would need to be considered further, alongside other environmental information, within any particular environmental management framework. Thus, collectively, all of the derived information relevant to each type of animal and plant could then be simplified into bands of dose rates relevant to their individual background radiation dose rates in order to set out 'Derived Consideration Levels (DCLs)'. The purpose of the DCLs would be to serve as points of reference at which one should consider what is known about the effects of radiation on particular types of animals or plants alongside other relevant information: such as the type of exposure situation (planned, emergency, or existing); the size of the area affected; the status of the actual populations or ecosystems concerned; the fraction of a population exposed; the particular animals and plants of interest; and the driving environmental management needs required in order to satisfy the legal framework within which any management action was being taken, and so on. The results of such considerations might then well be that actual managerial action, or other decisions would be taken at dose rates in a band higher or lower than the DCL band, but the reasons for so doing would be clearly stated.

6.2 Natural background

(343) As an initial step, and using existing information, it is useful first to review briefly what is known about the natural background of the different Reference Animals and Plants. (Such data are usually given in terms of dose rate per day.) In the aquatic environment, dose rates are expected to be about 1 to 10 μGy day^{-1} for adult benthic fish (IAEA, 1976; Copplestone et al, 2001; Brown et al, 2004); and within a range of 2 to 14 μGy day^{-1} for adult benthic crustaceans (crab) (IAEA, 1976; Brown et al, 2004); and about 2 to 12 μGy day^{-1} for macrophytes (seaweeds), based on northern latitude data (Brown et al, 2003). Broadly similar values have also recently been calculated for European waters generally (Brown et al 2004), but for a different set of natural radionuclides, and for less precisely defined biota. For the freshwater environment, pelagic fish are considered to have background dose rates of about 0.5 to 18 μGy day^{-1} (Brown et al 2004).

(344) With regard to the terrestrial environment, external dose rates of about 2 μGy day^{-1} have been calculated for earthworms within the soil, and 0.6 μGy day^{-1} and 0.8 μGy day^{-1} for deer and mice respectively on the soil (Gomez-Ros et al, 2004). Internal dose rates vary very considerably from one organ to another, and from one type of

animal to another, making it difficult to draw any clear picture of total average body dose rates. Nevertheless it has been estimated that dose rates from ^{210}Po in some tissues in some mammals could be in the range of 40 to 80 µGy day^{-1} and as high as 0.2 to 7 mGy day^{-1} to the lungs of small mammals living in the soil from radon (Gomez-Ros et al, 2004). Terrestrial plants have a total dose rate of about 2 to 20 µGy day^{-1} (Copplestone et al, 2001).

6.3 Identifying Preliminary Derived Consideration Levels

(345) So, using these data, together with the incomplete and varied quality and relevance of the known radiation effects data discussed in Chapter 5, the following Tables (**Table 8 to 11**) provide an attempt to summarise all of the data in order to suggest a preliminary set of Derived Consideration Levels. In doing so, it cannot again be more strongly emphasised that the comments in the 'boxes' are an extreme over-simplification of existing data, and that the shading of the boxes to indicate the bands of Derived Consideration Levels are based on informed opinion and not on any statistically derived, or rigorously reviewed and defensible, analysis of all the available data. Revisions will no doubt be made on such a basis; in the meantime, this current exercise will hopefully help to stimulate such actions in the future. Nevertheless, one has to start somewhere, and the following tables and associated commentary need to be viewed in this light.

(346) The tables have been constructed to cover dose rate ranges in bands from less than 0.1 mGy d^{-1} to greater than 100 mGy d^{-1}. Dose rates greater than 1Gy d^{-1} are essentially of no environmental relevance, even in emergency situations, but the data in this range have nevertheless been included because they contain the LD$_{50}$ values for each type of animal or plant type; they are thus of comparative value and, again, provide a useful point of reference for the other effects' data.

(347) With regard to the 'higher' vertebrates, the data for the two mammals can be banded over several orders of magnitude, and conclusions drawn not only with respect to the nature of the effect, but as to whether it has been observed at low dose rates as a result of chronic exposure experiments. From these data it would appear that at dose rates in the region of 0.1 to 1 mGy d^{-1} there is a very low probability of certain effects occurring that could result in reduced reproductive success or morbidity; but, at the band below that range (0.01 to 0.1 mGy d^{-1}), such effects have not been observed. It would therefore seem reasonable to pause at that dose rate band (highlighted in **Table 8**) and consider other information, as appropriate. For birds, however, there is no information available in either of these bands. But from what is generally known about bird metabolism, longevity, and reproductive behaviour, it is reasonable to expect some form of 'harm' occasionally to occur at such levels of dose, and thus the dose rate band of 0.1 to 1 mGy d^{-1} would similarly serve as a sensible level of dose rate to stop and consider further.

Table 8. Preliminary Dose Consideration Levels (DCLs) (in yellow) for Reference Deer, Rat, and Duck

Dose rate (mGy d^{-1})	Reference Deer	Reference Rat	Reference Duck
>1000	Mortality from haemopoietic syndrome [1 to 8 Gy LD$_{50/30}$]	Mortality from haemopoietic syndrome in adults [6 to 10 Gy LD$_{50/30}$] and [1 Gy LD$_{50}$] for embryos	Mortality in adults [9 Gy LD$_{50/60}$]; and [9 to13Gy LD$_{50}$] for eggs.
100 - 1000	Reduction in lifespan due to various causes.	Reduction in lifespan due to various causes.	Potential lethal effects on hatchlings.
10 - 100	Increased morbidity. Possible reduced lifespan. Reduced reproductive success.	Increased morbidity. Possible reduced lifespan. Reduced reproductive success.	Increased morbidity.
1 - 10	Potential for reduced reproductive success due to sterility of some adult males.	Potential for reduced reproductive success due to reduced fertility in males and females.	Potential for reduced reproductive success due to reduced hatchling viability.
0.1 - 1	Very low probability of effects	Very low probability of effects	No information
0.01 – 0.1	No observed effects.	No observed effects.	No information
< 0.01	Natural background	Natural background	Natural background

(348) With regard to the 'lower', poikilothermic vertebrates (**Table 9**), the data are far less complete, and there is a particular problem with regard to the lack of data generally at dose rates of less than 1 mGy d^{-1}. Some interpolation is therefore necessary, and the shaded box has therefore been placed on a level lower for the frog, at 0.1 to 1 0.1 to 1 mGy d^{-1}, compared with 1 to 10 mGy d^{-1} for the two types of fish, largely reflecting the lack of data on physiological effects with respect to the amphibians generally.

Table 9. Preliminary Dose Consideration Levels (DCLs) (highlighted) for Reference Frog, Trout, and Flatfish

Dose rate (mGy d^{-1})	Reference Frog	Reference Trout	Reference Flatfish
>1000	Mortality in adults [0.8 to 7 Gy LD$_{50/200}$; 18 to 22Gy LD$_{50}$]; mortality in tadpoles [2.7 to 32 Gy LD$_{50}$]	Mortality in embryos [0.3 to19 Gy LD$_{50}$]	Mortality for hatchlings [1.5 Gy LD$_{50}$]; larvae [0.9 Gy LD$_{50}$] ; adults [10 to 55 Gy LD$_{50/30;}$ 10 to 22 LD$_{50/50}$]

Dose rate	Reference Frog	Reference Trout	Reference Flatfish
100-1000	Mortality in eggs [0.6 Gy LD$_{50/40}$]	Potential increased morbidity.	Some mortality expected in larvae and hatchlings.
10-100	Reduced reproductive success.	Some deleterious effects expected on young fish, e.g., reduction in resistance to infections. Reduced reproductive success.	Reduced reproductive success.
1-10	Reduced reproductive success due to damage to female reproductive system.	Possible reduced reproductive success due to deformities in some larvae and young fish and retardation of gonad development.	Possible reduced reproductive success due to reduced fertility in males.
0.1-1	No observed effects	No information	No information
0.01 – 0.1	No information.	No information	No information

< 0.01	Natural background	Natural background	Natural background

(349) For the invertebrates (**Table 10**), there is again a complete lack of data at the lower dose rates. But in view of the fact that broadly 'equivalent' effects seen in vertebrates appear to require another order of magnitude of dose rate in order to appear in the invertebrates, the shaded area has been placed at 10 to 100 mGy d^{-1} for all three types, even though the only positive information is that obtained on annelids.

Table 10. Preliminary Dose Consideration Levels (DCLs) (highlighted) for Reference Bee, Crab, and Earthworm

Dose rate (mGy d^{-1})	Reference Bee	Reference Crab	Reference Earthworm
>1000	Mortality in adults [20-	Mortality in young	Mortality in adults

	3000 Gy LD$_{50}$]; larvae [1-2 Gy LD$_{50}$]	crabs [7 Gy/d for 50 days kills 95%] and adults [100-400 Gy LD$_{50/40}$]	[680 Gy LD$_{50/30}$]

100-1000	Possible reduced reproductive success due to effects on gonads and pupal mortality.	Possible effects on growth rates	Increased mortality. Reduced reproductive success
10-100	No information	No information	Reduced reproductive success after prolonged exposure.
1-10	No information	No information	No information
0.1-1	No information	No information	No information
0.01- 0.1	No information	No information	No information

<0.01	**Natural background**	**Natural background**	**Natural background**

(350) For plants (and seaweeds) (**Table 11**), the data are clearly constrained by the inequality of the data across the three types. The best data sets are for pine trees, which would suggest that exposure at dose rates in the region of 1 to 10 mGy d^{-1} could be of concern, but in view of the apparent differences in sensitivity at higher dose rates, and the potential for very long periods of exposure, it seems reasonable to set the shaded area in the 0.1 to 1 mGy d^{-1} zone.

(351) For grasses, some degree of reduced reproductive success could occur at dose rates in a band higher than that for pine trees, and the shaded zone has been set at the 1 to 10 mGy d^{-1} zone. For seaweeds, there is essentially no useful information at dose rates that might be expected in environmental situations and, although one might expect that grasses would be more radiosensitive than seaweeds, or algae in general, the same area has been shaded.

Table 11. Preliminary Dose Consideration Levels (DCLs) (highlighted) for Reference Pine tree, Wild grass, and Brown seaweed

Dose rate (mGy d^{-1})	Reference Pine tree	Reference Wild grass	Reference Brown seaweed
>1000	Mortality	Mortality [16-22 Gy LD$_{50}$].	Deleterious effects expected at very high

		Reduced reproductive success [4-16 Gy YD_{50}].	dose rates
100-1000	Mortality of some trees after prolonged exposure. [46 Gy LD_{50} at 130 mGy d^{-1}]	Reduced reproductive capacity	No information*
10-100	Mortality of some trees after very long exposure [76 Gy LD_{50} at ~30 mGy d^{-1} for ten years] Growth defects. Reduced reproductive success.	Reduced reproductive capacity	No information
1-10	Morbidity as expressed through anatomical and morphological damage. Prolonged exposure leads to reduced reproductive success.	No information	No information
0.1-1	No information	No information	No information
0.01 – 0.1	No information	No information	No information
<0.01	**Natural background**	**Natural background**	**Natural background**

*With respect to C5, no information was available at time of report

6.4 Matters for Consideration

(352) Notwithstanding the limitations of the data, it would nevertheless appear to be useful to set out the information in this way, and to do so relative to background dose rates. With regard to the banding of dose rates to generate preliminary Derived Consideration Levels (DCLs), however, the following points need to be restated.

(353) The Derived Consideration Levels are NOT intended to be regarded as dose limits, or 'substitute' values for them. They are zones of dose rates at which, with respect to the Reference Animals or Plants, or types similar to them, a more considered level of evaluation of the situation would be warranted. It does not imply that higher dose rates would be environmentally damaging, nor that lower dose rates were in some way 'safe' or non-damaging. But they are dose rates that could be used in any management action or decision-making process, in terms of being starting points from which further, auditable, information could be appended in order to justify or optimise any subsequent action that was taken.

(354) The factors that might be 'considered' could include the following – given here as examples, and not intended to serve as a definitive list.

- The nature of the exposure situation – normal, existing or emergency.
- The area or zone (km^2) within which such dose rates were assessed to occur.
- The time period predicted for such dose rates to obtain.
- The specific managerial interest, such as fisheries management, agriculture, nature conservation, habitat protection, and so on.
- The principal reason for the assessment being made, such as the need to comply with some form of existing legislation.
- The presence, or expected presence, of additional sources of chemicals, or other forms of environmental stress, in the same area.
- Whether or not the assessment related to actual species, or simply to generalised animal or plant types.
- The degree of precaution considered necessary, for various purposes.

(355) Virtually every exposure situation is likely to be unique, and thus a combination of any or all of the above factors would possibly lead to the selection of values different from those highlighted in the Tables; but the reasons for such selections should also be clearly stated.

(356) One aspect that also needs to be mentioned is the question of whether or not it would be sensible to combine one or more of the values in order to simplify the tables. This is considered not to be appropriate for three reasons. First, it would involve mixing up information on what effects have been looked for, but not observed, with those effects that have not been looked for, and thus it is not known if they are observable or not. Secondly, for some applications (such as fisheries management) it is better (or necessary) to be able to refer to the type of organism that is directly relevant (such as a flatfish or a crab). And in other cases (such as the protection of a wetland habitat) it may again be more useful or necessary to refer to a specific sub set of 'wetland types'. And thirdly, the impression should not be given that any particular Reference Animal or Plant type is intended to serve as a 'sentinel' type for any of the others.

(357) Another issue that is likely to arise more than any other is the extent to which one should select lower bands of dose rate in order to be precautionary, for one reason or another. The reasons could be because of the current lack of data at lower dose rates for many of the RAP types, or because of other uncertainties in the data or their derivation. Equally, a degree of precaution may be considerd necessary because of the importance of the site or habitat, or the importance of the actual species present or likely to be present. Such precautionary-based decisions are expected. But if such precautionary measures are to be considered, and included, in the decision making process (with regard to what the actual dose rate bandings should be, in comparison with the DCL levels cited here), then they should also be separately specified.

(358) Care should also be taken in using such values to make decisions with regard to populations of animals or plants, as opposed to small groups of individuals, for all of the reasons discussed in Chapter 2. Because although it is reasonable to suppose that any impacts at the population level will be a consequence of responses to irradiation that occur in the constituent individuals, there has, as yet, been little analysis of the links between these two end points (Woodhead, 2005). Thus, it is not possible to say with any confidence that measures to protect individual organisms would also, necessarily, protect the population. Population modelling approaches

demonstrate that the linkage between radiation effects in the individuals and in the population is very complex, and dependent on factors other than the radiation doses and the dose-response relationships. Future efforts to develop measures to protect the animate environment from the incremental radiation exposures arising from human activities will therefore need to consider both the individual and the population to ensure that the intended objective is achieved.

6.5 Conclusions

(359) This first step towards the derivation of Derived Consideration Levels is essentially that – a first step. Hopefully it will, even in the short term, provide some stimulus to explore how such DCLs could be used in different exposure situations, and for different managerial purposes. Hopefully they will also stimulate the required effort to fill in some of the glaring gaps in our knowledge, if only in an elementary way, with regard to the effects of radiation on these types of animals and plants. But at least, as new knowledge is gathered, and experience gained in its application, then it can be added to an existing framework.

(360) There are, however, a number of other issues relating to the application of this approach to different situations, and these are briefly addressed in the next chapter.

7   APPLICATIONS AND EXTRAPOLATIONS

7.1 Introduction

(361) As indicated at the end of the previous chapter, the need to make evaluations of the impact of radiation on the environment, now or in the future, will arise for reasons that stem from any or all of the various environmental management requirements discussed in Section 2.2, but probably particularly in relation to

pollution control and nature conservation, or under the general guise of what might be termed an *environmental impact assessment*. The practical consequence, however, is that this need may now be considered to include any of a number of objectives, each of which might need to be expressed, and deemed 'acceptable' or otherwise, in different ways (Pentreath, 2003). These might include the following: assurance of the public or their politicians, at national or international level, of the likely environmental impact of any actual or proposed practices, and demonstration of the ability to deal with any consequences in the event of accidents or emergencies; compliance with the spirit or the letter of trans-national general pollution or wildlife-protection obligations; compliance with national pollution control licensing requirements relating to particular industrial practices or to specific sites or areas; or compliance with the requirements of specific national wildlife and habitat protection legislation.

(362) Common to all of them, however, is the process of having to assess the situation, to analyse its component parts and then, if necessary, consider the various options for managing whatever situations may arise. This is particularly important when attempting to understand the purpose of the environmental evaluation, because each component may need to make use of completely different approaches and interpretations. But what should be common to both assessment and management is the basic scientific understanding, plus the means of expressing and using the relevant scientific information. This has been the basis of success for the radiological protection of humans, and therefore needs to be carefully considered with respect to protection of the environment generally.

(363) For the purpose of pollution control, the above protection objectives may, in turn, require the explicit demonstration of: the avoidance or minimisation generally of harm to the environment; or the ability to deal with the environment that is already deemed to have been harmed.

(364) And, for the purpose of nature conservation, the above protection objectives may, in turn, require assessments to be made of: the likelihood of harm to individuals of particular species; potential or actual effects on populations of one or more species, in terms of population integrity and viability (this would also apply to environmental exploitation); potential or actual effects on the principal (or majority) components of a specific habitat, or at a specific place; or potential or actual effects at ecosystem level, within a local area or more generally, but without specific reference or preference to any particular faunal or floral type. There may even be other considerations, as where the mere presence of radionuclides, "contaminating" an area, may be of concern to certain individuals or sectors of the public for ethical, moral, or social reasons (IAEA, 2002).

(365) In order to make an evaluation of the effects of radiation on the environment itself with respect to any particular situation or practice, there are clearly several factors to consider, including the radionuclides of interest, their sources, their rates of introduction, and their environmental distribution and fate. This basic information is also required in order to protect the general public. Many numerical models therefore already exist that can be applied to different practices, situations, and ecosystems. However, for environmental protection and other information is necessary, such as the

potential exposure to radiation of the fauna and flora within the area of radionuclide distribution; plus the likely consequences for them, in terms of radiation effects. Of these two, addressing the former should not be too difficult, the nature of the problem having much in common with the environmental information needed for human radiation protection. The latter, however, is more difficult, and the term 'consequences' is far more open-ended than it is for human protection; many other factors therefore need to be considered, not least the original objectives of the assessment.

(366) The consequences may need to be evaluated with respect to individual animals and plants, depending on the legal framework within which action is being considered, but undoubtedly the major requirement will be the need to make evaluations at the population or ecosystem level. Radiation effects on higher levels of biological organisation (e.g., populations and ecosystems) occur only if individual organisms are affected, and radiation effects' data have generally been obtained for individuals rather than for higher levels of organisation. In the natural environment the situation can become very complex because of the interactions between each individual and its surrounding ecosystem. The effects can also be modified by the presence of other environmental stressors or by combined effects related to the presence of other pollutants, and by interactions between different trophic levels. Because radiation effects at the population level – or higher – are mediated via effects on individuals of that population, it therefore seems appropriate to focus on radiation effects on the individual for the purpose of developing a framework of radiological assessment that can be generally applied to environmental issues. This approach is consistent with many of the existing assessment methods for non-radiological environmental contaminants. It is also essential in order to consider how effects such as reduced reproductive success can be interpreted in the context of the normal biology of different types of plants and animals. Even the concept of what constitutes a 'population' will differ amongst the various 'types' of Reference Animals and Plants.

(367) It also has to be recognised that, in many cases, much more specific data on local animals and plants may already be available with respect to specific sites; or that data are often required for organisms that are more relevant in other respects, such as their ecological importance at a local level, but the data sets will always be limited because of the sheer impracticality of ever deriving some of the required information – such as that relating to radiation effects. Such organisms might therefore be regarded as *secondary reference animals and plants*, provided that they could be shown to relate in some way (for example by using the same sort of dosimetry models) to one or more of the ICRP set of Reference Animals and Plants. There are therefore a number of issues relating to our ability to extrapolate from limited data bases and frameworks in order to deliver environmental protection in a wider and practical sense.

(368) There are thus three aspects of extrapolation and interpolation to other animal and plant types that need to be considered. One is that of differences in biology, in that the animals or plant are considerably different from those represented by the Reference Animals and Plants (by definition generalised to the taxonomic level of Family); the second is that of differences in dosimetry; and the third is that relating to differences in radiation effects.

7.2 Differences in Biology

(369) As has been noted at the beginning of this report, the Reference Animals and Plants have to be considered merely as points of reference. It is simply not possible to cater for all of the types in which interest may be expressed, and there will clearly be situations in which the biotic objects of interest will be different from those of the RAPs. Such difference could be relatively small, such as differences in the time span of a particular stage in the life cycle, or in overall life span. In other cases, differences in biology could make large differences to estimates of exposure to certain radionuclides via different pathways. Reference to the background information in **Appendix A** may therefore be of some value in considering to what extent the application of this approach to other types of animals and plants would make a significant difference, simply on the basis of differences in their basic biology. One way in which differences from the set of twelve RAPs would obviously make a difference, however, is that of shape and size, and thus with regard to estimates of dose received.

7.3 Differences in Radiation Dosimetry

(370) These issues are more easily addressed. There are several aspects of the extrapolation and interpolation of the basic dosimetry models used here for the Reference Animals and Plants to other biota, including shape, size, and location. With regard to shape, matters have been greatly simplified by the use of solid spheres and ellipsoids, although it is recognised that such shapes may not readily extrapolate to some forms of organism. Nevertheless, some flexibility is possible. Several variations on such shapes can be envisaged, as set out in **Table 12.**

(371) And in view of the uncertainties in all of the aspects of estimating exposure to radionuclides, both internally and externally, it is first of all useful to have some form of approximate indication of the effects of size and shape on the absorption of alpha, beta, and gamma radiation.

Table 12. Relative shapes and proportions of spheres, ovoids and ellipsoids (h_0: mean chord length of a sphere h: mean chord length of an ellipsoid)

Shape		Proportions	h/h_0
Sphere		[1:1:1]	1.0
Ovoid	prolate	[1:1:10]	0.59
		[1:1:50]	0.35
	oblate	[1:10:10]	0.41
		[1:50:50]	0.15

Ellipsoid	[1:2:3]	0.85
	[1:3:5]	0.70
	[1:5:10]	0.51
	[1:10:50]	0.25

(372) With regard to α particles, the range in tissue is 16 to 130 μm for energies in the range of 3 to 10 MeV. The dependence of the absorbed fraction of α-particles on the radius of spherical organisms and the α-energy is summarised in **Table 13**. The calculations are made with the EDEN model (Beaugelin-Seiller, 2006). For a *radius* of 1 mm, which is the size of the flatfish fish egg (the smallest Reference Animal and Plant), the absorbed fraction is about 1 for α-energies around 5 MeV. This energy is typical for many important α-emitters as e.g. ^{239}Pu, $^{234/238}$U and ^{226}Ra. For all other reference animals and plants, the absorbed fraction for α-emitters is 1. Thus doses from *external* exposure to α-particles are essentially negligible.

Table 13. Absorbed fractions for α-particles for spheres in relation to radius and energy of the α -particles (Beaugelin-Seiller, 2006)

Energy (MeV)	Absorbed fraction in sphere of radius:				
	1 *μm*	10 *μm*	100 *μm*	1 *mm*	10 *mm*
1	0.0328	0.41	0.94	0.99	1
3	0.0168	0.17	0.85	0.99	1
4	0.0103	0.1	0.78	0.98	1
4.5	0.0084	0.084	0.74	0.97	1
5	0.007	0.07	0.69	0.97	1
5.5	0.006	0.06	0.64	0.96	1
6	0.0052	0.052	0.58	0.96	1
8	0.0031	0.031	0.37	0.93	1
10	0.0021	0.021	0.21	0.89	0.99

(373) With regard to photons and electrons incorporated into the body, there are slight differences between spheres and other shapes. Absorbed fractions (AF) of electrons and photons in relation to mass and energy in spheres is illustrated in **Figures 6** and **7.**

Figure 6. Absorbed fractions for electrons in relation to mass and energy for spheres.

Electron sources in spheres
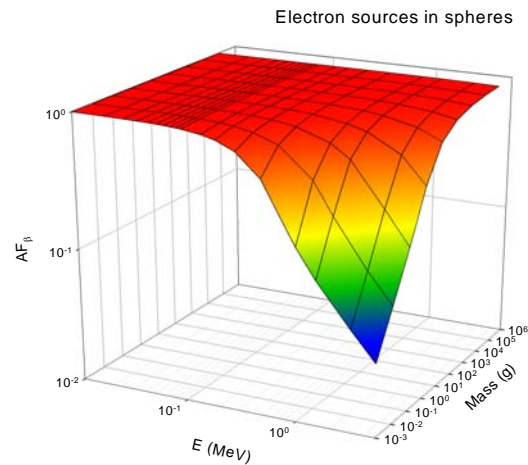
Figure 7. Absorbed fractions for photons in relation to mass and energy for spheres.

Photon sources in spheres
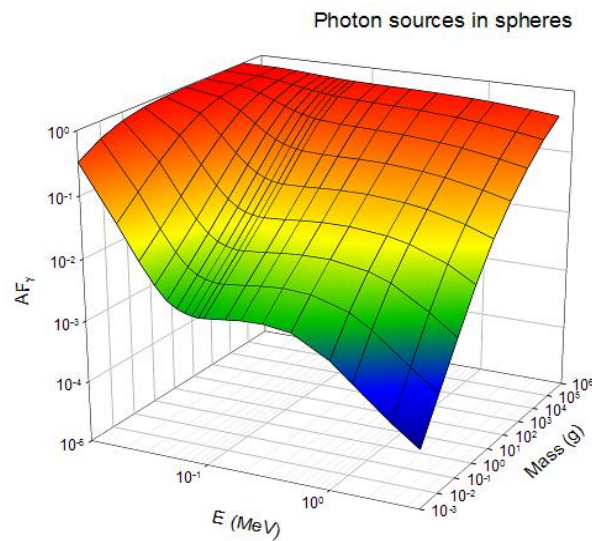
(374) Absorbed fractions for non-spherical shapes are summarised in **Figures 8 and 9** as a function of the initial electron or photon energy. For electron energies below 100 keV, the absorbed fraction is nearly 1, even for very small organisms. The range of electrons in living tissue increases from 160 μm for 100 keV electrons to 5 mm for 1 MeV electrons. The absorbed fraction is thus close to unity if the diameter of the target is well above the range of the electron. The absorbed fraction of electrons is considerably smaller than 0.5 only in cases where the targets are very small and the energies are high.

Figure 8. Absorbed fractions for non-spherical organisms (electrons) (h₀: mean chord length of a sphere h: mean chord length of an ellipsoid)
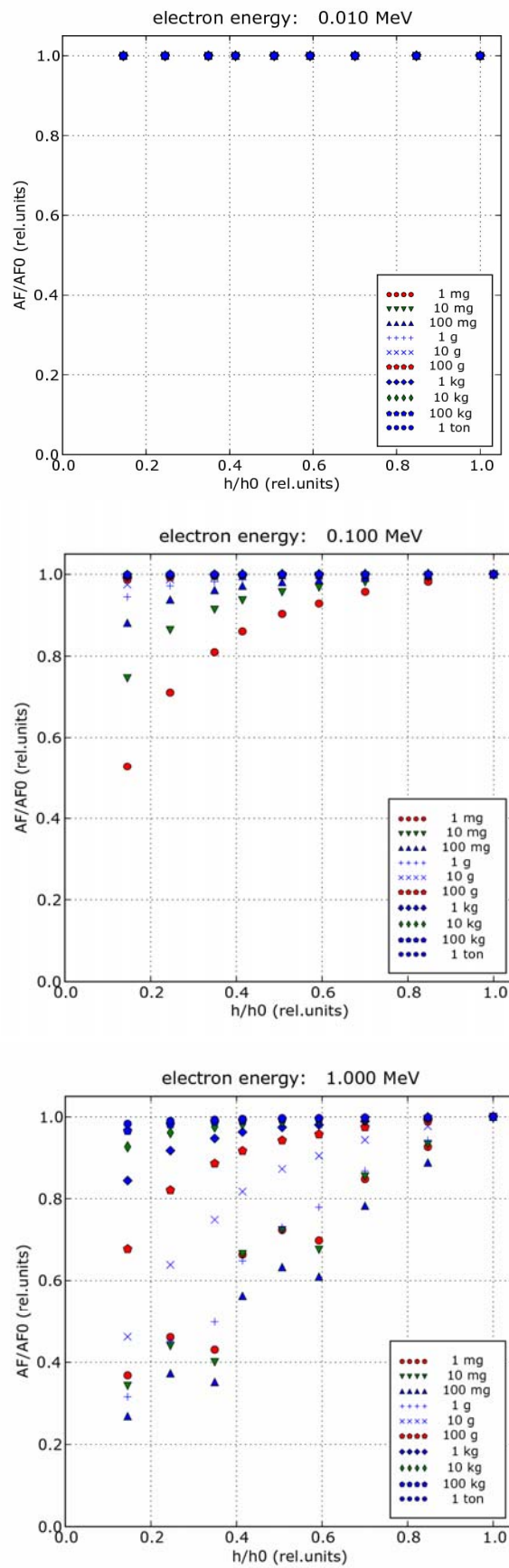
Figure 9. Absorbed fractions for non-spherical organisms (photons) (h_0: mean chord length of a sphere h: mean chord length of an ellipsoid)

photon energy: 0.010 MeV

photon energy: 0.100 MeV

photon energy: 1.000 MeV
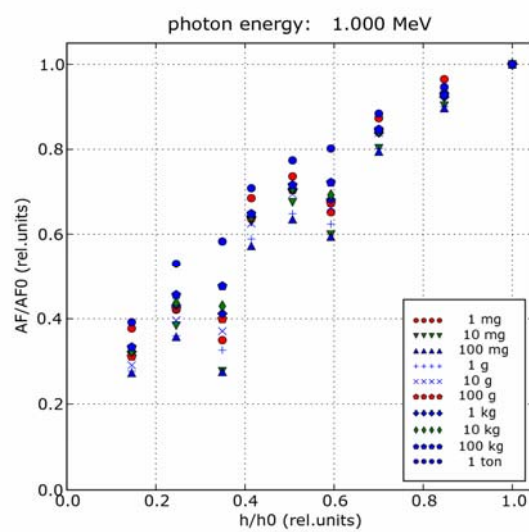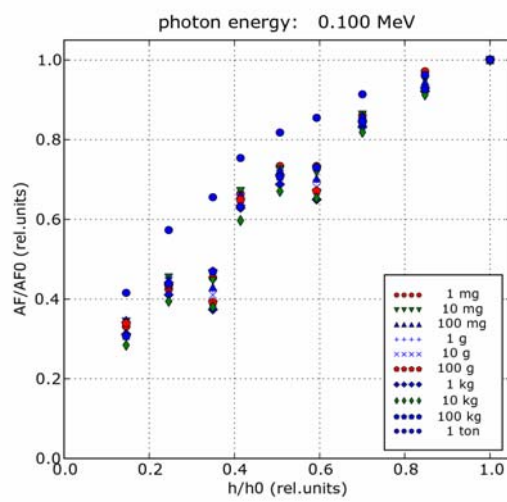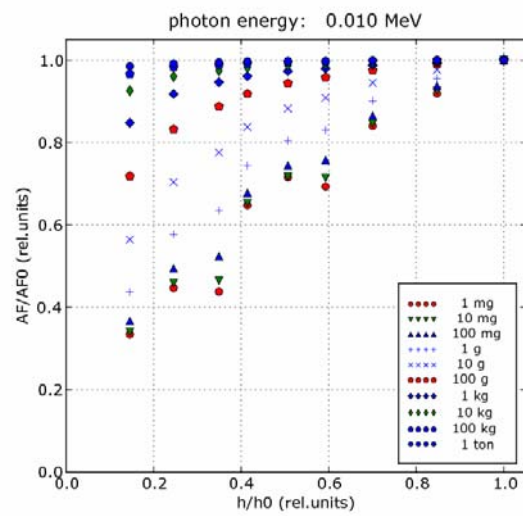
(375) With regard t   e mean free path
is considerably longer than the range of electrons, the absorbed fractions cover a wide
range (several orders of magnitude) from nearly 1 for low energy γ-radiation and large
organisms to less than 0.001 for small organisms and high photon energies. The

absorbed fraction is a non-linear function of target size and energy. The main processes that define the shape of the absorption factors are the Compton effect, the photo-electric effect, and pair production; their contributions to absorption depend on the photon energy. As a result, the absorbed fractions decrease in the range from 20 to 100 keV by a factor of 10 to 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 greater for small sized organisms.

(376) Other factors relate to the relative position of the source and the organism. This is particularly important in relation to organisms within or on soil or sediment contaminated to different depths. With regard to the location of the radiation source, dose conversion coefficients for low-energy photons to animals living on the soil are low, because small soil layers are sufficient to attenuate the photons completely. More complicated are the relationships with the thickness of the contaminated soil.

(377) With regard to photons, the size of the organism itself is not of great significance within contaminated soil, but the relative location of the source is. Thus, for example, **Figure 10** shows exposure rate as function of the photon energy and soil depth for a target with the shape of an earthworm. The upper 50 cm of the soil is assumed to be homogeneously contaminated. The maximum exposure rate is for an organism at a depth of 25 cm (i.e. in the middle of the layer), and the lowest is derived for organisms on the interface separating contaminated and uncontaminated layer (i.e. depths 0 and 50 cm). At these locations, the dose conversion coefficient is a factor of 2 lower compared with the centre of the contaminated layer, because the organisms are exposed to a 2π-geometry compared with a 4π-geometry within the contaminated layer.

(378) The difference in the exposure rate at a depth of 25 cm compared with a depth of 5 cm is only about 20 %. This small difference is due to the relatively short mean free path of photons in soil, which is about 0.2, 2 and 10 cm for 20 keV, 100-keV and 3 MeV photons, respectively.

(379) The relationship between energy and external exposures from photons to a planar source on the top of soil for on-soil organisms is more signicant. The dose conversion factor decreases from 10 to 100 keV by a factor of about 5 for small animals and by a factor of 2 for big animals (**Figure 11**). In this energy range, the mean free path of photons is much shorter, and once an interaction with matter occurs, a significant fraction of the energy is transferred. From 0.1 to 3 MeV, the absorbed dose per photon increases by approximately 2 orders of magnitude. The exposure decreases with increasing mass due to self-shielding, which is more pronounced for low energies.

Figure 10. Dose conversion factors for an earthworm for various depths in soil for mono-energetic photons for a uniformly contaminated source of the upper 50 cm of the soil (ρ= 1600 kg m^{-3}) (Pröhl, et al., 2003).
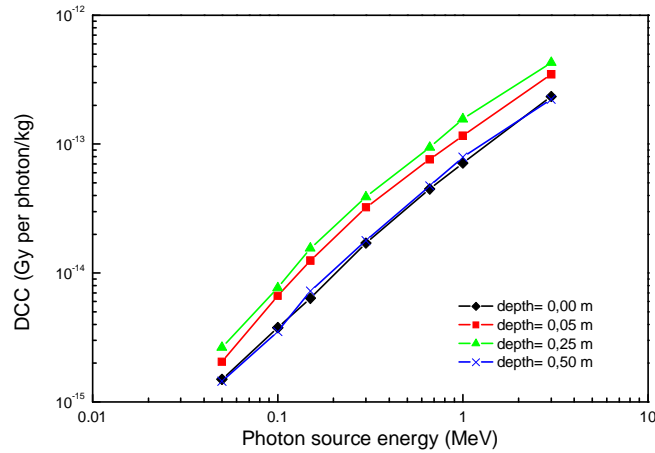
Figure 11. Dose conversion factors for external exposure for a reference rat (mass: 0.31 kg) and deer (mass: 245 kg) for mono-energetic photons emitted from a uniformly contaminated source of the upper 10 cm of the soil (ρ= 1600 kg m^{-3})
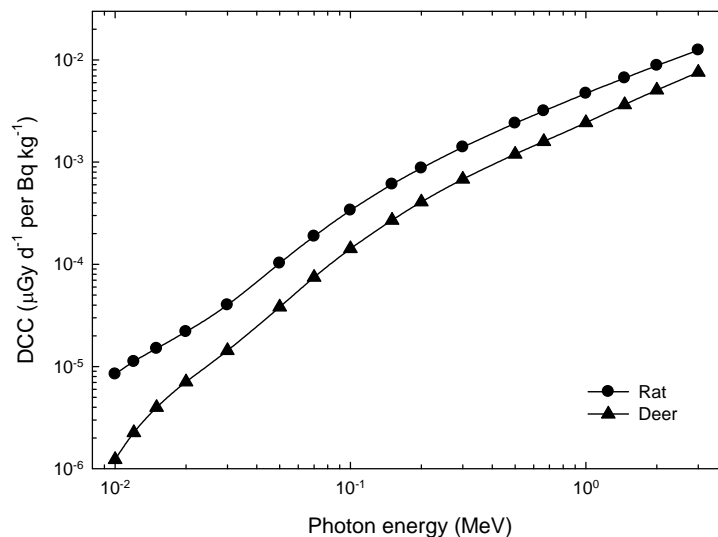
(380) The relationship between kerma in air at a height of 1 m and the thickness of a contaminated layer with a constant activity concentration is summarised in **Table 14**. For low-energy photons, radiation sources below a depth of 5 cm do not contribute to total kerma due to the self-shielding, whereas for 1 MeV photons about 50 % of kerma is due to activities below a depth of 5 cm.

Table 14. Relative air kerma at 1 m height above the air-ground interface from uniformly distributed mono-energetic sources at different energies (calculated according to DoE, 2002).

Source thickness (cm)	Relative air kerma for photon energy:			
	50 keV	0.1 MeV	0.5 MeV	1 MeV
1	0.55	0.29	0.19	0.17
5	0.97	0.77	0.57	0.51
15	1.00	1.00	0.90	0.84
Infinite	1.00	1.00	1.00	1.00

(381) All of these relationships illustrate that exposures to biota from external sources in the environment are the result of the interaction of size, energy, habitat and activity concentrations. Future ICRP work will examine some of these relationships with respect to the Reference Animals and Plants.

7.4 Differences in Radiation effects

(382) In contrast to dosimetry, it is not currently possible to provide recommendations as to how to perform extrapolations that have general applicability in relation to radiation effects, and thus each case has to be carefully considered on its own merits. Due to the relative paucity of information, the main cases for extrapolations, and challenges for methodological development, include the following. There are clearly issues with regard to extrapolating from high acute doses and dose rates of low LET γ- and X-rays to lower doses accumulated at lower dose rates. In the radiobiological and radioecological literature, the qualifiers "low-level", "chronic", "higher", "acute" and so on are often used without any definition. But a radiation exposure lasting several days may be effectively "chronic" for a short-lived organism, and yet effectively "acute" for a long-lived organism. Unfortunately, there are very few data that relate directly to the chronic, low-level irradiation conditions of relevance for animals and plants in the wild i.e. exposures at dose rates of 100 - 1000 μGy day^{-1} over the life span of the organisms, and the response endpoints most commonly assessed after acute, high dose, irradiation are not those that are relevant in such situations.

(383) Another issue is that of extrapolation from one organism to another. Although the information is limited, there is clear evidence that there are substantial variations in the radiosensitivity of organisms both within, and between taxonomic groups; this differential sensitivity also extends to different stages of the life cycle for any given organism. Possibly, extrapolation becomes easier the more closely related organisms are, and the more similar the effects endpoints considered for the relevant stage in the life cycle (Strand et al, 2003; Garnier –Laplace et al., 2004).

(384) And finally there is the issue of extrapolation from effects in the individual organism to possible impacts at the population and community levels. This will also, in many cases, involve the extrapolation from laboratory conditions (where most experimental information originates) to field conditions (where populations interact with the physical environment as well as with other organisms). Interactions at

community and ecosystem level can be particularly complex (Brechignac, 2003; Doi, 2004; Hinton and Brechignac, 2004). Nevertheless, it is necessary to start somewhere, and thus developing an understanding of the effects of radiation on a limited number of animals and plants, at the individual level, and exploring the consequences of such effects at *their* population levels, and amongst different populations, will clearly build into a broader understanding against which these wider issues can be assessed.

8. CONCLUSIONS

(385) As stated in the Introduction, the Commission has now broadened its scope in order to address the subject of environmental protection. In doing so, it acknowledges that, compared with human radiological protection, the more detailed objectives and management of environmental protection are often more complex and difficult to articulate. There is no simple or single universal definition of 'environmental protection', and the concept differs from country to country, and from one circumstance to another.

(386) The Commission also believes that its approach to environmental protection should be both commensurate with the overall level of risk, and compatible with other approaches being made to protect the environment from all other human impacts, particularly those arising from similar human activities. It acknowledges that in many circumstances, exposure to radiation is but one factor to consider, and therefore intended to provide high-level guidance and advice upon which regulators and operators may draw in order to demonstrate compliance, where necessary, with the wide range of international and national environmental legislation that already exists, or is likely to emerge in the near future.

(387) Such advice and guidance obviously has to be transparent, and have a common basis arising from our knowledge of exposure to radiation and its effects, set within some form of overall framework. It intended that this framework should therefore serve as a basis from which national and other bodies could develop, as necessary, more applied and specific numerical approaches to the assessment and management of risks to non-human species under different circumstances, and different exposure situations. Because of the vast complexity of the living environment, and the limited radiobiological and radioecological data bases relating to it, the Commission considered that, by setting out data for a limited number of Reference Animals and Plants, this would provide a vital component of the framework to gather and interpret data in order to provide more comprehensive advice in the future, whilst acknowledging that this information is still varied and fragmentary.

(388) This report, on the concept and use of Reference Animals and Plants, has therefore merely served as an introduction to the complex subject of environmental protection with regard to radiation. It introduces the rationale for selecting the Reference Animal and Plant types, and then gives emphasis to their biology, and to basic aspects of dosimetry and irradiation effects. Further publications will address in more detail such aspects as data bases for modelling exposure, possible refinements to dosimetry, and address such issues as RBE, and the application of the basic approach to different exposure situations.

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RAP Report

Appendix A

BIOLOGICAL BACKGROUND TO THE REFERENCE ANIMALS AND PLANTS

1. GENERAL INTRODUCTION TO BIOLOGICAL DESCRIPTIONS

1.1 Taxonomy

(1) Although the taxonomic framework for past and present life on Earth has always been somewhat flexible, and is still the subject of much debate, virtually all macroscopic forms of life can be simply divided into either animals or plants. Fungi are often considered separately, although they have also been – and sometimes still are – grouped with the plants. Single-celled organisms have also usually been considered separately (known traditionally as the Protista), as have bacteria, viruses, and similar micro-organisms. The modern trend is to assume a five-kingdom classification consisting of a super-kingdom called the Eukarya, which includes organisms whose cells have a distinct nucleus enveloped by a double membrane, plus double-membraned mitochondria, and thus includes the kingdoms Animalia, Plantae, Fungi, and Protoctisa; and the super-kingdom called the Prokarya (bacteria) in which these features are absent.

(2) Such variation and apparent uncertainty in the classification of animals and plants arises from the fact that it is based on a number of features - including morphological characteristics, physiological and biochemical features, DNA analyses, plus what is known or assumed about their evolutionary history - all of which is subject to reassessment and revision as new data arise. Animals are grouped into **Phyla**, on the basis that each Phylum has, more or less, the same 'body plan', and within each Phylum they are further grouped into **Classes**, then **Orders**, then **Families** (which share 'typical' traits and features), and then *Genera* as the number of features they have in common increases; finally, *Genera* are divided into *species*. There is no absolute definition as to what a species actually is, but it is usually taken as a description of individuals that (it is either known or expected) can only produce fertile offspring as a result of mating with similar individuals. In some cases, even further distinctions are made – into *sub-species*, or into races and varieties. Plants, too, are characterized in relation to features such as anatomy, embryo characteristics, and biochemistry, and are usually grouped into Divisions rather than Phyla.

(3) Features that differentiate either animals and plants at the level of Class or Order are often fairly detailed, and may be more a reflection of their evolutionary history than a factor that is relevant to the general biology of living species. Such groupings are also subject to considerable fluctuations and are the subject of academic study and debate. Thus there are no internationally accepted 'rules' on classification above Family (or 'Super Family') level, and this has therefore been suggested as the most suitable level of generalisation for Reference Animals and Plants.

(4) The total number of living species of animals and plants is by no means certain. Some 'new' species arise as a result of the re-classification of known animals and plants, others arise because they have only recently been 'discovered - which may simply relate to the fact that they have only recently been described scientifically. Nevertheless, the majority of 'large' organisms has probably been the subject of definitive description and classification. Thus it is considered that probably 99% of birds and 90% of other land vertebrates have already been described (Goto, 1982). It is generally assumed that there are certainly well over a million species of animals, and at least half that number of plants on Earth at present; although some recent estimates place the former as high as 3 to 4.5 million, and the latter as low as 0.35 million (Sauchanka, 1997). The generally accepted figure is about 1.75 million known species of living organisms. New species of animals and plants have been described in recent decades at the rate of about 10,000 per year, and approximately half of these are insects, the remainder consisting largely of a wide variety of other invertebrate animals (particularly from the marine environment), and plants.

(5) Animals usually have between 12 and 60 pairs (2n) of chromosomes, but there is considerable variation, even within Orders and Families (for example, in the Diptera (flies) 2n varies from 4 to 20; in the Lepidoptera (butterflies and moths) it varies from 14 to 446). The molecular biology of plants is much more variable than that of animals, with more frequent recombination and re-assortment of genes during meiosis. Nuclei, mitochondria, and plastids within plant cells, all have their distinct DNA systems. Polyploidy is common in plants (50% of all flowering plants), usually because a diploid (2n) plant, by irregular division, gives rise to a tetraploid (4n) plant. Then, as a result of pollination, triploid (3n) plants are formed. These are unable to produce gametes compatible with either 'parent', and thus the 2n and 4n forms often diverge because of the resultant genetic isolation (Collinson, 1988).

2. MAMMALS

2.1 General introduction

(6) Mammals are the most recently evolved class of vertebrate animals, and their current species diversity (about 4500) is less than that of birds, reptiles, or amphibians, and far less than that of fish. They do, however, probably have the greatest range of morphological diversity – from flying bats weighing only about 4g to 120t diving whales. All mammals have hair at least somewhere on their body, and they also lactate – feeding their young by producing milk.

(7) The major phylogenetic differences amongst living mammals relate to the manner by which they give birth and then nurture the very young. There are essentially three types: the monotremes, the marsupials, and the eutherians (or placental) mammals. Of these, the monotremes lay shell-covered eggs that are incubated and hatched outside the body. Living monotremes are restricted to Australia and New Guinea. Marsupials are generally characterised by the females' possession of an abdominal pouch – a marsupium – within which the young are carried; although in some species the 'pouch' consists merely of folds of skin around the mammae (mammary glands), and in others it only develops during the reproductive season. The young are first

nurtured internally within a yolk-sac placenta, but are born at a very early stage and subsequently nourished within the marsupium. Marsupials are native to Australia and America. All other living mammals are eutherian mammals, in that the young are nurtured internally, to varying degrees of development, by way of a placenta with villi that penetrate the uterine tissues of the female.

(8) The classification of mammals continues to be the subject of some debate. Sometimes the first two of these mammalian types are regarded as Sub-Classes or as Super-Orders, but in other cases the monotremes and marsupials are treated simply as Orders, alongside others (such as **Chiroptera** (bats) or **Pinnipedia** (seals)) which are placental mammals. If, however, one only considers the placental types then there are at least 18 Orders that, collectively, have a worldwide distribution.

(9) Apart from hair and mammae, all toothed mammals (some don't have teeth, such as baleen whales, and ant eaters) are diphyodont, in that the first set of teeth are replaced by a second set. Diets can be extremely wide ranging, and food energy is usually high in order to maintain relatively high and constant body temperatures, usually not much less than 38ºC. (Body temperatures are somewhat variable in marsupials, and can be highly irregular in monotremes.) Some species in arctic and temperate regions hibernate during cold periods, when metabolism is slowed and body temperatures fall.

(10) There are, in effect, three reference mammals for the purposes of ICRP: man; a large mammal, the deer; and a small mammal, the rat.

2.2 Deer

(13) Deer are hoofed (or 'ungulate') mammals, belonging to the Order Artiodactyla (the even-toed ungulates). All deer belong to the Family **Cervidae**, and they are the characteristic ungulates of the tundra, forest, and woodland zones of the entire Northern hemisphere as well as in areas south of the equator (Corbet, 1966; Nowark, 1991). There are seventeen Genera of deer, with some 45 recognised species across North and South America, Europe, Asia, and North Africa. Many species have also been added to native species in some geographic areas (in Europe five species of deer are native and five have been introduced from elsewhere), and some species have also been introduced into countries where deer are not native at all, such as Cuba, New Guinea, Australia and New Zealand.

(14) Deer are generally slim, long-legged animals and all but two Genera have antlers. And in those Genera where antlers are present, it is the male that carries them - with the exception of the Genus Rangifer (reindeer and caribou), in which antlers are borne by both males and females. In the Northern hemisphere the males shed their antlers each year (from January to April) following the mating season. Deer are herbivorous and live in large groups (herds) the size of which in any one species seems to vary with respect to where they live, such as in woodlands or in open country, the latter being the larger.

(15) Deer have gestation periods from about five to ten months, and some species have delayed implantation of the embryo. Usually only one or two calves are born, but some species may commonly produce three or four. Typical life spans in the wild vary considerably, but animals of some species in captivity have lived for well over twenty years.

2.3 Rats and mice

(17) Rats, mice, hamsters, voles, lemmings, and gerbils are all members of the Family **Muridae**, one of the 29 living Families of the Order **Rodentia**, the rodents. The rodents are remarkably uniform in structure, but their principal common characteristics relate to dentition and certain features of the skeleton. They are characterised by the presence of incisor teeth, of which only the front surface is covered in enamel (Mathews, 1952; Matheson, 1962; *Twigg, 1966*; van den Brink, 1967; Corbet & Harris, 1991).

(18) The **Muridae** is by far the largest rodent Family; indeed, with over 200 genera and 1000 species, it is the largest of all mammalian Families. They also have a 'natural' distribution that is essentially worldwide apart from Antarctica, certain Arctic islands, New Zealand, and other islands in tropical and temperate waters; but they are now also present in many of these areas as a result of human occupation. They have an upper split lip; four toes on the fore feet, five on the hind. Murids do not hibernate.

(19) Murids are found in a variety of habitats, but most species are primarily terrestrial; some are arboreal (tree dwelling), fossorial (burrowing) or semi-aquatic. They occur in both urban and rural areas. Most feed on plant material and invertebrate animals, although some may also hunt for small vertebrates, including fish. Seeds and other plant materials may be stored for winter use when natural food is scarce. They may be nocturnal or diurnal, and are usually active throughout the year. Some species are gregarious, some highly social, whilst others may live singly or in pairs. In warm regions breeding may take place continuously throughout the year and females often produce many litters each year. When conditions are less favourable, breeding occurs in summer or autumn. Gestation periods are usually short, litter sizes fairly large. Life expectancy in the wild is not long (about 1 to 4 years) but the reproductive rate can still be sufficient to cause rapid increases in population size – to the extent of causing 'plagues' – that then collapse (crash) as food supplies are exhausted. Such breeding cycles, sometimes also accompanied by population migrations, can occur every few years.

3. BIRDS

3.1 GENERAL INTRODUCTION

(22) Birds are the most ecologically widespread vertebrate animals on Earth. All living birds (Class **Aves**) are grouped into only two 'super' Orders – the **Palaeognathes**, which include the ostrich-like birds, or ratites, and the **Neognathes**, which include all of the remaining birds, arranged into a considerable number of

Orders and their Families, but all of which have essentially similar anatomical features. There are some 9000 species of birds and their classification – albeit something of an arbitrary framework – has been the subject of considerable debate. Assigning birds to different Orders depends primarily on rather subtle features of anatomy, particularly in relation to breastbone, palate, bill, legs, and feet.

(23) Birds have feathers made of keratin that provide both their means of insulation (feathers are more efficient than fur as insulators) and enable them to fly. Feathers are usually replaced, by a process of moulting, at least once a year. Some birds - such as the swift – spend at least nine months of each year continuously in the air; indeed one species, the sooty tern, is believed not to settle on the water for its first three or four years of life. Other species cannot fly at all and may spend their entire life on land, or largely in the water.

(24) Flight is energy intensive and birds therefore have a high food intake – which occupies much of their time – and they maintain relatively high body temperatures (greater than 38ºC). Powered flight has also resulted in a number of anatomical adaptations, including extensions of the lungs, as air sacks, into other parts of the body, plus the reduction of bone weight.

(25) Birds are unique in being the only vertebrates never to have evolved a 'live-bearing' species. All birds lay eggs soon after fertilization – another weight-reducing feature – that then have to be guarded and maintained at a fairly even temperature in order for the embryo to develop. The number of eggs laid by a bird and incubated at any one time is termed the clutch size. Some species (called determinate layers) have a fixed clutch size – such as pigeons, which only lay two eggs. Other species (indeterminate layers) vary the number according to different circumstances.

(26) Egg sizes differ somewhat within a clutch, as well as amongst clutches of the same species, and vary greatly amongst species. Most eggs are oval (or *ovate*) in shape, but others are classified as being *elliptical, subelliptical,* or *pyriform*. Eggs are usually incubated by direct contact with a parent bird, either by way of relatively bald patches of skin called brood pouches, or by way of webbed feet in the case of waterfowl, cormorants, gannets and others. The necessity to maintain a sufficiently high and constant incubation temperature appears generally to be directly related to the stage of embryonic development, although there are exceptions. Incubation periods differ greatly amongst species.

(27) Newly hatched birds – nestlings – are usually either naked, blind, and virtually helpless (*altricial* nestlings) or are covered in down and active soon after hatching (*precocial* nestlings). In both cases, however, young nestlings still need to be brooded in order to maintain their body temperature – as well as needing 'parents' or foster parents to provide food and, usually, protection from or warning against predators.

(28) Nestlings are thus dependent for some time upon their 'parents' before they can survive on their own. This is the 'nestling period'. (The time taken before it can fly (where relevant) is called the 'fledging period', and the young bird is then a 'fledgling'.) Precocial nestlings usually leave the nest fairly quickly and then may follow their parents but find their own food; or they may follow their parents who 'indicate' food to them; or their parents may feed them. Altricial nestlings, however,

are both brooded and fed by one or both parents for some time, until they are gradually neglected and can survive on their own. Near-adult size is usually achieved in a relatively short period of time, but birds may remain as 'juveniles' for several years before becoming sexually mature and then successfully breeding. Some species form breeding 'pair bonds' that last for life.

(29) Birds have a ZZ (♀), ZY(♀) sex chromosome pattern, the opposite of the XX (♀), XY(♀) mammalian pattern.

3.2 Ducks and Geese

(30) Ducks, geese, and swans collectively are members of the Family **Anatidae**, the larger of the two Families of the order **Anseriformes** (the other Family being the **Antimidae** – the screamers). And, of the **Anatidae**, there are some 164 species, of which 128 are ducks, being classified into 35 Genera. The **Anatidae** are sometimes divided into Sub-families: swans (**Cygninae**); geese (**Anserinae**); and various types of duck – tree ducks (**Dendrocygnae**), surface-feeding ducks (**Anatinae**), diving ducks (**Aythyinae**), stiff-tailed ducks (**Oxyurinae**), and mergansers (**Merginae**). Swans are rather restricted in their global distribution; geese less so. But the various types of ducks, collectively, occur virtually all over the world, from the Arctic to New Zealand.

(31) As the above various sub-divisions of the duck family indicate, ducks vary somewhat in their behaviour, largely in relation to feeding. The tree ducks (also known as 'whistling ducks') eat grass and seeds and frequently perch in trees. In contrast, the mergansers are rarely out of the water, have saw-edge mandibles and live primarily on fish; and the stiff-tailed ducks are almost helpless out of the water, feeding on a variety of small aquatic animals and plants. But the majority of ducks are either those that feed from the surface of the water by 'upending ', or 'dabbling' (also called 'puddle ducks') or by fully diving under the water. Many species are crepuscular (active at twilight) or spend some time feeding after dark, it being more energy efficient to rest or bask in the sun during the day and to be active at night. The food taken can be only animal, only plant, or a mixture of both. Herbivorous ducks can spend as much as 55% to 65% of each 24 hr period feeding; omnivorous ducks somewhat less (35%) (Owen & Black, 1990). The weight of ducks also varies throughout the year, increasing in the autumn, decreasing during the winter and increasing again in the spring (Cramp, 1977). A female can lose up to 25% of her weight during the breeding season. Ducks have been known to live well in excess of 20 years.

(32) Most ducks are seasonally monogamous, and a few maintain the same partners over several seasons. Copulation is necessary to fertilise each egg. Ducks lay their eggs in nests, lined with soft feathers (down), usually on the ground, but they may be in reed beds, in hollows in trees, or in burrows. Ducks are indeterminate layers, although clutch sizes vary amongst species, usually with a lower range of 4 to 7, and an upper range of 10 to 15 but, exceptionally over 30 in a season. The nestlings are precocial, brooded on the nest or on the 'shore', but otherwise swim with their

parents, climbing on their backs to rest when small. Fledged young generally remain with adults until the next season. Most dabbling and diving ducks can breed at one year old, but 'sea' ducks do not do so until they are two years old.

(33) Although some species moult their feathers sequentially, the majority have a flightless moulting period of several weeks, usually soon after breeding, whilst still on the breeding grounds. Much time and effort is expended in maintaining plumage condition, the feathers being oiled from a preening gland at the base of the tail.

(34) Adult ducks may remain in the same general area for most of their lives, or move from spring/summer breeding areas to autumn/winter feeding grounds. Such grounds may overlap. Some species, however, migrate considerable distances, and even from one continent to another. Although usually associated with lakes and ponds, some species of duck only resort to freshwater areas to breed, wintering in estuaries or at sea. Many species spend considerable periods of time out of the water.

4. AMPHIBIANS

4.1 General introduction

(38) Amphibians were the first vertebrate animals to relinquish an entirely aquatic existence. The Class **Amphibia** have traditionally been considered to consist of four Orders: the **Anura** (tailless amphibians – the frogs and toads), plus three smaller ones – the **Apoda** (caecilians), the **Trachystomata** (the sirens), and the **Caudata** (the newts and salamanders).   All amphibians are ectotherms, in that they are unable to raise their body temperatures by way of generating metabolic heat; but external sources can be variously used. Their metabolism is therefore more or less directly dependent on the ambient temperature – in air, soil or water (Moore, 1964; Stebbins & Cohen, 1995). The majority function best within a temperature range of 20 to 30ºC. Food intake is therefore also variable and does not need to be sustained in order to maintain body temperature. At low temperatures activity can be minimal and thus, in colder areas, amphibians hibernate during the winter months in what is essentially a state of torpor. Similarly, activity can be reduced at high temperatures and many species may be most active at night, or at morning and evening.

4.2 Frogs and Toads

(39) The **Anura** (frogs and toads) consists of a large number of Families although, as in all aspects of systematic zoology, views differ with regard to how many – from 21 to about 30 (Mattison, 1987). The principal cause of confusion in their nomenclature, however, is usually over the two common English words – frog and toad. These have no particular meaning and were originally coined in order to differentiate between what were, at the time, the only known two basic types – one with moist skin and one with dry, warty, skin. Nowadays the majority of Anuran Families are usually referred to as various 'types' of frog – pond frogs, ghost frogs, glass frogs, tree frogs and so on.   But a number of Families are also known as various 'types' of toad – such as spadefoot, or short-headed.   And yet the 'midwife toad' is a member of the

Discoglossid (painted frogs) Family, whereas the 'garlic frog' is a member of the Family **Pelobatid** (spadefoot toads). The Families with the largest numbers of species are the **Leptodactylidae** of central and South America; the **Ramidae** which, with the exception of Australia and New Zealand, occur world wide; and the **Hylidae**, which occur in most tropical and sub-tropical regions except Africa. But all non-polar regions contain one or more Families of frogs and toads.

(40) Most adult frogs have a body (snout to vent) length of about 2 to 10 cm (the largest is about 30 cm). They have much the same body shape, but their hind limbs are variously modified for leaping, swimming, climbing or burrowing. They occur in and around fresh waters and brackish waters, and in humid places such as leaf-litter, soil, and in tree canopies.

(41) An important physiological feature is the function of the skin, particularly with regard to respiration and maintaining water balance. The outer layer of the skin (the epidermis) is shed frequently – sometimes every few days – and, in the majority of species, is immediately eaten. Adult frogs and toads have a three-chambered heart and paired lungs, air being pumped in and out by raising and lowering the floor of the mouth (there are no ribs). But gas exchange also occurs across the skin, and some totally aquatic species have a highly wrinkled skin for that purpose. The skin also absorbs water: frogs and toads consist of about 80%, water but they do not drink. Aquatic species excrete large quantities of urine, containing ammonia. Terrestrial species excrete little urine, containing the less-toxic urea, or even just a white paste of uric acid. The skins of terrestrial species are often covered in mucus – to aid gas exchange – or may be covered by waxy substances to reduce evaporation. Physiological processes are temperature dependent, and each species has its own critical upper and lower temperature limits. Their blood cells contain nuclei. In cold areas frogs and toads hibernate, usually in soil or under other objects, although some species hibernate under water, at the bottom of ponds.

(42) The majority of species are carnivorous as adults, eating a wide range of small invertebrates, or even vertebrates. In many species the prey is captured by flicking out a sticky tongue, the tongue being attached at the front of the mouth, pointing backwards when withdrawn. Food size is important; it has to be swallowed whole. (The eyeballs may be retracted to help force the food down the throat.) They do not usually feed during the breeding season. Adults usually live within a fairly well defined territory, foraging at certain times of the day or night and returning to a particular resting or hiding place. Frogs and toads may live well over 12 years, and do not sexually mature until they are about two or three years old.

(43) The term amphibian derives from the Greek *amphi* (both) and *bias* (life), and the *majority* of frogs and toads lay their eggs in water. These develop into aquatic larvae that then metamorphose into terrestrial living adults. Both males and females have paired gonads (testes and ovaries) that lie alongside the kidneys, each associated with fat bodies that provide the nutrients for sperm and egg development. Eggs are typically laid directly into the water and immediately fertilised by sperm before the 'jelly' surrounding them begins to swell, the male having previously grasped the female in a position known as amplexus.

(44) The fertilised eggs develop into embryos that develop external gills, a well-developed mouth, and a tail. The hatched larvae – tadpoles – typically absorb their yolk sacs and then feed by grazing largely on algal material and bacteria. An operculum grows over the gills and the tadpoles become free swimming. With increasing size, hind limbs first appear, then fore limbs. The mouth then changes shape and the tail gradually becomes resorbed. The tadpole has then metamorphosed into an adult frog or toad. These processes may take many months, and in cold (mountainous) districts the tadpoles may over-winter before metamorphosing (Smith, 1973; Frazer, 1983).

(45) But there are important variations to this general pattern! Most species lay their eggs in water and these develop into feeding tadpoles that then develop into frogs. Several species, however, lay their eggs on land (or in very small bodies of water) and the tadpoles then develop directly into the adult form without feeding. Some species carry their eggs that then develop as non-feeding tadpoles in water; some carry both their eggs and their non-feeding tadpoles; and some only carry their non-feeding tadpoles. A number of species of both frogs and toads have, in fact, evolved a method of reproduction that omits the tadpole stage altogether. Their eggs have a tough outer membrane and all stages of development are completed within it, the young hatching as miniature adults. The eggs may be laid on land or carried on the back of the female. There are even a few species where the eggs are retained in the oviduct, emerging from the females as miniature adults, and in two species the young live on secretions from the uterus, again emerging as small adults. Two species, bizarrely, hatch their young and keep them in their stomachs until they hop out of the mouth as small adults!

5. FISH

5.1 General intorduction

(47) Fish are a very heterogeneous assemblage of animals. A reasonable general description is that they are jawed vertebrates, adapted to living in water, and possess gills throughout their life. Thus vertebrates can be divided between the **Agnatha** (jawless) and **Gnathostomata** (jawed), and the latter can, in turn, be divided between the **Pisces** (fish) and the **Tetrapoda** (amphibians, reptiles, birds and mammals). There are thought to be about 45,000 to 50,000 species of jawed vertebrates, of which well over half are fish. The fish, in turn, can be divided between the **Elasmobranchiomorphi** (*cartilaginous fish* and the extinct placoderms) and the **Teleostomi** (the *bony fish* and the extinct acanthodians). There are probably fewer than 1,000 species of surviving *cartilaginous fish*, and these are either elasmobranchs (sharks, skates and rays) or holocephalans (chimaeras). And without wishing to labour the subject of taxonomy too much, it is nevertheless worth noting that the surviving *bony fish* (the Class **Osteichthyes)** can be further sub-divided into four Sub-Classes, although these are sometimes merely grouped into two – the 'lobe-finned' fish and the 'ray-finned' fish. The majority of the latter are actinopterygians, and the vast majority (about 22,000 species) of these belong to the 'Sub'-Class **Teleostei** (Jobling, 1995).

(48) Fish inhabit almost every conceivable aquatic habitat, from soda springs to oceanic trenches. Different species can survive habitats with temperatures ranging

from over 40ºC to those with temperatures of less than 0ºC. There are at least 13,500 species of fish in the marine environment, the vast majority (some 8,500 species) occurring in shallow tropical and sub-tropical waters. Coastal and shelf (<200m depth) waters of temperate and polar regions contain only about 2,000 species, but their abundance can be very high, and many are subject to commercial exploitation. Relatively few species (about 350) occur in open ocean surface waters and the remainder occur in deep waters. The other species live in fresh or brackish waters. There are about 8,500 to 9,000 species of fish in the river drainage systems of southeastern Asia and South America alone.

(49) About 100 species migrate between freshwaters and the marine environment for the purposes of feeding or breeding. The majority of these spawn in fresh water but feed in the marine environment (termed 'anadromous'); the others ('catadromous') spawn in the marine environment but then spend most of their lives in freshwater habitats. The former type is more frequent at higher latitudes, which may be a reflection on the relatively high organic productivity of marine waters at these latitudes. Similarly, the higher frequency of catadromous species in lower latitudes may reflect the relatively poor productivity of sub-tropical, open ocean, waters.

(50) All fish have gills that open to the exterior via some form of slits or opercular openings. And they have paired 'limbs' in the form of fins. They also, generally, have a skin covered with scales, and a two-chambered heart that circulates only venous blood – but there are exceptions to both of these features. Fish may be herbivorous, carnivorous, omnivorous, or simply feed on detritus, both as larvae and as adults, with a consequent wide range of morphological and physiological adaptations for the ingestion, digestion, and absorption of nutrients.

(51) Larval fish respire primarily by diffusion across the skin, but in adult fish – although the skin may obtain its oxygen directly – respiration occurs across the gills, which may represent up to 75% of the total body-surface area. A small number of species can use gills to respire in both air and water, and a few have developed other parts of their body, particularly the gastrointestinal tract and the gas bladder (used for buoyancy) as an 'air-breathing' organ.

(52) Marine elasmobranch fish have a blood plasma that is almost isosmotic with seawater and body fluids that are slightly hyperosmotic, resulting in a slight influx of water. There is also a tendency for inorganic ions (largely sodium and chloride) to diffuse into the fish across the gills; these are excreted via a rectal gland. In contrast, marine teleost fish tend to lose some water across the skin – a process minimised by scales and the secretion of mucus – plus a considerable amount of water across the gills. Marine teleost fish therefore drink – from 5 or 10, to up to 40% of their body weight per day. They can also regulate the ionic strengths of their body fluids. Freshwater fish face a different set of problems in that they tend to gain water by passive absorption across the gills, and lose ions. They therefore produce a copious flow of dilute urine and actively absorb ions across the gill and gut.

5.2 Salmon and Trout

(53) The Family Salmonidae contains the salmon and the trout; some others types, such as the charr, grayling, smelts, and argentines have also been included in some classifications, but these fish are now generally considered as Families of their own (Wheeler,1978). All salmonids are characterised by having a small adipose fin - a small 'extra' fin, behind the dorsal fin. They have fully scaled bodies but scale-less heads. An airbladder is connected to the oesophagus by an open duct.

(54) Salmonids occur in both marine and fresh waters, and some are anadromous. The freshwater forms are essentially Northern hemisphere fish, but several species have now been widely introduced into fresh waters all over the world. Salmonids include some of the species of fish that are amongst the most valued commercially, and they are highly prized as 'sport' fish. They are also much used as experimental animals, and their presence in rivers and lakes is often taken to be indicative of good water quality.

(55) Salmon are generally characterised as fish that spawn in freshwater, spending the first few years of their life there, but then migrate to the sea to live, returning to the same stretch of fresh water to spawn once or more during their lifetime. Trout, on the other hand, are characterised as fish that generally live all their lives in fresh water, but may enter the sea or estuarine waters to feed as adults. But there are, of course, exceptions! Thus there are a number of species of salmon that do not migrate to the sea. In some cases this is because they live in land-locked lakes, as in parts of Canada and the eastern USA; but there are also non-migratory species of salmon that live if freshwater areas that do have access to the sea. On the other hand, although many species of trout also live in land-locked freshwater lakes, of those with free access to estuaries and the sea, only a few ever migrate into such waters to feed as adults.

(56) As to be expected, the life cycle of trout species is generally better understood than that of many salmon, the marine phase of the lives of the latter being still comparatively unknown. Salmon and trout species can belong to the same Genus, and are frequently difficult to distinguish for the casual observer. The various stages of their life history have become rather complicated in terms of nomenclature (Jones, 1959; Frost & Brown, 1967). Both salmon and trout eggs are denser than water and are laid in shallow deposits called *redds* within clean sand or, more usually, gravel. The eggs hatch into fry that still have a yolk sac hanging beneath them.

(57) For salmon, such young fish, still living within the sand or gravel, are called *alevins* (or *sac-fry* in the USA) until the yolk sac is fully absorbed. They then swim freely, as *fry* or *fingerlings*. At a larger size, and with a change in colour markings, fingerling salmon are known as *parr*, although there are a great many other local and dialect names for fish at this stage of development. Prior to migrating to the sea, the scales of salmon parr develop silvery deposits of guanine, and they are then called *smolts*. (The time of this transition appears to increase with latitude.) Adult salmon eventually return to the rivers to spawn, but do not feed. Some are comparatively young, and are then often referred to as *grilse*. After spawning, the spent salmon, in poor physical condition, are known as *kelts*. The vast majority then die, although along the Atlantic (but not the Pacific) coasts some female salmon do survive their migration back to the sea, recover their health, and return again to spawn one or more times.

(58) Trout terminology is usually somewhat simpler. In its first year it is termed a fingerling, in its second year a *yearling*, and thereafter it is simply a two-year-old, three-year-old and so on throughout its life.

(59) Depending on species, and on latitude, young salmon may go to sea at the age of two or three years, or not until they are seven or eight. Similarly, depending on species, adult salmon may spend anything from one or two up to seven or eight years at sea before returning to spawn in the upper reaches of rivers and streams. Trout living in lakes also return to their native rivers and streams to spawn. Some species may spawn in a number of successive years. Salmon generally live less than ten years but some trout have been known to live into their teens. Both salmon and trout are carnivorous, and live in the water column. Growth rates and other aspects of their physiology are highly temperature dependent, although other factors, such as water mineral content ('hardness'), are also relevant. Individual fish weights can therefore also vary considerably, and for each species records exist of fish that are virtually double the weight of the 'typical' adult weight. Weight also varies greatly in relation to the state of the gonads, which can account for at least 20% of body weight in females, and occupy much of the volume of the abdomen. Salmon and trout species can also be essentially similar in size, although trout are usually considered as being a smaller fish than the salmon. They have been intensively reared, farmed, and genetically modified.

5.3 Flatfish

(61) Swimming is an energy intensive activity and also requires the need to maintain a more or less neutral buoyancy. The majority of fish are therefore fairly economical in terms of the amount of time spent in active swimming, and many marine species have taken to an essentially passive existence on the sea floor. There are examples of both elasmobranch fish (the skates and rays, plus some forms of shark) and teleost fish that have a flattened body shape and lead a primarily benthic existence.

(62) The teleost flatfish are all forms that, as adults, effectively live on their left or right sides. Their larvae are of a 'conventional' fish shape, but during their development one eye moves to the other side of the head prior to the juvenile settling to live on the sea floor. The side with eyes becomes heavily pigmented; the underside typically remains un-pigmented. Teleost flatfish are thus often grouped as 'left-eyed' or 'right-eyed', depending on which eye normally moves from one side of the head to the other (Wheeler, 1978). Thus the 'left-eyed' flatfish, which have both eyes on the left side as adults, include the Family **Scophthalmidae** (eg turbot, brill and megrim – all confined to the Atlantic Ocean) and the Family **Bothidae** (the scaldfishes, that are widely distributed in tropical and warm waters in all the ocean basins). The majority of teleost flatfish taken commercially are, however, 'right-eyed'. Of particular importance are members of the Family **Pleuronectidae**, examples of which are widely distributed in cool temperate waters of the Atlantic, Pacific, and Indian Oceans. The majority are shallow-water, bottom-living fish; although some, such as the Greenland halibut, live part of the time, and actively hunt, in mid-water. Many species also penetrate estuaries and brackish waters. Typical Pleuronectids are the plaice, the flounder, dab and halibut. Another 'right-eyed' Family is the **Solidae** (eg the sole and solenet – but not the Lemon sole, which is a Pleuronectid!). It should however be noted that the 'right-eyed', 'left-eyed', demarcation is not an absolutely

strict rule. Thus, in the case of the 'right-eyed' Pleuronectid flounder, up to a third of the population may have their eyes on the left side as adults (Muus and Dahlstrom, 1964).

(63) Flatfish are carnivorous and usually feed at night. Most exhibit some form of migratory pattern between feeding and spawning grounds. They produce large numbers of eggs that are free floating, as are the larvae before they metamorphose into adult form and settle on the bottom. Many species are taken for human food and are thus fished commercially. The age of fish in temperate waters can be determined fairly easily, and thus it is known that a number of species can attain a considerable age – greater than fifty years. The life expectancy of commercial species, however, is very much determined by the extent and nature of such fisheries.

6. INSECTS

6.1 General introduction

(65) Insects are members of the **Arthropoda**, an enormous Phylum in which the adults are covered by a hard shell (a cuticle) of skeletal plates that have soft joints between them, enabling them to move. The Class **Insecta** is characterised by the fact that most of them have six legs at some stage in their life histories. An adult insect's body is divided into head, thorax, and abdomen. The head has one pair of antennae, the thorax usually three pairs of legs, plus wings. In fact all winged invertebrates are insects, although not all insects have wings! There are at least a million species of insect (about 80% of all known animals) and they can exist in enormous numbers. They occur in all environments, although only a few are marine.

(66) A key feature of insect physiology is the fact that respiration takes place via a system of air tubes (*trachea* and the smaller *tracheoles*) that penetrate all parts of the body and open to the exterior via spiracles. There are usually ten pairs of these openings along the thorax and abdomen. This, in itself, limits the size – particularly the width – of insect bodies, which are not usually more than 1 cm diameter and rarely is any point in the body more than about 5 mm from the surface. Body lengths, however, may be up to 30 cm (as in stick insects). Active insects have a variety of 'pumping mechanisms' to squeeze the air in and out of the tracheal systems.

(67) All adult insects are 'air breathers', although many aquatic larvae obtain oxygen by simple diffusion from water. Most aquatic adult insects carry a bubble of air underwater, which eventually has to be replenished. Some diffusion of oxygen occurs from the surrounding water into the air bubbles. In a few cases – known as plastron respiration – the adults are permanently coated in a very thin layer of air so that oxygen from the water continually diffuses into it. This is only effective in well-oxygenated water.

(68) The blood system of insects, as in all arthropods, has few blood vessels, the blood existing mainly in large cavities, bathing the organs of the body. A simple heart and dorsal blood vessel (the aorta) provides circulation, together with general body movements. The blood itself, which can account for up to 75% of an insect's weight, consists of plasma and cells, the main function of the latter being to clear the

body of bacteria and cell debris. Blood plays little or no role in transporting oxygen, but does carry carbon dioxide.

(69) Insects have relatively simple digestive systems, and waste is eliminated via a set of Malpighian tubules. The principal excretory product is uric acid.

(70) Adult insects have a hard external skeleton, made of chitin. This not only provides support but also greatly restricts water loss. It does, however, inhibit growth. Growth therefore has to occur in stages, by shedding the skeleton – a process called *ecdysis*. The majority of insects moult between four and ten times during their life (young and adult) but there are species that moult anything up to 50 times (Chinery, 1973). The stages between moults are called *instars*. Prior to moulting, the inner surfaces of the skeleton are resorbed and a new, softer layer secreted. The body then expands, by muscular action or by swallowing air or water, and the old skeleton is split and discarded. The adult then remains swollen until the new coat has hardened, and then new internal growth takes place as the 'ballast' air or water is eliminated.

(71) Insects are sub-classified into those that do not have (and whose ancestors appear never to have had) wings – the **Apterygota**; and those that do (or whose ancestors did) have wings – the **Pterygota**. And the latter, in turn, can be divided into those in which the wings develop gradually on the outside of the body (*exopterygote*) or internally (*endopterygote*). In the former (such as grasshoppers) the life cycle is then one of egg, nymph and adult, the nymphs essentially resembling the adult in form and appearance. But in the endopterygotes (such as butterflies) the life history is egg, larva (such as a caterpillar), pupa (or chrysalis) and adult, and the food sources of the larvae and adults are quite different.

6.2 Bees and wasps

(72) The endopterygote Order **Hymenoptera** (membrane winged), which has well over one hundred thousand species, contains the bees, wasps, ants, ichneuman flies and several other groups. A great many are parasites of other insects and, apart from the termites, are the only order that has species exhibiting true social behaviour.

(73) Female hymenopterans usually have a well-developed ovipositor, which is either used for drilling into plant or animal tissues in order to deposit eggs, or is modified as a sting. The eggs are generally white, elongated, and laid singly. Males are extremely rare in some species, and are often produced from eggs that have not been fertilised – a phenomenon called *parthenogenesis*. Some species have alternative sexual and parthenogenetic generations.

(74) Although there are many detailed anatomical and morphological differences between bees and wasps, one of the differences of some relevance to their radioecology is that wasps feed their young on animal material whereas bees feed their larvae on nectar (honey) and pollen. The wasps therefore have no specialised 'pollen-gathering' apparatus and, compared with bees, have rather short tongues. There are solitary and social species of both bees and wasps.

(75) Bees have traditionally been classified into up to eleven Families, but they may be classified into two, or just one. There are at least 25,000 species worldwide, with about 4,000 and 7,000 in North and South American respectively, 3,000 in Australia, the remainder occurring in Europe, Africa and Asia. Indeed, they occur in virtually all parts of the world where there is vegetation on the ground (O'Toole and Raw, 1991).

(76) Differences amongst Families relate to a number of features, including the methods used to obtain food, and the way in which it is transported via external appendages. Some Families only contain species that live a solitary life style, and some Families have a fairly restricted geographical distribution. The Family that has been studied more than any other is the Apidae, which consists of highly social species. It contains the bumblebees, and the 'honeybees', which occur naturally in Africa, the Middle East, and Europe but have also been introduced into most areas of the world in order to provide honey (Free & Butler, 1959; Butler, 1959). It also contains the 'stingless' bees that occur in Central and South America, and throughout most of the tropics.

(77) Most bee species are solitary, each female, after having mated, working alone to construct a nest. This is either lined with her own secretions, as in the burrowing or mining bees, or else lined with other materials – such as in the mason, leaf-cutter, and carpenter bees. Typically only 6 to 12 cells are made, each cell being provided with an egg plus the pollen and nectar necessary for the development of the larva. The females live for only a few weeks. Many species live in dense aggregations, but do not cooperate with one another, and in some cases several females share a common nest but, again, with no cooperation amongst them.

(78) There are, however, many species that live in a social context of varying complexity. These are classified as quasi-social, semi-social, sub-social, eusocial, social, and highly social; the principal differences amongst them being the number of egg-laying females, and the roles played by their offspring (O'Toole and Raw, 1991). Quasi- and semi-social bees have a number of female bees that lay eggs. Sub-social bees consist of a single egg-laying female and her immediate offspring, whereas eusocial bees also consist of an egg-laying female but with two or more generations of adult females that function as workers – such as the sweat bees and the bumblebees. In contrast, the social bees, at their most extreme, live in colonies that are, essentially, enormous single-family units. Each consists of an egg-laying female, the *queen*, plus her many sterile daughters, the *workers*, which behave in a highly cooperative way to gather food, build the nest, and rear the young. Males (*drones*) are only reared occasionally, as required. They normally nest in dry caves or hollow trees, but it is through their 'domestication' in beehives that their biology has been studied in some detail.

(79) The principal feature of the social bees' nests is the honeycomb – a thin sheet of wax covered with hexagonal cells. Additional building materials are also used, particularly *propolis* or *batumen*, which consists of wax plus resin collected from sticky buds and plant wounds. The nests usually have two parts: one contains the queen and the cells in which the larvae are reared (the brood chamber); the other, surrounding, chamber contains groups of larger cells used to store, separately, honey and pollen. Only the queen lays eggs, and she does little else. The eggs are laid in

open cells constructed by the workers. The vast majority of the eggs are fertilised (2n) and could develop into either queen bees or workers, depending upon the food given to them. Males, however, are derived from unfertilised eggs (n) and are laid in cells of a different size, seemingly built by the workers at their discretion. All of the larvae are fed by the worker bees.

(80) The worker bees (up to 80,000 of them at any one time per colony) have tasks that are age related. For the first half of their short adult lives (about 40 days) they serve as a 'nurse' or 'house' bees; for the second half they serve first as 'guard' bees and then finally as a 'field' bees or 'foragers'. (Worker bees in the summer months live for only about five or six weeks, but workers hatched in the autumn can live for several – up to six- months.) Eggs hatch within a few days into legless larvae that grow rapidly, usually moulting four or five times. The larvae spin cocoons and enter a non-feeding *prepupal* stage, and some species overwinter in this inactive phase. Within the pupal stage itself, most larval tissues and organs are broken down and reassembled to form adult structures. The adults emerge when their external cuticle has hardened, and the wings are then expanded by pumping blood into them. Under certain circumstances queen bees and males leave the nest. The males mate only once, their genitalia being removed and retained by the female. Depending on species, the queens may mate once, twice, or up to 10 times or more, the sperm being thoroughly mixed before being stored in a spermatheca and used to produce female offspring. A successful queen normally lives in a colony for several years, eventually being succeeded by a queen from her own colony.

(81) Temperature and humidity within bees' nests are highly controlled. Honeybee larvae are likely to die at temperatures below 32ºC or above 36ºC. Temperatures are usually maintained at ±1ºC, the workers generating heat by 'shivering' their wing muscles, or providing cooling by 'fanning' their wings to draw in air. If necessary, water droplets are used to lower temperatures within the brood cells.

(82) One further aspect of relevance to the radioecology of bees is their rather complex diet. Worker bees collect both pollen and nectar. Pollen is a fine powdery substance produced by the male parts (anthers) of flowers. Nectar is a liquid solution of sugars – sucrose, fructose and glucose. It is secreted from special glands (nectarines) that are usually situated at the internal bases of petals. Some bees also collect oils from flowers, the oils being produced in thin-walled glands called elaiophores, sometimes occurring in special 'spurs' of modified petals. Some bees are very specialised in the narrow range of species of flowers they visit; others visit a wide variety. Pollen is taken into the nest and deposited into cells. Foraging bees returning with nectar regurgitate it, and the 'house' bees suck it into their stomachs. By repeatedly opening and closing their mouthparts, water evaporates and the nectar thickens to form honey. After about 20 or 30 minutes, this honey is also deposited into cells. These cells of pollen and honey serve as food stores for the winter. Some dilute honey is retained as food by the workers both for energy and for secretion, as wax (used to build the cells) via a gland in the abdomen. Young worker bees also secrete a special food - called royal jelly – to larvae, from glands in the head.

7 CRUSTACEANS

7.1 General introduction

(84) Crustaceans are also members of the vast phylum of **Arthropoda**, but are primarily aquatic, although terrestrial forms do occur. The Class **Crustacea** includes a wide variety of forms, all of which have a basic body plan that relates to the types of appendages that they posses on their first few segments (somites) of their body. The Class has been variously divided into Sub-Classes and Orders, primarily on the basis of features relating to the specialisation of their limbs, the extent to which their overall body shape has been modified, and the possession or not of a structure called the carapace, or shell, that is essentially a fold of hardened skin that protects the anterior part of the body. The majority of crustaceans are mobile, but notable exceptions are the barnacles (**Cirripedia**).

(85) Crustaceans, like insects, are covered by a cuticle. This is usually stout relative to the size of the animal, and is often strengthened by calcification. In smaller forms, respiration usually occurs by gaseous exchange across the general surface of the body, but in crustaceans with stouter cuticles, or of much larger size, this is supplemented, or completely replaced by, the use of special organs upon which the cuticle remains thin. The most important of such areas are the lining of the carapace (if such a structure is present) and certain plates called epipodites that are attached to the bases of some of the limbs. These are commonly referred to as 'gills', and in some groups they are extensively branched and folded in order to increase their surface area. Crustaceans also have a well-developed vascular system, including pigments that carry oxygen. Thus, unlike the insects, these particular arthropods are not restricted in size because of the limitations of their method of respiration.

(86) A few types of crustaceans are hermaphroditic, but the vast majority are not. The fertilised eggs are usually retained by the female for various lengths of time and, typically, the larvae are free swimming before metamorphosing into their adult forms. Growth is achieved by a process of moulting.

7.2 Crabs and lobsters

(87) It has been estimated that there are at least 26000 species of crustaceans, and 18000 of these belong to the Sub-Class **Malacostraca.** And within the Malacostraca, by far the largest number, some 8500 species, belong to the Order **Decapoda,** which includes some 4500 species of crabs, plus such familiar forms as lobsters and shrimps (Warner, 1977). The decapods have a carapace that covers both the head and the thorax, but not the segmented abdomen. They are so named because their last five pairs of thoracic limbs are adapted for locomotion in one form or another (walking or swimming) although the first pair often have chelae (pincers) on their ends and may play little or no part in locomotary activity.

(88) Crabs are characterised by a typical body shape that is squat, broad, and compact, with the abdomen reduced and tucked away underneath, resulting in a form that has considerable strength and mobility. They are usually greater in width than in apparent length, and have the first 'walking' appendages modified into a large pair of claws (or

chelipeds), leaving four pairs of 'legs'. They have a branchial chamber that contains the 'gills' across which water is actively pumped by specially modified appendages. A well-developed blood system carries oxygen around the body, assisted by a simple heart. The blood contains a copper-containing protein, haemocyanin, which is blue when oxygenated, colourless when not. The blood also carries large quantities of glycogen, and is capable of forming clots when exposed to air. Crabs also have a well-formed digestive system, plus a large gland called the hepatopancreas that takes up the largest space within the 'body' of the crab. It serves both as an organ of digestion and of food storage, and is thus the site of accumulation of many elements. Ionic regulation, other than that of sodium and chlorde, which is achieved by specialised cells in the gills, is carried out by a pair of 'green glands', particularly with regard to the excretion of magnesium and sulphate. The main nitrogenous excretory product, ammonia, is lost by diffusion across the gills.

(89) Different species of crabs have developed a wide range of life styles. These include the ability to climb, swim, walk, run, and to burrow into the sediment. They are all essentially opportunistic omnivores, but with a preference to being predatory carnivores. Where specialisation in feeding has taken place, it is in relation to the method of obtaining food rather than the nature of the food itself. Nevertheless, different species of crab have evolved to live in brackish and fresh waters, and on land. This is particularly the case in tropical regions, where overall temperature fluctuations are minimal. They have also been most successful in environments close to the sea, where competition from terrestrial animals is least, such as mangrove swamps and sandy scrubland. Such species have developed a number of anatomical and physiological adaptations to survive in such environments, including a thinning of the carapace over the gill chamber to enable gaseous exchange directly with the internal body fluids.

(90) In tropical waters crabs may breed throughout the year, but in temperate waters breeding is seasonal. Mating often occurs soon after the female has moulted, and sperm is transferred and deposited in receptacles (*spermotheca*) on the female's abdomen, where a plug of sperm may be retained for many months. As the female extrudes the eggs, they are fertilised by contact with the sperm plug and then held by the female under her abdomen by adhering to hairs on the small abdominal appendages. The female may then carry the eggs for days, weeks, or many months, depending on species. The eggs are small (fractions of a mm in diameter) and numerous – up to several million. When they hatch, the larvae have to be released and they then generally form part of the plankton. The larvae are initially shrimp-like in appearance, free swimming, and grow by moulting, gradually changing into their adult body pattern. The early larval forms are called *zoea*, the latter forms, which more closely resemble the adult form, are called *megalopa*, and these eventually settle and grow into adults.

(91) From a radioecological point of view, apart from the different stages of their life cycle, the most relevant feature of crab biology is their method of growth – moulting. Crabs are always at some stage in a 'moult cycle', from newly or recently moulted, to an inter-moult stage, a pre-moult stage, and the relatively short activity of moulting itself, an action called ecdysis. In the pre-moult stage, most of the organic content and some of the inorganic content of the shell is resorbed, the latter being stored in the hepatopancreas. During ecdysis, the crab absorbs water across the gut, expands, and

sheds the old carapace and remainder of its shell. In the post-moult stages, organic and mineral reserves in the hepatopancreas are transferred to the new carapace and the rest of the shell, and they are at a minimum in the hepatopancreas in the intermoult stage. Thus the internal location and concentration of elements varies considerably throughout this continuous cycle.

(92) Initially, crabs may double their volume at each moult, but the percentage change, and the rate of moulting, decreases with age, particularly after puberty. The process of moulting also allows crabs to regenerate lost limbs, although it usually takes two or moults for a lost limb to be regenerated to its full size. Moulting continues throughout life. Some species attain a more or less adult size after one or two years, but others may continue to grow to twenty years or more (Warner, 1977).

(93) The 'true' crabs (with a short abdomen) have often been assigned to an 'Infra-Order', the **Brachyura**, which are then variously ascribed to numerous Families and Super Families. These groupings are the subject of considerable debate, but very similar forms are those belonging to the **Cancridae**, the **Oxyrhyncha** and the **Brachyrhyncha**.

8 ANNELIDS

8.1 General introduction

(95) The **Phylum Annelida** consists of segmented worms that have a visceral, fluid-filled cavity, the coelom, derived from the splitting of a layer of internal embryonic tissue. Around this cavity lies a muscular wall consisting of an external arrangement of circular muscles surrounded by an internal layer of longitudinal muscles. The coelom therefore acts as a hydrostatic skeleton, so that by relaxing and contracting alternate muscle layers the animals can shorten and lengthen their bodies, and coil them into various shapes. They typically also possess an external layer, a cuticle, plus bristles made of chitin that are arranged segmentally and imbedded in, and secreted by, pits on the external surface (Dales, 1963).

(96) The segmented pattern of annelids is probably their most obvious external feature. Internally the segments are traversed by a gut system that runs the length of the body; this system, together with the vascular and nervous systems, collectively links the segments into a functional whole. Each segment connects to the external surface via pairs of ducts - the coelomoducts and the nephridia, or structures derived from their combination.

(97) The annelids are usually divided into at least five Classes. Two of them are relatively minor: the **Archiannelida**, consisting of very small worms found in surface muds and similar habitats; and the **Myzostomaria** that are parasitic on certain types of feather stars and brittle stars. Of the major Classes, there are the **Polychaeta**, which are primarily marine worms – about 5300 species have been described - although there are a few estuarine and freshwater species. Somewhat different are the **Hirudinea**, the leeches, of which about 300 species have been described. They are primarily a freshwater group, although some do live on marine fish, and some occur in soils or on foliage in tropical regions. But by far the most well known are members of the Class **Oligochaeta**, of which there are about 3000 described species in the

terrestrial, freshwater, and estuarine environments, including the ubiquitous earthworms (Dales, 1963).

8.2 Earthworms

(98) Earthworms are Oligochaetes, a Class that has the least variety in external appearance. They occur all over the world, although somewhat rarely in deserts, areas under constant snow and ice, and in areas entirely lacking in soil and vegetation. Their grouping at family level has been in constant flux (Edwards & Bohlen, 1996) but fortunately the dominant Families (or Super-Families) are very widespread, and the most important are the **Lumbricidae**, which occur naturally in Europe, western Asia, and North America, partly because of their spread by Europeans, and the **Megascolecidae,** which occur primarily in southwest Asia, Australia, and the Pacific islands.

(99) Earthworms are hermaphrodite but are not, generally, self-fertilizing, most species reproducing by cross-fertilisation. They are more or less continuous breeders. Sperm are exchanged and each animal then produces a capsule, or 'cocoon' that contains the parent's eggs and the partner's sperm. Fertilization takes place within the capsule. The number of capsules produced during the year appears to be closely related to soil temperatures and can vary from less than 10 to over 100, depending upon species, although some species can produce over 1000. Temperature also appears to affect the time of hatching from the capsule, which can vary by a factor of three or more for the same species (Edwards and Bohlen,1996). Hatching times can vary from a few weeks to a few months. Each capsule is typically a few mm in diameter and may contain from 1 to 20 worms in the various species of Lumbricid. Growth usually continues throughout life, and life spans can potentially be many years, again depending upon species, but is usually much less than this potential because of predation.

(100) Earthworms can use a variety of organic materials for food, including plant material, decaying animal organic matter, or even soil itself if necessary. If conditions are particularly adverse then many species burrow deeper into the soil; some actively enter a period of what is known as facultative diapause, emptying their gut contents and rolling up into a tight ball within a mucus lined cell.

(101) [Chromosome numbers in earthworms seem to vary considerably, not only between species, but within them – although the situation is complicated because some species are divided into 'polymorphs', each of which has a different chromosome number! But typical chromosome numbers given in Sims and Gerard (1985) (and presumably n, not 2n) are in the 30s, with some over 100! Need to find out more!]

9. TREES

9.1 General introduction

(103) The general description of a tree is that it is a woody perennial plant that attains a certain stature and height (typically of several metres) on a single stem (Mitchell, 1974). Trees therefore occur scattered across the Orders and Families of the two large **Classes** of 'flowering' plants, the **Gymnospermae** and the **Angiospermae**. Both Classes have much in common. The former consists of five **Orders**, but only three of them contain 'trees': the **Ginkgoales**, the **Coniferales**, and the **Taxales**. The latter, the Angiosperms, are now the dominant plant group on Earth and are divided into two major **Orders**, the **Monocotyledons** and the **Dicotyledons**.

(104) The essential feature of woody plants like trees is the way in which they are able to grow. In other flowering plants the area of dividing cells – the *meristem* – is confined to the buds on the stems, and to the tips of the roots; they are therefore termed 'apical' meristems. But in trees (except for the Monocotyledons) there is a complete covering of these meristematic cells, called the *cambium*, which envelops the shoots, branches, trunk, and the roots. Each season the cambial cells in the stem divide to produce layers of cells on their external and internal surfaces. Internally they become 'wood' cells, primarily *xylem*; externally they become *primarily* phloem (sieve tube cells) – sometimes called the 'bast'. And external to the bast a small 'bark' cambium grows a layer of bark cells each year on its external side. The diameter of the tree thus increases.

(105) Growth in Monocotyledons is somewhat different. They have no complete covering of cambium, and in some forms the stem remains the same thickness as when it first grew. But in other Monocotyledons, such as the palms, the meristem at the apex creates small bundles of tissue as it grows, particularly at the origins of leaves. These also divide and increase annually, providing a source of trunk thickening. The growing points are confined to a few buds, usually a single central one, and the growing tip is therefore below it, inside the stem. New leaves grow out of the tip, and as the growing point moves up it pushes the new leaves vertically, the old leaves gradually becoming horizontal around the stem.

(106) An important feature of tree growth is that all types (except, again, the Monocotyledons) end the year's growth with a central bud surrounded by side-buds that, in turn, form branches. In most coniferous trees this pattern results in tall straight plants, but the majority of tree types lose the central axis and become diffusely branched. The nature of the terminal bud is therefore of considerable relevance. There are essentially three types. They can be large and contain, already formed, the entire shoot tissue for the following year. They can be medium, containing the first portion of the following year's shoot. Or they can be small and only contain the first leaves and a small part of the new shoot.

(107) The conducting cells of the tree stem function for a limited time only (considered to be typically of the order of 20 to 30 years) and they then become lignified. The active cells are therefore in an outer ring of the trunk, which is anything from tens of cms thick in vigorously growing young trees to about only 1cm thick in very old trees. This ring of functioning cells is called the sapwood; internally is the dead heartwood that provides the structural strength of the trunk and branches of a large tree.

(108) Below ground, water and nutrients can only be extracted by the root hairs, and only those just behind the root tip are active. Root hairs last only a few weeks and thus continual growth of root hairs is essential. In temperate regions, root hairs are the first part of the plant to grow in the spring, drawing upon stored nutrients in order to do so.

(109) Above ground, the leaves contain chlorophyll. This absorbs energy from daylight and uses it to synthesise carbohydrates, starch and cellulose, by a complex series of processes (photosynthesis) from water and carbon dioxide in the air. Energy is obtained from the oxidation of the carbohydrates. The creation of carbohydrates during the day liberates oxygen; their oxidation (respiration), during the day and night, liberates carbon dioxide.

(110) The sexual organs of trees are 'flowers'. A single flower can be entirely male, entirely female, or both. Each tree may have flowers of only one sex (*dioecious*) or flowers of both sexes may be on the same tree (*monoecious*). The majority of the 'flowering' trees have flowers that are themselves of both sexes. There are, however, variations on all of these basic types. Pollination, from tree to tree, is either by wind or by insects.

[Genetics?]

9.2 Pine trees

(111) Pine trees are Gymnosperms, which are collectively regarded as a relatively primitive set of plants, in which the female reproductive cell, the ovule, is not enclosed in an ovary but lies on a 'scale'. The reproductive organs are analogous to a single compound flower, or as groups of single flowers, and each group is called a *strobilus*. The Order **Coniferales** is generally taken to include all of the families of conifers except the yews and the nut-meg trees or 'torreyas'. It therefore includes the Families of **Cupressaceae** (cypresses), the **Taxodiaceae** (which includes the sequoia), and the important **Pinaceae** (the pines). The pine Family consists of about ten Genera and over 200 species. They include many of the familiar conifers, such as the cedars, larches, pines and spruces, and extend across the whole of the Northern hemisphere. They all have needle-like leaves and woody female cones with spirally arranged scales each bearing two seeds.

(112) Pine trees have large buds that rapidly extend in the spring to provide the full season's growth, and the terminal bud for the following year is formed before it has fully extended. Thus the year's growth is completed quickly – although it may be delivered in a series of separate bursts - and the remainder of the growing season is devoted to creating the following year's growth, condensed within the new bud. (This process requires sunlight but little water.)

(113) A pine tree essentially consists of a tapering column – the stem, or trunk – surrounded in a sheath of bark. The trunk supports branches that carry the crown of narrow leaves (needles) plus the male and female reproductive organs. Below the ground the root system consists of a taproot plus branch roots that serve both to anchor the stem and to obtain water and minerals from the soil. The ratio between the

size (weight) of the above ground shoot to the root changes as the seedlings develop. At the age of 1 year they may be equal, but in a mature tree only about 10% of its total weight lies beneath the ground (Mirov, 1967). A common feature of pine trees is the association of the root system with fungi to form what are termed *mycorrhiza*. Different species of fungi form different mycorrhizal associations with different species of pines.

(114) At physiological maturity the tree develops male (microsporangia) and female (megasporangia) organs, each of which are borne in separate stroboli. [The Genus *Pinus*, is monoecious.] After pollination the male organs (catkins) are shed, the female small megasporangia (conelets) then growing into the large and familiar pinecones that contain the fertilized seeds.

(115) Reproduction in pine trees is somewhat complex. The male strobilus contains pollen sacs that produce large quantities of pollen. Each pollen grain has an air sac on each side. The female strobilus essentially consists of an axis containing ovuliferous scales, each of which has two ovules that contain a mass of cells called the nucellus. Wind-borne pollen grains stick to the scales, in contact with the nucellus. A tube then grows from the grain, penetrating the nucellus. Simultaneously, the nucellus produces a cell that divides to produce four haploid (n) cells, only one of which subsequently develops. All of this takes a long time. Over a year may pass before an unfertilized egg develops. During the first year the pollen tube grows slowly and penetrates only a small distance into the nucellus. In temperate regions it ceases to grow during the winter, so that two 'growing seasons' are required before fertilization actually takes place by way of the sperm nuclei fusing with the nucleus of the ovule to form a zygote. In more tropical regions this entire process only takes about one year! The zygotes then also divide, so that four or eight 'embryos' are created, although only one or two develop to maturity. [Actually, it is all even more complex than this!]

(116) After fertilization is complete, the female cones grow rapidly and, in temperate regions, mature (if pollination occurred in the 'spring') at the end of the second summer – some 18 months later! Mature pinecones vary from 2 to 3 cm, to 60 cm in length, depending on species, and can weigh from 2 to 1100 gm. Each cone may contain from ? to ? seeds, each seed consisting of an embryo embedded in a tissue food reserve. Seeds vary from ? to over 1 cm in length.

(117) Seeds may remain viable within the discarded pinecone for many years. In the ground, seeds may germinate in a matter of days or, depending upon species, may require prolonged exposure to low temperatures, or may require adequate levels of moisture, before germinating. The seedlings, in turn, pass through a juvenile stage before maturing into a tree that is capable of reproducing. The capacity of trees to produce seeds decreases in 'old age' but does not cease entirely.

(118) Growth is intermittent and, in temperate climates, variable in relation to seasons. Different parts of the tree also grow at different times of the year. In the spring, the roots grow first, then the shoot tips, then the cells of the vascular cambium, between the 'bark' and the internal tissues of the trunk, and then the needles. Pine trees 'mature' at a very young age, and may produce male and female cones at about 5 years of age, or less. They have a natural life spans that typically ranges from about

100 years to 600 years, but some species (e.g. *Pinus aristata*, the bristlecone pine), are considered to live for several thousand years.

(119) The most important macroelements obtained by pines from soil are N and P, plus K, S, Mg and Ca. Small quantities of other elements have also been shown to be essential for young pine trees, particularly Fe and Zn.

10. GRASSES

10.1 General introduction

The **Angiosperms**, a Class of flowering plants, is divided into two Orders, the **Dicotyledons** and the **Monocotyledons**. The two differ in that Dicotyledons – by far the largest Order – have two seed leaves instead of one in the embryo, and by other structural features, such as net-veined leaves, the arrangement of the vascular tissues, and the arrangement of the parts of their flowers. Grasses, however, belong to the latter Order, the Monocotyledons.

(122) All grasses belong to the same Family, the **Poaceae** (Formerly the **Gramineae**), and vary in appearance from the familiar grasses in fields and hedgerows to cereal crops, rice, and more exotic forms such as bamboo. They have a word-wide distribution: indeed grasslands have been considered to cover a third of the Earth's terrestrial surface (Clayton & Renvoize, 1986).

(123) Grasses are not easy to describe, but are usually considered to be flowering plants with stems that are almost hollow (except at the swollen leaf junctions), the flowers arrange in opposite rows in spikelets, each flower having two small leaves called *bracts*. Their leaves are alternate, in two rows, usually long, narrow, with parallel veins and forming a sheath around the stem of the plant. The flowers are minute, usually with three stamens (that produce the microspores) and two feathery styles (that lead to the female receptacle of the macrospores). Each flower is enclosed in two scale-like bracts, arranged in a spikelet. The spikelets may or may not be stalked, often bear bristles, and are arranged in terminal flower-heads that vary from small dense cylinders to widely branched sprays (McClintok & Fitter, 1956). Pollination is by wind and the fruits (usually called seed, or grain) are often described as small 'nutlets', but are properly called *caryopses*.

(124) The life cycle of most grasses is highly seasonal. Some are annuals, over-wintering as seed; some are perennials, containing dormant buds or 'innovation' shoots at their base. All have a fibrous root system that is relatively shallow, and commonly over half of it dies each year. The main branch system, and its buds, may occur just above the soil (tussock), at the surface (sward-forming), or just below (rhizomatous).

11. SEAWEEDS

11.1 General introduction

(126) Seaweeds are algae – a group of organisms that are non-flowering, do not have roots, leafy shoots, or sophisticated internal tissues for the transport of water, sugars, and nutrients. Their classification is subject to much debate and comment, and they are not usually now classified as plants but as Protoctista, and thus in the same kingdom as amoebae, ciliates and slime moulds. There is not even a clear definition of the term seaweed, but seaweeds have been traditionally considered to be large (macro) algae that are grouped into three types: green, red, and brown. These types arise because seaweeds use chlorophyll *a* (within chloroplasts in their cells) as a basis of photosynthesis – which gives them a green colour, but a range of other pigments are also used to provide protection against UV radiation. Thus red seaweeds may contain phycoerythrin, phycocyanin, and allophycocyanin that mask the green pigments. Brown seaweeds similarly contain carotenoids. Even green seaweeds contain other pigments, but these do not mask their green colour. Traditionally, therefore, the larger seaweeds have been grouped under three groups, the green **Chlorophyceae**, the red **Rhodophyceae**, and the brown **Phaeophyceae**, but these have all been the subject of much discussion and various other, and quite radical, classifications have been proposed (Lobban & Harrison, 1994; Thomas, 2002). Such proposals are not considered here. Nevertheless, it is therefore not surprising that estimates of the numbers of species of seaweeds is greatly variable, but it is usually assumed that there are about 1500 to 2000 species of brown seaweeds and 5000 to 6000 species of red seaweeds, all predominantly marine, plus 1000 to 2000 species of green seaweeds, in all aquatic environments, worldwide.

(127) Seaweeds have complicated life-cycles. In general there is an asexual phase (sporophyte), when the cells of the plant are diploid (2n), followed by a separate sexual phase (gametophyte) when the cells are haploid (1n). Following fusion of male and female gametes to form a sporophyte there is then another gametophyte stage. But there is no regular pattern of alternating phases, and the sporophyte may itself reproduce asexually by producing spores or by simply fragmenting. There are confusing variations. For example, some seaweeds simply have a large (2n) sporophyte (the plant that one sees) that develops either male or female, or both, conceptacles on its surface, within which the sperm and ova are formed. These are released into the water, fuse, and form a zygote that then settles and grows into another diploid plant. But in some species the sporophytes produce equal numbers of microscopic haploid spores. These settle and germinate into microscopic encrusting haploid plants. Each plant then in turn produces sperm and ova that are released, the resulting zygote growing into another sporophyte. In some species, however, the large plant seen is not a diploid sporophyte but a large haploid plant. This can produce asexually by producing haploid (n) spores that grow into duplicate plants, or produce male and female cells that fuse on the frond of the plant. These fused cells can then, in turn, produce diploid spores (2n) that settle and grow. The minute diploid plants, too, can also spread by (asexually) producing spores, but they can also produce haploid spores that settle and grow into the large haploid plant!

(128) Some seaweeds are annuals, some perennials. The differences are not related to size. Some large seaweeds are annuals. Some live only a few weeks. Some of the perennials may live for two or three years as very small plants, then grow rapidly, reproduce, and die. Some lose their fronds and then grow them again the following year. Many species are known to live for several years; one lives in excess of thirty years!

(129) Most of the larger seaweeds live on the shore or in adjacent shallow waters. They are therefore subject to much ware and tear, and to the risk of desiccation at low water. Many produce copious mucus. They are also subject to considerable variation in salinity (creating osmotic stress) and temperature.

11.2 Brown seaweeds

(130) The entire body, or *thallus*, of a phaeophyte (brown) seaweed typically has a structure that anchors it to the substrate, the *holdfast*, a stem or stalk, called a *stipe*, plus fronds or *blades* that emerge from the stipe. The plant may be much less than a metre long, but the giant kelps can attain lengths of 50 metres and grow at a staggering rate of 0.5 metre a day. The holdfast does not act as a conventional root system, and nutrients such as N, P, and trace elements are taken up directly from the seawater. Some species have gas filled bladders (pneumatocysts) to ensure that the blades float as close as possible to the surface of the water in order to obtain sunlight. In many brown seaweeds the stipes and fronds have considerable internal structure, with an outer layer of pigmented cells that overlies a layer of colourless cells with, in some species, an innermost 'medullary' core. This innermost layer may contain elongated cells with perforated end walls that form sieve tubes, along which sugars and amino acids are transported to different parts of the plant.

(131) Brown seaweeds contain a fucoxanthin protein that masks the chlorophylls *a* and *b*. The principal products of photosynthesis are a sugar alcohol (mannitol) and the polysaccharide laminarin (Chapman & Chapman, 1962).

(132) Brown seaweeds have a very wide geographical range. They also contain the largest number of Genera. The visible thalli of the plants are (I think!) all sporophytes, but there is more than one form of life cycle amongst the group. Some species are monoecious, others dioecious; there is not even consistency within the same Genus! Brown seaweeds may occur on any part of the intertidal or sub-tidal zone. They may therefore be exposed to seawater or covered in silt or mud for different periods of time.

12 POPULATIONS

(136) In describing the dynamics of a single population, basic assumptions are made with regard to such parameters as the number of births per population (the *crude birth rate*) or of a particular cohort (the *specific birth rate*) of the population. The *intrinsic rate of increase* (*r*) of a population is also used, being essentially the number of offspring an individual will have, minus the individual death rate, on average, per unit

time. It is therefore often possible to calculate, under ideal conditions, the *biotic potential* of a species' population by way of the *maximum intrinsic rate of increase* (r_{max}) and therefore, in theory, and by implication, any deleterious effect upon it. Changes in the size of populations over time have usually been considered in terms of whether or not the relevant factors are dependent or independent of density, although these terms are now often avoided (Berryman, 1999). The latter are the simplest in concept, and assume that both the rates of birth and death are proportional to the numbers of individuals present, and not limited by the 'carrying capacity' or other limiting factors of the environment.

(137) The changes in population numbers can be simulated in various ways, typically using exponential, sigmoid, or even 'stochastic' forms of mathematical models. Where species have overlapping generations, it is often useful to model discrete cohorts, or just reproductive rates of females only, by the use of matrix models (Hastings, 1997). For organisms that live a relatively short time, per capita age-dependent birth and death rates can be determined by following a single cohort through time – called *vertical life tables*. For species that are relatively long lived, however, it is more useful to calculate birth and death rates at specific points in time – *horizontal life tables*. Continuous time models can also be used. (Age-structured population matrix models were developed in some detail by Leslie (1945, 1948)). The potential future population size can obviously be strongly influenced by the current age distribution of individuals in a population, and thus *reproductive values* of individuals at specific ages may therefore be defined, and these may be important parameters in characterising population detriment.

(138) Population genetic issues are clearly of relevance to the needs to maintain biological diversity. In terms of genetics, populations have two important attributes, *gene frequencies* and *gene pools*. Gene frequencies are the proportions of the different variants (alleles) of a gene that are present in a population, and the sum total of the genes in the reproductive gametes of a population is the gene pool. Diploid organisms may have the same (homozygous) or different (heterozygous) genes at the same locus, but some plants and animals are triploid or more (polyploid), and others are haploid. Variability is reduced in small populations by differences in the reproductive success of its individuals, resulting in *genetic drift*.

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RAP Report 07
Appendix (B)

COMPARISON OF DIFFERENT DOSIMETRIC APPROACHES

(1) In order to help select the appropriate method for the ICRP set of Reference Animals and Plants, an inter-comparison exercise was undertaken based on the absorbed fractions for mono-energetic photons. The targets selected for the comparison were the organisms common to all of the considered models (EDEN, EPIC, EA R&D 128, FASSET/ERICA, RESRAD-Biota) and the Reference Animals and Plants. The comparison provided for the photon energies 60, 122, 662, and 1250 keV, which can be experimentally reproduced by the principal γ-lines in the emission spectra of ^{241}Am, ^{57}Co, ^{137}Cs and ^{60}Co (mean of two γ-lines), respectively.

(2) **Tables B.1** and **B.2** compare the external dose for organisms living in soil (earthworm and rat) and on soil. For in-soil species, the radiation source is assumed to be 50-*cm*-thick soil layer, while for on-soil organisms the comparison has been done for a plane source at 0.5 *g cm*$^{-2}$ depth. For both geometries, two facts are noticeable:

- the models based on Monte Carlo techniques that simulate radiation transport as EDEN, RESRAD and FASSET/ERICA provide relatively similar results. The approaches applied by EA R&D and EPIC use kerma approximations of radiation transport which tend to yield higher values of absorbed dose per unit source strength than the other models; and

- this effect is most pronounced for the EA approach, whereas EPIC provides results that are closer to the Monte Carlo models.

(3) **Table B.3** compares the absorbed fractions calculated by the approaches for various organisms. In all models, ellipsoidal geometries with a homogeneous distribution of the radiation source in the organism are assumed. In this case, the differences among the results are generally less than those obtained for external exposure. However, for small organisms and high energies, EPIC, EDEN, and EA R&D 128 predict much higher absorbed fractions, since these models do not account for the escape of secondary particles from the organism.

(4) The models applied to estimate exposures to flora provide, by and large, comparable results. Larger differences are observed in some details as e.g. the overestimation of the absorbed fraction for high-energy photons by some of the models. The largest number of geometries and exposure situations is considered by the FASSET-ERICA methodology, on the base of which a flexible dosimetry tool (Ulanovsky and Pröhl, 2006) has been developed that allows the calculation of dose conversion coefficients for a wide range of organisms which also cover the specific

dimensions of the RAPs selected by the ICRP. So, this methodology is used to calculate the DCCs for the RAPs

Table B.1 Comparison of external absorbed doses for in-soil-organisms per unit photon 50-*cm*-depth volume source strength (*Gy* per photon *kg*$^{-1}$)

Organism	Model	Photon energy (*keV*)			
		60	122	662	1250
Earthworm	EDEN	2.7×10^{-15}	9.0×10^{-15}	6.5×10^{-14}	1.3×10^{-13}
	EPIC	3.5×10^{-15}	1.3×10^{-14}	1.7×10^{-13}	3.3×10^{-13}
	EA R&D 128	9.4×10^{-15}	1.9×10^{-14}	1.0×10^{-13}	2.0×10^{-13}
	ERICA/FASSET	3.9×10^{-15}	1.1×10^{-14}	9.4×10^{-14}	1.8×10^{-13}
	RESRAD-Biota	2.6×10^{-15}	1.0×10^{-14}	9.9×10^{-14}	1.9×10^{-13}
Rat	EDEN	3.2×10^{-15}	1.0×10^{-14}	6.2×10^{-14}	1.3×10^{-13}
	EPIC	3.3×10^{-15}	1.2×10^{-14}	1.6×10^{-13}	3.1×10^{-13}
	EA R&D 128	8.4×10^{-15}	1.8×10^{-14}	9.8×10^{-14}	1.9×10^{-13}
	ERICA/FASSET	3.6×10^{-15}	1.1×10^{-14}	8.8×10^{-14}	1.7×10^{-13}
	RESRAD-Biota	2.6×10^{-15}	9.5×10^{-15}	8.7×10^{-14}	1.7×10^{-13}

Table B.2 Comparison of absorbed doses for on-soil-organisms per unit photon plane source strength (*Gy* per photon *m*$^{-2}$)

Organism	Model	Photon energy (*keV*)			
		60	122	662	1250
Earthworm	EDEN	1.0×10^{-15}	3.2×10^{-15}	3.1×10^{-14}	6.4×10^{-14}
	EPIC	1.4×10^{-15}	5.4×10^{-15}	4.8×10^{-14}	9.3×10^{-14}
	EA R&D 128	4.7×10^{-15}	9.6×10^{-15}	5.2×10^{-14}	9.9×10^{-14}
	ERICA	1.7×10^{-15}	5.4×10^{-15}	3.5×10^{-14}	6.9×10^{-14}
	RESRAD-Biota	1.2×10^{-15}	3.8×10^{-15}	3.0×10^{-14}	6.1×10^{-14}
Rat	EDEN	1.2×10^{-15}	3.6×10^{-15}	2.5×10^{-14}	5.1×10^{-14}
	EPIC	1.3×10^{-15}	5.2×10^{-15}	4.4×10^{-14}	8.7×10^{-14}
	EA R&D 128	4.2×10^{-15}	8.8×10^{-15}	4.9×10^{-14}	9.3×10^{-14}
	ERICA	1.7×10^{-15}	5.3×10^{-15}	3.5×10^{-14}	6.7×10^{-14}
	RESRAD-Biota	1.2×10^{-15}	3.8×10^{-15}	2.7×10^{-14}	6.1×10^{-14}

Table B.3 Comparison of photon absorbed fractions calculated by different models for selected ellipsoidal organisms

Target	Model	Photon energy (keV)			
		60	122	662	1250
Flatfish egg	EDEN	2.7×10^{-3}	1.9×10^{-3}	2.4×10^{-3}	2.2×10^{-3}
	EPIC	2.2×10^{-3}	1.9×10^{-3}	2.4×10^{-3}	2.2×10^{-3}
	EA R&D 128	2.5×10^{-3}	2.4×10^{-3}	2.3×10^{-3}	2.1×10^{-3}
	ERICA	2.2×10^{-3}	1.9×10^{-3}	1.3×10^{-3}	4.8×10^{-4}
	RESRAD-Biota	2.2×10^{-3}	1.9×10^{-3}	1.3×10^{-3}	4.6×10^{-4}
Earthworm	EDEN				
	EPIC	0.017	0.015	0.018	0.017
	EA R&D 128				
	ERICA	0.20	0.016	0.018	0.015
	RESRAD-Biota				
Rat	EDEN				
	EPIC	0.091	0.075	0.087	0.079
	EA R&D 128				
	ERICA	0.12	0.088	0.089	0.077
	RESRAD-Biota				
Duck	EDEN	0.23	0.15	0.14	0.12
	EPIC	0.14	0.12	0.14	0.12
	EA R&D 128	0.22	0.15	0.14	0.12
	ERICA	0.21	0.15	0.14	0.12
	RESRAD-Biota	0.15	0.12	0.13	0.12
Adult deer	EDEN	0.79	0.71	0.65	0.51
	EPIC	0.65	0.58	0.60	0.56
	EA R&D 128	0.80	0.66	0.55	0.51
	ERICA	0.76	0.68	0.60	0.54
	RESRAD-Biota	0.69	0.60	0.56	0.52
Pine tree trunk	EDEN	0.49	0.32	0.30	0.26
	EPIC	-	-	-	-
	EA R&D 128	0.33	0.29	0.22	0.20
	ERICA*	0.61	0.53	0.44	0.38
	RESRAD-Biota	0.27	0.20	0.22	0.20

* It has to be checked whether ERICA assumed the same dimensions as the other models

Appendix C: TABULATED VALUES OF DOSE CONVERSION FACTORS FOR REFERENCE ANIMALS AND PLANTS

Table 1. Dose conversion coefficients for the following organism

Organism name : Deer (adult) - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 2.45×10^2
Body shape proportions : 0.4620 0.4620
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.6×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.9×10^{-3}	0	0	100	6.0×10^{-9}	0	0	100
^{40}K	9.2×10^{-3}	0	0	100	6.0×10^{-6}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.9×10^{-15}	0	0	100
^{51}Cr	3.5×10^{-4}	0	15	85	1.2×10^{-6}	0	0	100
^{54}Mn	6.9×10^{-3}	0	1	99	3.2×10^{-5}	0	0	100
^{57}Co	1.5×10^{-3}	0	12	88	3.7×10^{-6}	0	0	100
^{58}Co	1.1×10^{-2}	0	0	100	3.8×10^{-5}	0	0	100
^{60}Co	2.0×10^{-2}	0	0	100	9.7×10^{-5}	0	0	100
^{59}Ni	9.6×10^{-5}	0	65	35	3.7×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	6.6×10^{-3}	0	1	99	2.2×10^{-5}	0	0	100
^{75}Se	3.8×10^{-3}	0	2	98	1.4×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	3.3×10^{-9}	0	0	100
^{90}Sr	1.6×10^{-2}	0	0	100	2.9×10^{-12}	0	0	100
^{95}Zr	7.8×10^{-3}	0	0	100	2.9×10^{-5}	0	0	100
^{94}Nb	1.5×10^{-2}	0	0	100	6.1×10^{-5}	0	0	100
^{95}Nb	6.9×10^{-3}	0	0	100	3.0×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	5.6×10^{-3}	0	1	99	1.8×10^{-5}	0	0	100
^{106}Ru	2.1×10^{-2}	0	0	100	8.0×10^{-6}	0	0	100
^{110m}Ag	2.3×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	4.5×10^{-7}	0	0	100
^{124}Sb	1.9×10^{-2}	0	0	100	7.0×10^{-5}	0	0	100
^{125}Sb	5.2×10^{-3}	0	1	99	1.7×10^{-5}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	2.8×10^{-6}	0	0	100

^{132}Te	3.0×10^{-2}	0	0	100	9.9×10^{-5}	0	0	100
^{125}I	8.0×10^{-4}	0	18	82	9.5×10^{-7}	0	0	100
^{129}I	1.2×10^{-3}	0	10	90	5.8×10^{-7}	0	0	100
^{131}I	6.0×10^{-3}	0	0	100	1.5×10^{-5}	0	0	100
^{132}I	2.5×10^{-2}	0	0	100	8.9×10^{-5}	0	0	100
^{133}I	1.1×10^{-2}	0	0	100	2.4×10^{-5}	0	0	100
^{134}Cs	1.5×10^{-2}	0	0	100	6.1×10^{-5}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.0×10^{-2}	0	0	100	8.3×10^{-5}	0	0	100
^{137}Cs	8.2×10^{-3}	0	0	100	2.2×10^{-5}	0	0	100
^{140}Ba	3.5×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{140}La	2.5×10^{-2}	0	0	100	8.9×10^{-5}	0	0	100
^{141}Ce	3.1×10^{-3}	0	1	99	2.4×10^{-6}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	1.8×10^{-6}	0	0	100
^{152}Eu	1.3×10^{-2}	0	1	99	4.4×10^{-5}	0	0	100
^{154}Eu	1.4×10^{-2}	0	0	100	4.8×10^{-5}	0	0	100
^{155}Eu	1.5×10^{-3}	0	4	96	1.7×10^{-6}	0	0	100
^{192}Ir	1.0×10^{-2}	0	0	100	3.2×10^{-5}	0	0	100
^{210}Pb	6.0×10^{-3}	0	2	98	5.5×10^{-8}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	3.3×10^{-10}	0	0	100
^{226}Ra	3.6×10^{-1}	92	0	8	6.8×10^{-5}	0	0	100
^{228}Ra	1.5×10^{-2}	0	1	99	3.7×10^{-5}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	3.8×10^{-6}	0	0	100
^{228}Th	4.7×10^{-1}	94	0	6	5.9×10^{-5}	0	0	100
^{229}Th	7.0×10^{-2}	96	0	3	2.6×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.3×10^{-8}	0	0	100
^{231}Th	2.6×10^{-3}	0	8	92	4.1×10^{-7}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	6.6×10^{-9}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	9.1×10^{-7}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	1.4×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.3×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	6.6×10^{-9}	0	0	100
^{235}U	6.6×10^{-2}	93	0	7	5.6×10^{-6}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	3.5×10^{-9}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	7.4×10^{-7}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	6.0×10^{-9}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	4.1×10^{-9}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	5.8×10^{-9}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	4.9×10^{-11}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.6×10^{-7}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	8.3×10^{-9}	0	0	100
^{243}Cm	8.3×10^{-2}	96	0	4	4.3×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	7.4×10^{-9}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	8.1×10^{-9}	0	0	100

Table 2. Dose conversion coefficients for the following organism

Organism name : Deer (adult) - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 2.45×10^2
Body shape proportions : 0.4620 0.4620
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.6×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.9×10^{-3}	0	0	100	3.6×10^{-7}	0	0	100
^{40}K	9.2×10^{-3}	0	0	100	3.9×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	5.9×10^{-12}	0	0	100
^{51}Cr	3.5×10^{-4}	0	15	85	7.2×10^{-5}	0	0	100
^{54}Mn	6.9×10^{-3}	0	1	99	2.0×10^{-3}	0	0	100
^{57}Co	1.5×10^{-3}	0	12	88	2.0×10^{-4}	0	0	100
^{58}Co	1.1×10^{-2}	0	0	100	2.4×10^{-3}	0	0	100
^{60}Co	2.0×10^{-2}	0	0	100	6.2×10^{-3}	0	0	100
^{59}Ni	9.6×10^{-5}	0	65	35	8.9×10^{-39}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	6.6×10^{-3}	0	1	99	1.4×10^{-3}	0	0	100
^{75}Se	3.8×10^{-3}	0	2	98	8.1×10^{-4}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	2.0×10^{-7}	0	0	100
^{90}Sr	1.6×10^{-2}	0	0	100	1.1×10^{-10}	0	0	100
^{95}Zr	7.8×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{94}Nb	1.5×10^{-2}	0	0	100	3.8×10^{-3}	0	0	100
^{95}Nb	6.9×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	5.6×10^{-3}	0	1	99	1.1×10^{-3}	0	0	100
^{106}Ru	2.1×10^{-2}	0	0	100	4.9×10^{-4}	0	0	100
^{110m}Ag	2.3×10^{-2}	0	0	100	6.7×10^{-3}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	1.2×10^{-5}	0	0	100
^{124}Sb	1.9×10^{-2}	0	0	100	4.5×10^{-3}	0	0	100
^{125}Sb	5.2×10^{-3}	0	1	99	9.9×10^{-4}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.6×10^{-4}	0	0	100
^{132}Te	3.0×10^{-2}	0	0	100	6.1×10^{-3}	0	0	100
^{125}I	8.0×10^{-4}	0	18	82	1.6×10^{-5}	0	0	100

^{129}I	1.2×10^{-3}	0	10	90	9.6×10^{-6}	0	0	100
^{131}I	6.0×10^{-3}	0	0	100	8.9×10^{-4}	0	0	100
^{132}I	2.5×10^{-2}	0	0	100	5.5×10^{-3}	0	0	100
^{133}I	1.1×10^{-2}	0	0	100	1.5×10^{-3}	0	0	100
^{134}Cs	1.5×10^{-2}	0	0	100	3.8×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.0×10^{-2}	0	0	100	5.2×10^{-3}	0	0	100
^{137}Cs	8.2×10^{-3}	0	0	100	1.4×10^{-3}	0	0	100
^{140}Ba	3.5×10^{-2}	0	0	100	7.0×10^{-3}	0	0	100
^{140}La	2.5×10^{-2}	0	0	100	5.7×10^{-3}	0	0	100
^{141}Ce	3.1×10^{-3}	0	1	99	1.3×10^{-4}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{152}Eu	1.3×10^{-2}	0	1	99	2.7×10^{-3}	0	0	100
^{154}Eu	1.4×10^{-2}	0	0	100	3.0×10^{-3}	0	0	100
^{155}Eu	1.5×10^{-3}	0	4	96	7.4×10^{-5}	0	0	100
^{192}Ir	1.0×10^{-2}	0	0	100	1.9×10^{-3}	0	0	100
^{210}Pb	6.0×10^{-3}	0	2	98	1.8×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	2.1×10^{-8}	0	0	100
^{226}Ra	3.6×10^{-1}	92	0	8	4.3×10^{-3}	0	0	100
^{228}Ra	1.5×10^{-2}	0	1	99	2.3×10^{-3}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	2.1×10^{-4}	0	0	100
^{228}Th	4.7×10^{-1}	94	0	6	3.8×10^{-3}	0	0	100
^{229}Th	7.0×10^{-2}	96	0	3	1.3×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	6.0×10^{-7}	0	0	100
^{231}Th	2.6×10^{-3}	0	8	92	1.7×10^{-5}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.2×10^{-7}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	5.3×10^{-5}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	8.1×10^{-5}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	7.2×10^{-7}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	4.0×10^{-7}	0	0	100
^{235}U	6.6×10^{-2}	93	0	7	3.1×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	2.4×10^{-7}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	3.3×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.4×10^{-7}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.3×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.3×10^{-7}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.5×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.2×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	3.0×10^{-7}	0	0	100
^{243}Cm	8.3×10^{-2}	96	0	4	2.4×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.7×10^{-7}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.2×10^{-7}	0	0	100

Table 3. Dose conversion coefficients for the following organism

Organism name : Rat - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : $3.14{\times}10^{-1}$
Body shape proportions : 0.3000 0.2500
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$7.9{\times}10^{-5}$	0	75	25	–	0	0	0
^{14}C	$6.8{\times}10^{-4}$	0	1	99	–	0	0	0
^{32}P	$9.2{\times}10^{-3}$	0	0	100	–	0	0	0
^{33}P	$1.1{\times}10^{-3}$	0	1	99	–	0	0	0
^{35}S	$6.8{\times}10^{-4}$	0	2	98	–	0	0	0
^{36}Cl	$3.8{\times}10^{-3}$	0	0	100	$1.2{\times}10^{-8}$	0	0	100
^{40}K	$8.0{\times}10^{-3}$	0	0	100	$1.1{\times}10^{-5}$	0	0	100
^{45}Ca	$1.1{\times}10^{-3}$	0	1	99	$1.6{\times}10^{-14}$	0	0	100
^{51}Cr	$1.1{\times}10^{-4}$	0	48	52	$2.5{\times}10^{-6}$	0	0	100
^{54}Mn	$1.1{\times}10^{-3}$	0	5	95	$6.5{\times}10^{-5}$	0	0	100
^{57}Co	$4.7{\times}10^{-4}$	0	39	61	$8.7{\times}10^{-6}$	0	0	100
^{58}Co	$4.0{\times}10^{-3}$	0	1	99	$7.7{\times}10^{-5}$	0	0	100
^{60}Co	$4.0{\times}10^{-3}$	0	0	100	$1.9{\times}10^{-4}$	0	0	100
^{59}Ni	$9.5{\times}10^{-5}$	0	66	34	$4.5{\times}10^{-43}$	0	0	100
^{63}Ni	$2.4{\times}10^{-4}$	0	12	88	–	0	0	0
^{65}Zn	$2.7{\times}10^{-3}$	0	2	98	$4.4{\times}10^{-5}$	0	0	100
^{75}Se	$7.8{\times}10^{-4}$	0	8	92	$3.0{\times}10^{-5}$	0	0	100
^{79}Se	$7.7{\times}10^{-4}$	0	1	99	–	0	0	0
^{89}Sr	$7.8{\times}10^{-3}$	0	0	100	$6.6{\times}10^{-9}$	0	0	100
^{90}Sr	$1.5{\times}10^{-2}$	0	0	100	$8.2{\times}10^{-12}$	0	0	100
^{95}Zr	$2.5{\times}10^{-3}$	0	0	100	$5.9{\times}10^{-5}$	0	0	100
^{94}Nb	$4.2{\times}10^{-3}$	0	0	100	$1.2{\times}10^{-4}$	0	0	100
^{95}Nb	$1.5{\times}10^{-3}$	0	1	99	$6.0{\times}10^{-5}$	0	0	100
^{99}Tc	$1.4{\times}10^{-3}$	0	0	100	–	0	0	0
^{103}Ru	$2.2{\times}10^{-3}$	0	2	98	$3.8{\times}10^{-5}$	0	0	100
^{106}Ru	$1.8{\times}10^{-2}$	0	0	100	$1.6{\times}10^{-5}$	0	0	100
^{110m}Ag	$4.4{\times}10^{-3}$	0	0	100	$2.1{\times}10^{-4}$	0	0	100
^{109}Cd	$1.3{\times}10^{-3}$	0	6	94	$1.3{\times}10^{-6}$	0	0	100
^{124}Sb	$7.1{\times}10^{-3}$	0	0	100	$1.4{\times}10^{-4}$	0	0	100
^{125}Sb	$2.0{\times}10^{-3}$	0	4	96	$3.4{\times}10^{-5}$	0	0	100
^{129m}Te	$1.3{\times}10^{-2}$	0	0	100	$5.9{\times}10^{-6}$	0	0	100
^{132}Te	$1.1{\times}10^{-2}$	0	1	99	$2.0{\times}10^{-4}$	0	0	100
^{125}I	$5.1{\times}10^{-4}$	0	28	72	$2.6{\times}10^{-6}$	0	0	100

^{129}I	1.0×10^{-3}	0	12	88	1.6×10^{-6}	0	0	100
^{131}I	3.1×10^{-3}	0	0	100	3.1×10^{-5}	0	0	100
^{132}I	9.4×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{133}I	6.3×10^{-3}	0	0	100	4.8×10^{-5}	0	0	100
^{134}Cs	4.1×10^{-3}	0	0	100	1.2×10^{-4}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	4.5×10^{-3}	0	1	99	1.7×10^{-4}	0	0	100
^{137}Cs	4.1×10^{-3}	0	0	100	4.5×10^{-5}	0	0	100
^{140}Ba	1.6×10^{-2}	0	1	99	2.1×10^{-4}	0	0	100
^{140}La	9.7×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	5.6×10^{-6}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	3.8×10^{-6}	0	0	100
^{152}Eu	5.4×10^{-3}	0	2	98	8.8×10^{-5}	0	0	100
^{154}Eu	5.4×10^{-3}	0	1	99	9.4×10^{-5}	0	0	100
^{155}Eu	9.8×10^{-4}	0	7	93	4.3×10^{-6}	0	0	100
^{192}Ir	4.2×10^{-3}	0	1	99	6.6×10^{-5}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	1.5×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.7×10^{-10}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	1.3×10^{-4}	0	0	100
^{228}Ra	7.9×10^{-3}	0	3	97	7.4×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	8.2×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	1.1×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	6.1×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.1×10^{-8}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.0×10^{-6}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	1.9×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	3.0×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	3.1×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.3×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	9.9×10^{-9}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.8×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.0×10^{-8}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.6×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.7×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	9.6×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.1×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.3×10^{-8}	0	0	100

Table 4. Dose conversion coefficients for the following organism

Organism name : Rat - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 3.14×10^{-1}
Body shape proportions : 0.3000 0.2500
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.2×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	7.3×10^{-7}	0	0	100
^{40}K	8.0×10^{-3}	0	0	100	7.1×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.3×10^{-11}	0	0	100
^{51}Cr	1.1×10^{-4}	0	48	52	1.5×10^{-4}	0	0	100
^{54}Mn	1.1×10^{-3}	0	5	95	4.0×10^{-3}	0	0	100
^{57}Co	4.7×10^{-4}	0	39	61	4.6×10^{-4}	0	0	100
^{58}Co	4.0×10^{-3}	0	1	99	4.6×10^{-3}	0	0	100
^{60}Co	4.0×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{59}Ni	9.5×10^{-5}	0	66	34	2.5×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.7×10^{-3}	0	2	98	2.7×10^{-3}	0	0	100
^{75}Se	7.8×10^{-4}	0	8	92	1.7×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.8×10^{-3}	0	0	100	4.0×10^{-7}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	3.8×10^{-10}	0	0	100
^{95}Zr	2.5×10^{-3}	0	0	100	3.5×10^{-3}	0	0	100
^{94}Nb	4.2×10^{-3}	0	0	100	7.5×10^{-3}	0	0	100
^{95}Nb	1.5×10^{-3}	0	1	99	3.6×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	2.2×10^{-3}	0	2	98	2.2×10^{-3}	0	0	100
^{106}Ru	1.8×10^{-2}	0	0	100	9.8×10^{-4}	0	0	100
^{110m}Ag	4.4×10^{-3}	0	0	100	1.3×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	3.3×10^{-5}	0	0	100
^{124}Sb	7.1×10^{-3}	0	0	100	8.4×10^{-3}	0	0	100
^{125}Sb	2.0×10^{-3}	0	4	96	2.0×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	3.2×10^{-4}	0	0	100
^{132}Te	1.1×10^{-2}	0	1	99	1.2×10^{-2}	0	0	100
^{125}I	5.1×10^{-4}	0	28	72	4.6×10^{-5}	0	0	100

^{129}I	1.0×10^{-3}	0	12	88	2.7×10^{-5}	0	0	100
^{131}I	3.1×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{132}I	9.4×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{133}I	6.3×10^{-3}	0	0	100	2.9×10^{-3}	0	0	100
^{134}Cs	4.1×10^{-3}	0	0	100	7.4×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	4.5×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{137}Cs	4.1×10^{-3}	0	0	100	2.7×10^{-3}	0	0	100
^{140}Ba	1.6×10^{-2}	0	1	99	1.3×10^{-2}	0	0	100
^{140}La	9.7×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	2.9×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	2.1×10^{-4}	0	0	100
^{152}Eu	5.4×10^{-3}	0	2	98	5.3×10^{-3}	0	0	100
^{154}Eu	5.4×10^{-3}	0	1	99	5.7×10^{-3}	0	0	100
^{155}Eu	9.8×10^{-4}	0	7	93	1.8×10^{-4}	0	0	100
^{192}Ir	4.2×10^{-3}	0	1	99	3.9×10^{-3}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	6.6×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.0×10^{-8}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	8.1×10^{-3}	0	0	100
^{228}Ra	7.9×10^{-3}	0	3	97	4.5×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.6×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	6.9×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	3.0×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	4.8×10^{-5}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	1.7×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.0×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.6×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	6.9×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	8.4×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.6×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.4×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.2×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.0×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	5.2×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	9.8×10^{-7}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.1×10^{-7}	0	0	100

Table 5. Dose conversion coefficients for the following organism

Organism name : Rat - in-soil

Habitat : terrestrial

Biota : animal

Body mass (kg) : 3.14×10^{-1}

Body shape proportions : 0.3000 0.2500

External exposure : in-soil

Source geometry : 50-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.2×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	1.8×10^{-6}	0	0	100
^{40}K	8.0×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	5.2×10^{-11}	0	0	100
^{51}Cr	1.1×10^{-4}	0	48	52	3.5×10^{-4}	0	0	100
^{54}Mn	1.1×10^{-3}	0	5	95	1.0×10^{-2}	0	0	100
^{57}Co	4.7×10^{-4}	0	39	61	9.2×10^{-4}	0	0	100
^{58}Co	4.0×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	4.0×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{59}Ni	9.5×10^{-5}	0	66	34	2.0×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.7×10^{-3}	0	2	98	6.9×10^{-3}	0	0	100
^{75}Se	7.8×10^{-4}	0	8	92	3.9×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.8×10^{-3}	0	0	100	1.0×10^{-6}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	3.0×10^{-9}	0	0	100
^{95}Zr	2.5×10^{-3}	0	0	100	9.0×10^{-3}	0	0	100
^{94}Nb	4.2×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{95}Nb	1.5×10^{-3}	0	1	99	9.3×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	2.2×10^{-3}	0	2	98	5.6×10^{-3}	0	0	100
^{106}Ru	1.8×10^{-2}	0	0	100	2.4×10^{-3}	0	0	100
^{110m}Ag	4.4×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	7.2×10^{-5}	0	0	100
^{124}Sb	7.1×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{125}Sb	2.0×10^{-3}	0	4	96	4.9×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	8.0×10^{-4}	0	0	100
^{132}Te	1.1×10^{-2}	0	1	99	3.0×10^{-2}	0	0	100
^{125}I	5.1×10^{-4}	0	28	72	1.1×10^{-4}	0	0	100

^{129}I	1.0×10^{-3}	0	12	88	7.3×10^{-5}	0	0	100
^{131}I	3.1×10^{-3}	0	0	100	4.3×10^{-3}	0	0	100
^{132}I	9.4×10^{-3}	0	0	100	2.7×10^{-2}	0	0	100
^{133}I	6.3×10^{-3}	0	0	100	7.2×10^{-3}	0	0	100
^{134}Cs	4.1×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	4.5×10^{-3}	0	1	99	2.5×10^{-2}	0	0	100
^{137}Cs	4.1×10^{-3}	0	0	100	6.8×10^{-3}	0	0	100
^{140}Ba	1.6×10^{-2}	0	1	99	3.3×10^{-2}	0	0	100
^{140}La	9.7×10^{-3}	0	0	100	2.7×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	6.1×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	5.2×10^{-4}	0	0	100
^{152}Eu	5.4×10^{-3}	0	2	98	1.3×10^{-2}	0	0	100
^{154}Eu	5.4×10^{-3}	0	1	99	1.4×10^{-2}	0	0	100
^{155}Eu	9.8×10^{-4}	0	7	93	3.6×10^{-4}	0	0	100
^{192}Ir	4.2×10^{-3}	0	1	99	9.2×10^{-3}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	1.3×10^{-5}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.0×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	2.0×10^{-2}	0	0	100
^{228}Ra	7.9×10^{-3}	0	3	97	1.1×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.0×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	1.8×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	6.3×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	4.4×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	9.5×10^{-5}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.0×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	2.6×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.0×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	4.4×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	3.5×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.5×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	2.4×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.7×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.3×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.2×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.3×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	3.5×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	1.1×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	3.2×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.4×10^{-6}	0	0	100

Table 6. Dose conversion coefficients for the following organism

Organism name : Duck egg - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 5.03×10^{-2}
Body shape proportions : 0.6670 0.6670
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.0×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	1.2×10^{-8}	0	0	100
^{40}K	7.8×10^{-3}	0	0	100	1.1×10^{-5}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.6×10^{-14}	0	0	100
^{51}Cr	9.2×10^{-5}	0	57	43	2.6×10^{-6}	0	0	100
^{54}Mn	6.6×10^{-4}	0	8	92	6.7×10^{-5}	0	0	100
^{57}Co	4.0×10^{-4}	0	45	55	8.8×10^{-6}	0	0	100
^{58}Co	3.5×10^{-3}	0	1	99	7.8×10^{-5}	0	0	100
^{60}Co	2.9×10^{-3}	0	0	100	1.9×10^{-4}	0	0	100
^{59}Ni	9.5×10^{-5}	0	67	33	4.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.4×10^{-3}	0	3	97	4.5×10^{-5}	0	0	100
^{75}Se	5.6×10^{-4}	0	11	89	3.1×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.6×10^{-3}	0	0	100	6.7×10^{-9}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	8.3×10^{-12}	0	0	100
^{95}Zr	2.1×10^{-3}	0	0	100	6.0×10^{-5}	0	0	100
^{94}Nb	3.4×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{95}Nb	1.2×10^{-3}	0	1	99	6.2×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.9×10^{-3}	0	2	98	3.9×10^{-5}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	1.7×10^{-5}	0	0	100
^{110m}Ag	3.1×10^{-3}	0	1	99	2.2×10^{-4}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	1.3×10^{-6}	0	0	100
^{124}Sb	6.2×10^{-3}	0	0	100	1.4×10^{-4}	0	0	100
^{125}Sb	1.7×10^{-3}	0	4	96	3.5×10^{-5}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	6.0×10^{-6}	0	0	100
^{132}Te	1.0×10^{-2}	0	1	99	2.1×10^{-4}	0	0	100
^{125}I	4.3×10^{-4}	0	34	66	2.7×10^{-6}	0	0	100

^{129}I	9.6×10^{-4}	0	12	88	1.6×10^{-6}	0	0	100
^{131}I	2.9×10^{-3}	0	0	100	3.1×10^{-5}	0	0	100
^{132}I	8.1×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{133}I	5.9×10^{-3}	0	0	100	4.9×10^{-5}	0	0	100
^{134}Cs	3.3×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	3.4×10^{-3}	0	1	99	1.7×10^{-4}	0	0	100
^{137}Cs	3.8×10^{-3}	0	0	100	4.6×10^{-5}	0	0	100
^{140}Ba	1.4×10^{-2}	0	1	99	2.1×10^{-4}	0	0	100
^{140}La	8.5×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	5.7×10^{-6}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	3.8×10^{-6}	0	0	100
^{152}Eu	4.8×10^{-3}	0	2	98	8.9×10^{-5}	0	0	100
^{154}Eu	4.8×10^{-3}	0	1	99	9.6×10^{-5}	0	0	100
^{155}Eu	9.3×10^{-4}	0	7	93	4.3×10^{-6}	0	0	100
^{192}Ir	3.7×10^{-3}	0	1	99	6.7×10^{-5}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	1.5×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.8×10^{-10}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	1.3×10^{-4}	0	0	100
^{228}Ra	7.3×10^{-3}	0	3	97	7.5×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	8.4×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	1.1×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	6.2×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	1.1×10^{-6}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	2.0×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	3.1×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	3.1×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.3×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.0×10^{-8}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.9×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.1×10^{-8}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.8×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	9.8×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.3×10^{-8}	0	0	100

Table 7. Dose conversion coefficients for the following organism

Organism name : Duck egg - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 5.03×10^{-2}
Body shape proportions : 0.6670 0.6670
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.0×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	7.4×10^{-7}	0	0	100
^{40}K	7.8×10^{-3}	0	0	100	7.2×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.4×10^{-11}	0	0	100
^{51}Cr	9.2×10^{-5}	0	57	43	1.5×10^{-4}	0	0	100
^{54}Mn	6.6×10^{-4}	0	8	92	4.0×10^{-3}	0	0	100
^{57}Co	4.0×10^{-4}	0	45	55	4.6×10^{-4}	0	0	100
^{58}Co	3.5×10^{-3}	0	1	99	4.7×10^{-3}	0	0	100
^{60}Co	2.9×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{59}Ni	9.5×10^{-5}	0	67	33	2.5×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.4×10^{-3}	0	3	97	2.8×10^{-3}	0	0	100
^{75}Se	5.6×10^{-4}	0	11	89	1.8×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.6×10^{-3}	0	0	100	4.1×10^{-7}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	3.8×10^{-10}	0	0	100
^{95}Zr	2.1×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{94}Nb	3.4×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{95}Nb	1.2×10^{-3}	0	1	99	3.7×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.9×10^{-3}	0	2	98	2.3×10^{-3}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	1.0×10^{-3}	0	0	100
^{110m}Ag	3.1×10^{-3}	0	1	99	1.3×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	3.4×10^{-5}	0	0	100
^{124}Sb	6.2×10^{-3}	0	0	100	8.5×10^{-3}	0	0	100
^{125}Sb	1.7×10^{-3}	0	4	96	2.0×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	3.3×10^{-4}	0	0	100
^{132}Te	1.0×10^{-2}	0	1	99	1.2×10^{-2}	0	0	100
^{125}I	4.3×10^{-4}	0	34	66	4.6×10^{-5}	0	0	100

^{129}I	9.6×10^{-4}	0	12	88	2.7×10^{-5}	0	0	100
^{131}I	2.9×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{132}I	8.1×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{133}I	5.9×10^{-3}	0	0	100	3.0×10^{-3}	0	0	100
^{134}Cs	3.3×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	3.4×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{137}Cs	3.8×10^{-3}	0	0	100	2.7×10^{-3}	0	0	100
^{140}Ba	1.4×10^{-2}	0	1	99	1.3×10^{-2}	0	0	100
^{140}La	8.5×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	2.9×10^{-4}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	2.2×10^{-4}	0	0	100
^{152}Eu	4.8×10^{-3}	0	2	98	5.4×10^{-3}	0	0	100
^{154}Eu	4.8×10^{-3}	0	1	99	5.8×10^{-3}	0	0	100
^{155}Eu	9.3×10^{-4}	0	7	93	1.8×10^{-4}	0	0	100
^{192}Ir	3.7×10^{-3}	0	1	99	3.9×10^{-3}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	6.7×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.1×10^{-8}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	8.2×10^{-3}	0	0	100
^{228}Ra	7.3×10^{-3}	0	3	97	4.6×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.6×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	7.0×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	3.1×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	4.9×10^{-5}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	1.8×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.1×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	7.0×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	8.5×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.8×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.4×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.3×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.1×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	5.3×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.3×10^{-7}	0	0	100

Table 8. Dose conversion coefficients for the following organism

Organism name : Duck - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 1.26×10^0
Body shape proportions : 0.3330 0.2670
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.4×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	1.2×10^{-8}	0	0	100
^{40}K	8.2×10^{-3}	0	0	100	1.1×10^{-5}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.5×10^{-14}	0	0	100
^{51}Cr	1.4×10^{-4}	0	39	61	2.4×10^{-6}	0	0	100
^{54}Mn	1.7×10^{-3}	0	3	97	6.2×10^{-5}	0	0	100
^{57}Co	5.8×10^{-4}	0	31	69	8.2×10^{-6}	0	0	100
^{58}Co	4.7×10^{-3}	0	1	99	7.3×10^{-5}	0	0	100
^{60}Co	5.7×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	4.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	3.1×10^{-3}	0	2	98	4.2×10^{-5}	0	0	100
^{75}Se	1.1×10^{-3}	0	6	94	2.8×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.9×10^{-3}	0	0	100	6.2×10^{-9}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	7.8×10^{-12}	0	0	100
^{95}Zr	3.1×10^{-3}	0	0	100	5.5×10^{-5}	0	0	100
^{94}Nb	5.3×10^{-3}	0	0	100	1.2×10^{-4}	0	0	100
^{95}Nb	2.1×10^{-3}	0	1	99	5.7×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	2.5×10^{-3}	0	2	98	3.6×10^{-5}	0	0	100
^{106}Ru	1.9×10^{-2}	0	0	100	1.5×10^{-5}	0	0	100
^{110m}Ag	6.4×10^{-3}	0	0	100	2.0×10^{-4}	0	0	100
^{109}Cd	1.4×10^{-3}	0	6	94	1.2×10^{-6}	0	0	100
^{124}Sb	8.4×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{125}Sb	2.3×10^{-3}	0	3	97	3.2×10^{-5}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	5.6×10^{-6}	0	0	100
^{132}Te	1.3×10^{-2}	0	0	100	1.9×10^{-4}	0	0	100
^{125}I	6.0×10^{-4}	0	24	76	2.5×10^{-6}	0	0	100

^{129}I	1.1×10^{-3}	0	11	89	1.5×10^{-6}	0	0	100
^{131}I	3.4×10^{-3}	0	0	100	2.9×10^{-5}	0	0	100
^{132}I	1.1×10^{-2}	0	0	100	1.7×10^{-4}	0	0	100
^{133}I	6.8×10^{-3}	0	0	100	4.6×10^{-5}	0	0	100
^{134}Cs	5.3×10^{-3}	0	0	100	1.2×10^{-4}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	6.0×10^{-3}	0	0	100	1.6×10^{-4}	0	0	100
^{137}Cs	4.5×10^{-3}	0	0	100	4.3×10^{-5}	0	0	100
^{140}Ba	1.8×10^{-2}	0	1	99	2.0×10^{-4}	0	0	100
^{140}La	1.1×10^{-2}	0	0	100	1.6×10^{-4}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	5.3×10^{-6}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	3.6×10^{-6}	0	0	100
^{152}Eu	6.2×10^{-3}	0	1	99	8.3×10^{-5}	0	0	100
^{154}Eu	6.3×10^{-3}	0	1	99	9.0×10^{-5}	0	0	100
^{155}Eu	1.0×10^{-3}	0	6	94	4.0×10^{-6}	0	0	100
^{192}Ir	4.8×10^{-3}	0	0	100	6.2×10^{-5}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	1.4×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.3×10^{-10}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	1.2×10^{-4}	0	0	100
^{228}Ra	8.6×10^{-3}	0	3	97	7.0×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	7.7×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	1.0×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	5.8×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.0×10^{-8}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	9.8×10^{-7}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	1.6×10^{-8}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	1.8×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	2.8×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.9×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.2×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	9.3×10^{-9}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	1.7×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.6×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	9.9×10^{-9}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.6×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.1×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.6×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	9.0×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.0×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100

Table 9. Dose conversion coefficients for the following organism

Organism name : Duck - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 1.26×10^0
Body shape proportions : 0.3330 0.2670
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.4×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	6.9×10^{-7}	0	0	100
^{40}K	8.2×10^{-3}	0	0	100	6.8×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.1×10^{-11}	0	0	100
^{51}Cr	1.4×10^{-4}	0	39	61	1.4×10^{-4}	0	0	100
^{54}Mn	1.7×10^{-3}	0	3	97	3.8×10^{-3}	0	0	100
^{57}Co	5.8×10^{-4}	0	31	69	4.3×10^{-4}	0	0	100
^{58}Co	4.7×10^{-3}	0	1	99	4.4×10^{-3}	0	0	100
^{60}Co	5.7×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	2.4×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	3.1×10^{-3}	0	2	98	2.6×10^{-3}	0	0	100
^{75}Se	1.1×10^{-3}	0	6	94	1.6×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.9×10^{-3}	0	0	100	3.8×10^{-7}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	3.5×10^{-10}	0	0	100
^{95}Zr	3.1×10^{-3}	0	0	100	3.3×10^{-3}	0	0	100
^{94}Nb	5.3×10^{-3}	0	0	100	7.1×10^{-3}	0	0	100
^{95}Nb	2.1×10^{-3}	0	1	99	3.5×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	2.5×10^{-3}	0	2	98	2.1×10^{-3}	0	0	100
^{106}Ru	1.9×10^{-2}	0	0	100	9.3×10^{-4}	0	0	100
^{110m}Ag	6.4×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{109}Cd	1.4×10^{-3}	0	6	94	3.1×10^{-5}	0	0	100
^{124}Sb	8.4×10^{-3}	0	0	100	8.0×10^{-3}	0	0	100
^{125}Sb	2.3×10^{-3}	0	3	97	1.9×10^{-3}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	3.1×10^{-4}	0	0	100
^{132}Te	1.3×10^{-2}	0	0	100	1.1×10^{-2}	0	0	100
^{125}I	6.0×10^{-4}	0	24	76	4.3×10^{-5}	0	0	100

^{129}I	1.1×10^{-3}	0	11	89	2.5×10^{-5}	0	0	100
^{131}I	3.4×10^{-3}	0	0	100	1.7×10^{-3}	0	0	100
^{132}I	1.1×10^{-2}	0	0	100	1.0×10^{-2}	0	0	100
^{133}I	6.8×10^{-3}	0	0	100	2.7×10^{-3}	0	0	100
^{134}Cs	5.3×10^{-3}	0	0	100	7.0×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	6.0×10^{-3}	0	0	100	9.6×10^{-3}	0	0	100
^{137}Cs	4.5×10^{-3}	0	0	100	2.6×10^{-3}	0	0	100
^{140}Ba	1.8×10^{-2}	0	1	99	1.2×10^{-2}	0	0	100
^{140}La	1.1×10^{-2}	0	0	100	1.0×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	2.7×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	2.0×10^{-4}	0	0	100
^{152}Eu	6.2×10^{-3}	0	1	99	5.0×10^{-3}	0	0	100
^{154}Eu	6.3×10^{-3}	0	1	99	5.5×10^{-3}	0	0	100
^{155}Eu	1.0×10^{-3}	0	6	94	1.7×10^{-4}	0	0	100
^{192}Ir	4.8×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	6.2×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	3.8×10^{-8}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	7.7×10^{-3}	0	0	100
^{228}Ra	8.6×10^{-3}	0	3	97	4.3×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.3×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	6.6×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	2.8×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.6×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	4.5×10^{-5}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	9.4×10^{-7}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	1.0×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	1.6×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.9×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	6.5×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	7.9×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.4×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.1×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.3×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	5.9×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	5.7×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	4.9×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	9.2×10^{-7}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	6.7×10^{-7}	0	0	100

Table 10. Dose conversion coefficients for the following organism

Organism name : Duck - aquatic

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 1.26×10^0

Body shape proportions : 0.3330 0.2670

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	8.5×10^{-12}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	4.3×10^{-7}	0	0	100
^{32}P	9.4×10^{-3}	0	0	100	2.3×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	1.5×10^{-6}	0	0	100
^{35}S	6.8×10^{-4}	0	2	98	4.6×10^{-7}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	3.3×10^{-5}	0	0	100
^{40}K	8.2×10^{-3}	0	0	100	2.1×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.5×10^{-6}	0	0	100
^{51}Cr	1.4×10^{-4}	0	39	61	3.7×10^{-4}	0	0	100
^{54}Mn	1.7×10^{-3}	0	3	97	1.0×10^{-2}	0	0	100
^{57}Co	5.8×10^{-4}	0	31	69	1.4×10^{-3}	0	0	100
^{58}Co	4.7×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	5.7×10^{-3}	0	0	100	3.0×10^{-2}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	5.9×10^{-7}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	2.7×10^{-8}	0	0	100
^{65}Zn	3.1×10^{-3}	0	2	98	7.0×10^{-3}	0	0	100
^{75}Se	1.1×10^{-3}	0	6	94	4.6×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	5.7×10^{-7}	0	0	100
^{89}Sr	7.9×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	4.8×10^{-4}	0	0	100
^{95}Zr	3.1×10^{-3}	0	0	100	8.8×10^{-3}	0	0	100
^{94}Nb	5.3×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{95}Nb	2.1×10^{-3}	0	1	99	9.1×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	2.9×10^{-6}	0	0	100
^{103}Ru	2.5×10^{-3}	0	2	98	5.5×10^{-3}	0	0	100
^{106}Ru	1.9×10^{-2}	0	0	100	3.5×10^{-3}	0	0	100
^{110m}Ag	6.4×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{109}Cd	1.4×10^{-3}	0	6	94	1.2×10^{-4}	0	0	100
^{124}Sb	8.4×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{125}Sb	2.3×10^{-3}	0	3	97	5.0×10^{-3}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.1×10^{-3}	0	0	100
^{132}Te	1.3×10^{-2}	0	0	100	3.1×10^{-2}	0	0	100
^{125}I	6.0×10^{-4}	0	24	76	2.5×10^{-4}	0	0	100

^{129}I	1.1×10^{-3}	0	11	89	1.7×10^{-4}	0	0	100
^{131}I	3.4×10^{-3}	0	0	100	4.5×10^{-3}	0	0	100
^{132}I	1.1×10^{-2}	0	0	100	2.7×10^{-2}	0	0	100
^{133}I	6.8×10^{-3}	0	0	100	7.3×10^{-3}	0	0	100
^{134}Cs	5.3×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	1.0×10^{-6}	0	0	100
^{136}Cs	6.0×10^{-3}	0	0	100	2.6×10^{-2}	0	0	100
^{137}Cs	4.5×10^{-3}	0	0	100	6.7×10^{-3}	0	0	100
^{140}Ba	1.8×10^{-2}	0	1	99	3.5×10^{-2}	0	0	100
^{140}La	1.1×10^{-2}	0	0	100	2.8×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	8.8×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	1.4×10^{-3}	0	0	100
^{152}Eu	6.2×10^{-3}	0	1	99	1.4×10^{-2}	0	0	100
^{154}Eu	6.3×10^{-3}	0	1	99	1.5×10^{-2}	0	0	100
^{155}Eu	1.0×10^{-3}	0	6	94	6.7×10^{-4}	0	0	100
^{192}Ir	4.8×10^{-3}	0	0	100	9.6×10^{-3}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	9.3×10^{-5}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.0×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	2.2×10^{-2}	0	0	100
^{228}Ra	8.6×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.2×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	2.0×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	9.9×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	5.8×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.6×10^{-4}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.4×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	6.7×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.4×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	5.2×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	3.7×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.9×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	2.3×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	2.9×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.3×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.9×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.2×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.0×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.5×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	3.7×10^{-6}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	1.5×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	3.4×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	3.0×10^{-6}	0	0	100

Table 11. Dose conversion coefficients for the following organism

Organism name : Frog egg - aquatic

Habitat : aquatic

Biota : aquatic

Body mass (kg) : $5.24{\times}10^{-4}$

Body shape proportions : 1.0000 1.0000

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$7.9{\times}10^{-5}$	0	75	25	$2.9{\times}10^{-10}$	0	0	100
^{14}C	$6.8{\times}10^{-4}$	0	1	99	$5.2{\times}10^{-6}$	0	0	100
^{32}P	$6.9{\times}10^{-3}$	0	0	100	$2.7{\times}10^{-3}$	0	0	100
^{33}P	$1.0{\times}10^{-3}$	0	1	99	$1.7{\times}10^{-5}$	0	0	100
^{35}S	$6.7{\times}10^{-4}$	0	2	98	$5.5{\times}10^{-6}$	0	0	100
^{36}Cl	$3.5{\times}10^{-3}$	0	0	100	$3.7{\times}10^{-4}$	0	0	100
^{40}K	$6.3{\times}10^{-3}$	0	0	100	$4.0{\times}10^{-3}$	0	0	100
^{45}Ca	$1.1{\times}10^{-3}$	0	1	99	$1.8{\times}10^{-5}$	0	0	100
^{51}Cr	$7.2{\times}10^{-5}$	0	74	26	$4.3{\times}10^{-4}$	0	0	100
^{54}Mn	$1.9{\times}10^{-4}$	0	30	70	$1.1{\times}10^{-2}$	0	0	100
^{57}Co	$3.2{\times}10^{-4}$	0	57	43	$1.7{\times}10^{-3}$	0	0	100
^{58}Co	$2.9{\times}10^{-3}$	0	2	98	$1.3{\times}10^{-2}$	0	0	100
^{60}Co	$1.6{\times}10^{-3}$	0	0	100	$3.4{\times}10^{-2}$	0	0	100
^{59}Ni	$8.9{\times}10^{-5}$	0	71	29	$7.2{\times}10^{-6}$	0	0	100
^{63}Ni	$2.4{\times}10^{-4}$	0	12	88	$3.5{\times}10^{-7}$	0	0	100
^{65}Zn	$2.1{\times}10^{-3}$	0	3	97	$8.0{\times}10^{-3}$	0	0	100
^{75}Se	$3.1{\times}10^{-4}$	0	21	79	$5.3{\times}10^{-3}$	0	0	100
^{79}Se	$7.7{\times}10^{-4}$	0	1	99	$6.8{\times}10^{-6}$	0	0	100
^{89}Sr	$6.1{\times}10^{-3}$	0	0	100	$2.0{\times}10^{-3}$	0	0	100
^{90}Sr	$1.0{\times}10^{-2}$	0	0	100	$5.3{\times}10^{-3}$	0	0	100
^{95}Zr	$1.7{\times}10^{-3}$	0	0	100	$1.0{\times}10^{-2}$	0	0	100
^{94}Nb	$2.4{\times}10^{-3}$	0	0	100	$2.2{\times}10^{-2}$	0	0	100
^{95}Nb	$7.2{\times}10^{-4}$	0	2	98	$1.1{\times}10^{-2}$	0	0	100
^{99}Tc	$1.4{\times}10^{-3}$	0	0	100	$3.3{\times}10^{-5}$	0	0	100
^{103}Ru	$1.6{\times}10^{-3}$	0	3	97	$6.5{\times}10^{-3}$	0	0	100
^{106}Ru	$9.0{\times}10^{-3}$	0	0	100	$1.4{\times}10^{-2}$	0	0	100
^{110m}Ag	$1.4{\times}10^{-3}$	0	1	99	$3.8{\times}10^{-2}$	0	0	100
^{109}Cd	$1.2{\times}10^{-3}$	0	7	93	$3.4{\times}10^{-4}$	0	0	100
^{124}Sb	$4.1{\times}10^{-3}$	0	0	100	$2.6{\times}10^{-2}$	0	0	100
^{125}Sb	$1.4{\times}10^{-3}$	0	5	95	$5.9{\times}10^{-3}$	0	0	100
^{129m}Te	$1.1{\times}10^{-2}$	0	1	99	$4.1{\times}10^{-3}$	0	0	100
^{132}Te	$7.2{\times}10^{-3}$	0	1	99	$3.7{\times}10^{-2}$	0	0	100
^{125}I	$3.1{\times}10^{-4}$	0	47	53	$5.4{\times}10^{-4}$	0	0	100

^{129}I	9.0×10^{-4}	0	13	87	3.3×10^{-4}	0	0	100
^{131}I	2.6×10^{-3}	0	0	100	5.4×10^{-3}	0	0	100
^{132}I	5.6×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{133}I	4.8×10^{-3}	0	0	100	9.3×10^{-3}	0	0	100
^{134}Cs	2.3×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{135}Cs	9.2×10^{-4}	0	1	99	1.2×10^{-5}	0	0	100
^{136}Cs	2.1×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	3.2×10^{-3}	0	0	100	8.1×10^{-3}	0	0	100
^{140}Ba	1.1×10^{-2}	0	1	99	4.2×10^{-2}	0	0	100
^{140}La	6.0×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	1.1×10^{-3}	0	0	100
^{144}Ce	9.9×10^{-3}	0	0	100	9.0×10^{-3}	0	0	100
^{152}Eu	3.8×10^{-3}	0	2	98	1.6×10^{-2}	0	0	100
^{154}Eu	3.7×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	8.3×10^{-4}	0	0	100
^{192}Ir	3.1×10^{-3}	0	1	99	1.1×10^{-2}	0	0	100
^{210}Pb	5.1×10^{-3}	0	2	98	9.0×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	2.8×10^{-2}	0	0	100
^{228}Ra	5.9×10^{-3}	0	4	96	1.4×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	2.6×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	3.2×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{234}Th	8.2×10^{-3}	0	0	100	4.5×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.1×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.4×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.4×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	4.3×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.2×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.2×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.0×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.8×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.8×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100

Table 12. Dose conversion coefficients for the following organism

Organism name : Frog egg mass - aquatic

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 3.14×10^{-1}

Body shape proportions : 0.3000 0.2500

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	2.5×10^{-13}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	6.8×10^{-7}	0	0	100
^{32}P	9.2×10^{-3}	0	0	100	3.7×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	2.3×10^{-6}	0	0	100
^{35}S	6.8×10^{-4}	0	2	98	7.2×10^{-7}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	4.9×10^{-5}	0	0	100
^{40}K	8.0×10^{-3}	0	0	100	2.3×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	2.4×10^{-6}	0	0	100
^{51}Cr	1.1×10^{-4}	0	48	52	3.9×10^{-4}	0	0	100
^{54}Mn	1.1×10^{-3}	0	5	95	1.1×10^{-2}	0	0	100
^{57}Co	4.7×10^{-4}	0	39	61	1.5×10^{-3}	0	0	100
^{58}Co	4.0×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	4.0×10^{-3}	0	0	100	3.2×10^{-2}	0	0	100
^{59}Ni	9.5×10^{-5}	0	66	34	9.4×10^{-7}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	5.1×10^{-8}	0	0	100
^{65}Zn	2.7×10^{-3}	0	2	98	7.4×10^{-3}	0	0	100
^{75}Se	7.8×10^{-4}	0	8	92	4.9×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	8.8×10^{-7}	0	0	100
^{89}Sr	7.8×10^{-3}	0	0	100	2.7×10^{-4}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	7.4×10^{-4}	0	0	100
^{95}Zr	2.5×10^{-3}	0	0	100	9.3×10^{-3}	0	0	100
^{94}Nb	4.2×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{95}Nb	1.5×10^{-3}	0	1	99	9.7×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	4.4×10^{-6}	0	0	100
^{103}Ru	2.2×10^{-3}	0	2	98	5.9×10^{-3}	0	0	100
^{106}Ru	1.8×10^{-2}	0	0	100	4.3×10^{-3}	0	0	100
^{110m}Ag	4.4×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	1.7×10^{-4}	0	0	100
^{124}Sb	7.1×10^{-3}	0	0	100	2.3×10^{-2}	0	0	100
^{125}Sb	2.0×10^{-3}	0	4	96	5.4×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	1.3×10^{-3}	0	0	100
^{132}Te	1.1×10^{-2}	0	1	99	3.3×10^{-2}	0	0	100
^{125}I	5.1×10^{-4}	0	28	72	3.4×10^{-4}	0	0	100

^{129}I	1.0×10^{-3}	0	12	88	2.2×10^{-4}	0	0	100
^{131}I	3.1×10^{-3}	0	0	100	4.8×10^{-3}	0	0	100
^{132}I	9.4×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{133}I	6.3×10^{-3}	0	0	100	7.8×10^{-3}	0	0	100
^{134}Cs	4.1×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	1.6×10^{-6}	0	0	100
^{136}Cs	4.5×10^{-3}	0	1	99	2.7×10^{-2}	0	0	100
^{137}Cs	4.1×10^{-3}	0	0	100	7.1×10^{-3}	0	0	100
^{140}Ba	1.6×10^{-2}	0	1	99	3.7×10^{-2}	0	0	100
^{140}La	9.7×10^{-3}	0	0	100	3.0×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	9.6×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	1.9×10^{-3}	0	0	100
^{152}Eu	5.4×10^{-3}	0	2	98	1.5×10^{-2}	0	0	100
^{154}Eu	5.4×10^{-3}	0	1	99	1.6×10^{-2}	0	0	100
^{155}Eu	9.8×10^{-4}	0	7	93	7.4×10^{-4}	0	0	100
^{192}Ir	4.2×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	1.4×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	2.3×10^{-2}	0	0	100
^{228}Ra	7.9×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.3×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	2.1×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	1.1×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	7.1×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.9×10^{-4}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	4.6×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	8.9×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.9×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	6.5×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	5.3×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	2.1×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	3.6×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	3.3×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	5.2×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.6×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	5.0×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.2×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.9×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	5.9×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	1.6×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	5.4×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	4.6×10^{-6}	0	0	100

Table 13. Dose conversion coefficients for the following organism

Organism name : Tadpole - aquatic
Habitat : aquatic
Biota : aquatic
Body mass (kg) : 4.42×10^{-4}
Body shape proportions : 0.5000 0.5000
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	3.2×10^{-10}	0	1	99
^{14}C	6.8×10^{-4}	0	1	99	5.5×10^{-6}	0	0	100
^{32}P	6.8×10^{-3}	0	0	100	2.9×10^{-3}	0	0	100
^{33}P	1.0×10^{-3}	0	1	99	1.8×10^{-5}	0	0	100
^{35}S	6.7×10^{-4}	0	2	98	5.8×10^{-6}	0	0	100
^{36}Cl	3.5×10^{-3}	0	0	100	4.0×10^{-4}	0	0	100
^{40}K	6.1×10^{-3}	0	0	100	4.1×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.9×10^{-5}	0	0	100
^{51}Cr	7.1×10^{-5}	0	74	26	4.3×10^{-4}	0	0	100
^{54}Mn	1.8×10^{-4}	0	31	69	1.1×10^{-2}	0	0	100
^{57}Co	3.2×10^{-4}	0	58	42	1.7×10^{-3}	0	0	100
^{58}Co	2.8×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.5×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{59}Ni	8.9×10^{-5}	0	71	29	7.7×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	3.7×10^{-7}	0	0	100
^{65}Zn	2.1×10^{-3}	0	3	97	8.1×10^{-3}	0	0	100
^{75}Se	3.0×10^{-4}	0	21	79	5.4×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	7.2×10^{-6}	0	0	100
^{89}Sr	6.0×10^{-3}	0	0	100	2.1×10^{-3}	0	0	100
^{90}Sr	1.0×10^{-2}	0	0	100	5.6×10^{-3}	0	0	100
^{95}Zr	1.7×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.4×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	7.1×10^{-4}	0	2	98	1.1×10^{-2}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	3.5×10^{-5}	0	0	100
^{103}Ru	1.6×10^{-3}	0	3	97	6.5×10^{-3}	0	0	100
^{106}Ru	8.6×10^{-3}	0	0	100	1.4×10^{-2}	0	0	100
^{110m}Ag	1.4×10^{-3}	0	1	99	3.8×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	3.4×10^{-4}	0	0	100
^{124}Sb	4.1×10^{-3}	0	0	100	2.6×10^{-2}	0	0	100
^{125}Sb	1.4×10^{-3}	0	5	95	5.9×10^{-3}	0	0	100
^{129m}Te	1.0×10^{-2}	0	1	99	4.3×10^{-3}	0	0	100
^{132}Te	7.1×10^{-3}	0	1	99	3.7×10^{-2}	0	0	100
^{125}I	3.1×10^{-4}	0	47	53	5.5×10^{-4}	0	0	100

^{129}I	9.0×10^{-4}	0	13	87	3.3×10^{-4}	0	0	100
^{131}I	2.5×10^{-3}	0	0	100	5.4×10^{-3}	0	0	100
^{132}I	5.4×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{133}I	4.7×10^{-3}	0	0	100	9.4×10^{-3}	0	0	100
^{134}Cs	2.3×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{135}Cs	9.2×10^{-4}	0	1	99	1.3×10^{-5}	0	0	100
^{136}Cs	2.1×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	3.2×10^{-3}	0	0	100	8.1×10^{-3}	0	0	100
^{140}Ba	1.1×10^{-2}	0	1	99	4.2×10^{-2}	0	0	100
^{140}La	5.9×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	1.1×10^{-3}	0	0	100
^{144}Ce	9.5×10^{-3}	0	0	100	9.4×10^{-3}	0	0	100
^{152}Eu	3.8×10^{-3}	0	2	98	1.6×10^{-2}	0	0	100
^{154}Eu	3.6×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.8×10^{-4}	0	7	93	8.3×10^{-4}	0	0	100
^{192}Ir	3.0×10^{-3}	0	1	99	1.1×10^{-2}	0	0	100
^{210}Pb	5.0×10^{-3}	0	2	98	9.5×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	2.8×10^{-2}	0	0	100
^{228}Ra	5.8×10^{-3}	0	4	96	1.4×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	2.6×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	3.2×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100
^{234}Th	7.9×10^{-3}	0	0	100	4.7×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.1×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.4×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.4×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	4.4×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.8×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.4×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.2×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.1×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.9×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.8×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100

Table 14. Dose conversion coefficients for the following organism

Organism name : Frog - aquatic

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 3.14×10^{-2}

Body shape proportions : 0.3750 0.3130

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	5.9×10^{-11}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	1.4×10^{-6}	0	0	100
^{32}P	8.9×10^{-3}	0	0	100	7.5×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	4.6×10^{-6}	0	0	100
^{35}S	6.7×10^{-4}	0	2	98	1.5×10^{-6}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	1.0×10^{-4}	0	0	100
^{40}K	7.7×10^{-3}	0	0	100	2.6×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	4.9×10^{-6}	0	0	100
^{51}Cr	8.8×10^{-5}	0	60	40	4.2×10^{-4}	0	0	100
^{54}Mn	5.5×10^{-4}	0	10	90	1.1×10^{-2}	0	0	100
^{57}Co	3.8×10^{-4}	0	48	52	1.6×10^{-3}	0	0	100
^{58}Co	3.4×10^{-3}	0	2	98	1.3×10^{-2}	0	0	100
^{60}Co	2.6×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{59}Ni	9.4×10^{-5}	0	67	33	2.0×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	9.1×10^{-8}	0	0	100
^{65}Zn	2.4×10^{-3}	0	3	97	7.8×10^{-3}	0	0	100
^{75}Se	5.0×10^{-4}	0	13	87	5.2×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	1.8×10^{-6}	0	0	100
^{89}Sr	7.5×10^{-3}	0	0	100	5.5×10^{-4}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	1.5×10^{-3}	0	0	100
^{95}Zr	2.0×10^{-3}	0	0	100	9.8×10^{-3}	0	0	100
^{94}Nb	3.2×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{95}Nb	1.1×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	9.0×10^{-6}	0	0	100
^{103}Ru	1.8×10^{-3}	0	2	98	6.2×10^{-3}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	6.1×10^{-3}	0	0	100
^{110m}Ag	2.7×10^{-3}	0	1	99	3.7×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	7	93	2.5×10^{-4}	0	0	100
^{124}Sb	5.9×10^{-3}	0	0	100	2.5×10^{-2}	0	0	100
^{125}Sb	1.7×10^{-3}	0	4	96	5.7×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	1.8×10^{-3}	0	0	100
^{132}Te	9.5×10^{-3}	0	1	99	3.5×10^{-2}	0	0	100
^{125}I	4.0×10^{-4}	0	36	64	4.5×10^{-4}	0	0	100

^{129}I	9.5×10^{-4}	0	13	87	2.8×10^{-4}	0	0	100
^{131}I	2.8×10^{-3}	0	0	100	5.1×10^{-3}	0	0	100
^{132}I	7.7×10^{-3}	0	0	100	3.1×10^{-2}	0	0	100
^{133}I	5.8×10^{-3}	0	0	100	8.3×10^{-3}	0	0	100
^{134}Cs	3.1×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	3.3×10^{-6}	0	0	100
^{136}Cs	3.1×10^{-3}	0	1	99	2.9×10^{-2}	0	0	100
^{137}Cs	3.7×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{140}Ba	1.4×10^{-2}	0	1	99	3.9×10^{-2}	0	0	100
^{140}La	8.1×10^{-3}	0	0	100	3.1×10^{-2}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	1.0×10^{-3}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	3.2×10^{-3}	0	0	100
^{152}Eu	4.6×10^{-3}	0	2	98	1.5×10^{-2}	0	0	100
^{154}Eu	4.6×10^{-3}	0	1	99	1.7×10^{-2}	0	0	100
^{155}Eu	9.2×10^{-4}	0	7	93	7.9×10^{-4}	0	0	100
^{192}Ir	3.6×10^{-3}	0	1	99	1.1×10^{-2}	0	0	100
^{210}Pb	5.7×10^{-3}	0	2	98	2.6×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	2.4×10^{-2}	0	0	100
^{228}Ra	7.1×10^{-3}	0	3	97	1.3×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.4×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	2.2×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	1.2×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	9.7×10^{-6}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	2.4×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	6.9×10^{-6}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	1.5×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	5.4×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	8.9×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	8.8×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	2.3×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	6.4×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	3.7×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	9.4×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	4.2×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	9.0×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.6×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	3.4×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.0×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.7×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	9.5×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.8×10^{-6}	0	0	100

Table 15. Dose conversion coefficients for the following organism

Organism name : Frog - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 3.14×10^{-2}
Body shape proportions : 0.3750 0.3130
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	8.9×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	1.3×10^{-8}	0	0	100
^{40}K	7.7×10^{-3}	0	0	100	1.2×10^{-5}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.6×10^{-14}	0	0	100
^{51}Cr	8.8×10^{-5}	0	60	40	2.6×10^{-6}	0	0	100
^{54}Mn	5.5×10^{-4}	0	10	90	6.7×10^{-5}	0	0	100
^{57}Co	3.8×10^{-4}	0	48	52	8.9×10^{-6}	0	0	100
^{58}Co	3.4×10^{-3}	0	2	98	7.9×10^{-5}	0	0	100
^{60}Co	2.6×10^{-3}	0	0	100	1.9×10^{-4}	0	0	100
^{59}Ni	9.4×10^{-5}	0	67	33	4.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.4×10^{-3}	0	3	97	4.5×10^{-5}	0	0	100
^{75}Se	5.0×10^{-4}	0	13	87	3.1×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.5×10^{-3}	0	0	100	6.7×10^{-9}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	8.4×10^{-12}	0	0	100
^{95}Zr	2.0×10^{-3}	0	0	100	6.0×10^{-5}	0	0	100
^{94}Nb	3.2×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{95}Nb	1.1×10^{-3}	0	1	99	6.2×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.8×10^{-3}	0	2	98	3.9×10^{-5}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	1.7×10^{-5}	0	0	100
^{110m}Ag	2.7×10^{-3}	0	1	99	2.2×10^{-4}	0	0	100
^{109}Cd	1.3×10^{-3}	0	7	93	1.3×10^{-6}	0	0	100
^{124}Sb	5.9×10^{-3}	0	0	100	1.4×10^{-4}	0	0	100
^{125}Sb	1.7×10^{-3}	0	4	96	3.5×10^{-5}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	6.0×10^{-6}	0	0	100
^{132}Te	9.5×10^{-3}	0	1	99	2.1×10^{-4}	0	0	100
^{125}I	4.0×10^{-4}	0	36	64	2.7×10^{-6}	0	0	100

^{129}I	9.5×10^{-4}	0	13	87	1.6×10^{-6}	0	0	100
^{131}I	2.8×10^{-3}	0	0	100	3.1×10^{-5}	0	0	100
^{132}I	7.7×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{133}I	5.8×10^{-3}	0	0	100	4.9×10^{-5}	0	0	100
^{134}Cs	3.1×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	3.1×10^{-3}	0	1	99	1.7×10^{-4}	0	0	100
^{137}Cs	3.7×10^{-3}	0	0	100	4.6×10^{-5}	0	0	100
^{140}Ba	1.4×10^{-2}	0	1	99	2.1×10^{-4}	0	0	100
^{140}La	8.1×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	5.7×10^{-6}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	3.9×10^{-6}	0	0	100
^{152}Eu	4.6×10^{-3}	0	2	98	9.0×10^{-5}	0	0	100
^{154}Eu	4.6×10^{-3}	0	1	99	9.6×10^{-5}	0	0	100
^{155}Eu	9.2×10^{-4}	0	7	93	4.4×10^{-6}	0	0	100
^{192}Ir	3.6×10^{-3}	0	1	99	6.7×10^{-5}	0	0	100
^{210}Pb	5.7×10^{-3}	0	2	98	1.5×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.8×10^{-10}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	1.3×10^{-4}	0	0	100
^{228}Ra	7.1×10^{-3}	0	3	97	7.6×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	8.4×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	1.1×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	6.3×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	1.1×10^{-6}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	2.0×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	3.1×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	3.1×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	1.3×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.0×10^{-8}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.9×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.1×10^{-8}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.8×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	9.8×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.3×10^{-8}	0	0	100

Table 16. Dose conversion coefficients for the following organism

Organism name : Frog - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 3.14×10^{-2}
Body shape proportions : 0.3750 0.3130
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	8.9×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	7.5×10^{-7}	0	0	100
^{40}K	7.7×10^{-3}	0	0	100	7.3×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.4×10^{-11}	0	0	100
^{51}Cr	8.8×10^{-5}	0	60	40	1.5×10^{-4}	0	0	100
^{54}Mn	5.5×10^{-4}	0	10	90	4.1×10^{-3}	0	0	100
^{57}Co	3.8×10^{-4}	0	48	52	4.7×10^{-4}	0	0	100
^{58}Co	3.4×10^{-3}	0	2	98	4.7×10^{-3}	0	0	100
^{60}Co	2.6×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{59}Ni	9.4×10^{-5}	0	67	33	2.5×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.4×10^{-3}	0	3	97	2.8×10^{-3}	0	0	100
^{75}Se	5.0×10^{-4}	0	13	87	1.8×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	7.5×10^{-3}	0	0	100	4.1×10^{-7}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	3.8×10^{-10}	0	0	100
^{95}Zr	2.0×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{94}Nb	3.2×10^{-3}	0	0	100	7.7×10^{-3}	0	0	100
^{95}Nb	1.1×10^{-3}	0	1	99	3.7×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.8×10^{-3}	0	2	98	2.3×10^{-3}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	1.0×10^{-3}	0	0	100
^{110m}Ag	2.7×10^{-3}	0	1	99	1.3×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	7	93	3.4×10^{-5}	0	0	100
^{124}Sb	5.9×10^{-3}	0	0	100	8.5×10^{-3}	0	0	100
^{125}Sb	1.7×10^{-3}	0	4	96	2.0×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	3.3×10^{-4}	0	0	100
^{132}Te	9.5×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{125}I	4.0×10^{-4}	0	36	64	4.7×10^{-5}	0	0	100

^{129}I	9.5×10^{-4}	0	13	87	2.7×10^{-5}	0	0	100
^{131}I	2.8×10^{-3}	0	0	100	1.9×10^{-3}	0	0	100
^{132}I	7.7×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{133}I	5.8×10^{-3}	0	0	100	3.0×10^{-3}	0	0	100
^{134}Cs	3.1×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	3.1×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{137}Cs	3.7×10^{-3}	0	0	100	2.7×10^{-3}	0	0	100
^{140}Ba	1.4×10^{-2}	0	1	99	1.3×10^{-2}	0	0	100
^{140}La	8.1×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	2.9×10^{-4}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	2.2×10^{-4}	0	0	100
^{152}Eu	4.6×10^{-3}	0	2	98	5.4×10^{-3}	0	0	100
^{154}Eu	4.6×10^{-3}	0	1	99	5.9×10^{-3}	0	0	100
^{155}Eu	9.2×10^{-4}	0	7	93	1.8×10^{-4}	0	0	100
^{192}Ir	3.6×10^{-3}	0	1	99	4.0×10^{-3}	0	0	100
^{210}Pb	5.7×10^{-3}	0	2	98	6.8×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.1×10^{-8}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	8.2×10^{-3}	0	0	100
^{228}Ra	7.1×10^{-3}	0	3	97	4.6×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.7×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	7.0×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	3.1×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	4.9×10^{-5}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	1.8×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.1×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	7.0×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.2×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	8.6×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.8×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.4×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.4×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.1×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	5.3×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.3×10^{-7}	0	0	100

Table 17. Dose conversion coefficients for the following organism

Organism name : Trout egg

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 3.35×10^{-5}

Body shape proportions : 1.0000 1.0000

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	4.7×10^{-12}	0	0	100
^{14}C	6.7×10^{-4}	0	1	99	1.2×10^{-5}	0	0	100
^{32}P	4.0×10^{-3}	0	0	100	5.6×10^{-3}	0	0	100
^{33}P	1.0×10^{-3}	0	1	99	4.1×10^{-5}	0	0	100
^{35}S	6.6×10^{-4}	0	2	98	1.3×10^{-5}	0	0	100
^{36}Cl	3.0×10^{-3}	0	0	100	8.8×10^{-4}	0	0	100
^{40}K	4.0×10^{-3}	0	0	100	6.3×10^{-3}	0	0	100
^{45}Ca	1.0×10^{-3}	0	1	99	4.3×10^{-5}	0	0	100
^{51}Cr	6.7×10^{-5}	0	79	21	4.4×10^{-4}	0	0	100
^{54}Mn	1.0×10^{-4}	0	54	46	1.2×10^{-2}	0	0	100
^{57}Co	3.0×10^{-4}	0	62	38	1.7×10^{-3}	0	0	100
^{58}Co	2.6×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.3×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{59}Ni	8.3×10^{-5}	0	76	24	1.3×10^{-5}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	1.0×10^{-6}	0	0	100
^{65}Zn	1.9×10^{-3}	0	3	97	8.2×10^{-3}	0	0	100
^{75}Se	2.5×10^{-4}	0	26	74	5.4×10^{-3}	0	0	100
^{79}Se	7.6×10^{-4}	0	1	99	1.6×10^{-5}	0	0	100
^{89}Sr	3.8×10^{-3}	0	0	100	4.2×10^{-3}	0	0	100
^{90}Sr	6.2×10^{-3}	0	0	100	9.4×10^{-3}	0	0	100
^{95}Zr	1.5×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.1×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	6.3×10^{-4}	0	2	98	1.1×10^{-2}	0	0	100
^{99}Tc	1.3×10^{-3}	0	0	100	7.9×10^{-5}	0	0	100
^{103}Ru	1.5×10^{-3}	0	3	97	6.6×10^{-3}	0	0	100
^{106}Ru	4.0×10^{-3}	0	1	99	1.9×10^{-2}	0	0	100
^{110m}Ag	1.0×10^{-3}	0	2	98	3.8×10^{-2}	0	0	100
^{109}Cd	1.1×10^{-3}	0	7	93	3.7×10^{-4}	0	0	100
^{124}Sb	2.8×10^{-3}	0	0	100	2.8×10^{-2}	0	0	100
^{125}Sb	1.3×10^{-3}	0	5	95	6.1×10^{-3}	0	0	100
^{129m}Te	7.1×10^{-3}	0	1	99	7.5×10^{-3}	0	0	100
^{132}Te	5.1×10^{-3}	0	1	99	3.9×10^{-2}	0	0	100
^{125}I	2.9×10^{-4}	0	51	49	5.7×10^{-4}	0	0	100

^{129}I	8.8×10^{-4}	0	13	87	3.4×10^{-4}	0	0	100
^{131}I	2.3×10^{-3}	0	0	100	5.7×10^{-3}	0	0	100
^{132}I	3.6×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{133}I	3.5×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{134}Cs	1.9×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{135}Cs	9.1×10^{-4}	0	1	99	2.9×10^{-5}	0	0	100
^{136}Cs	1.9×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	2.7×10^{-3}	0	0	100	8.6×10^{-3}	0	0	100
^{140}Ba	7.7×10^{-3}	0	2	98	4.5×10^{-2}	0	0	100
^{140}La	3.9×10^{-3}	0	0	100	3.6×10^{-2}	0	0	100
^{141}Ce	2.1×10^{-3}	0	1	99	1.3×10^{-3}	0	0	100
^{144}Ce	5.2×10^{-3}	0	0	100	1.4×10^{-2}	0	0	100
^{152}Eu	3.2×10^{-3}	0	3	97	1.7×10^{-2}	0	0	100
^{154}Eu	3.0×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.7×10^{-4}	0	7	93	8.5×10^{-4}	0	0	100
^{192}Ir	2.7×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{210}Pb	3.9×10^{-3}	0	3	97	2.0×10^{-3}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	98	0	2	3.0×10^{-2}	0	0	100
^{228}Ra	4.5×10^{-3}	0	5	95	1.6×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.5×10^{-1}	98	0	2	3.0×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	2.0×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	10	90	3.8×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{234}Th	4.7×10^{-3}	0	1	99	7.9×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.4×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.5×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	99	0	1	4.6×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	2.2×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	8.9×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.4×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.3×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.3×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.9×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100

Table 18. Dose conversion coefficients for the following organism

Organism name : Trout
Habitat : aquatic
Biota : aquatic
Body mass (kg) : 1.26×10^{0}
Body shape proportions : 0.1600 0.1200
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	8.5×10^{-12}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	4.3×10^{-7}	0	0	100
^{32}P	9.4×10^{-3}	0	0	100	2.6×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	1.5×10^{-6}	0	0	100
^{35}S	6.8×10^{-4}	0	2	98	4.6×10^{-7}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	3.3×10^{-5}	0	0	100
^{40}K	8.2×10^{-3}	0	0	100	2.1×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.5×10^{-6}	0	0	100
^{51}Cr	1.3×10^{-4}	0	41	59	3.8×10^{-4}	0	0	100
^{54}Mn	1.5×10^{-3}	0	4	96	1.0×10^{-2}	0	0	100
^{57}Co	5.5×10^{-4}	0	33	67	1.4×10^{-3}	0	0	100
^{58}Co	4.5×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	5.1×10^{-3}	0	0	100	3.1×10^{-2}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	5.9×10^{-7}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	2.7×10^{-8}	0	0	100
^{65}Zn	3.0×10^{-3}	0	2	98	7.1×10^{-3}	0	0	100
^{75}Se	1.0×10^{-3}	0	6	94	4.6×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	5.7×10^{-7}	0	0	100
^{89}Sr	7.9×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	5.6×10^{-4}	0	0	100
^{95}Zr	2.9×10^{-3}	0	0	100	9.0×10^{-3}	0	0	100
^{94}Nb	5.0×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{95}Nb	1.9×10^{-3}	0	1	99	9.3×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	2.9×10^{-6}	0	0	100
^{103}Ru	2.4×10^{-3}	0	2	98	5.6×10^{-3}	0	0	100
^{106}Ru	1.9×10^{-2}	0	0	100	3.8×10^{-3}	0	0	100
^{110m}Ag	5.7×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{109}Cd	1.4×10^{-3}	0	6	94	1.3×10^{-4}	0	0	100
^{124}Sb	8.0×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{125}Sb	2.2×10^{-3}	0	3	97	5.1×10^{-3}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.1×10^{-3}	0	0	100
^{132}Te	1.3×10^{-2}	0	0	100	3.1×10^{-2}	0	0	100
^{125}I	5.8×10^{-4}	0	25	75	2.7×10^{-4}	0	0	100

^{129}I	1.0×10^{-3}	0	11	89	1.8×10^{-4}	0	0	100
^{131}I	3.4×10^{-3}	0	0	100	4.6×10^{-3}	0	0	100
^{132}I	1.1×10^{-2}	0	0	100	2.8×10^{-2}	0	0	100
^{133}I	6.7×10^{-3}	0	0	100	7.4×10^{-3}	0	0	100
^{134}Cs	4.9×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	1.0×10^{-6}	0	0	100
^{136}Cs	5.5×10^{-3}	0	0	100	2.6×10^{-2}	0	0	100
^{137}Cs	4.4×10^{-3}	0	0	100	6.8×10^{-3}	0	0	100
^{140}Ba	1.7×10^{-2}	0	1	99	3.5×10^{-2}	0	0	100
^{140}La	1.1×10^{-2}	0	0	100	2.9×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	9.0×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	1.6×10^{-3}	0	0	100
^{152}Eu	6.0×10^{-3}	0	1	99	1.4×10^{-2}	0	0	100
^{154}Eu	6.0×10^{-3}	0	1	99	1.5×10^{-2}	0	0	100
^{155}Eu	1.0×10^{-3}	0	6	94	6.9×10^{-4}	0	0	100
^{192}Ir	4.6×10^{-3}	0	0	100	9.8×10^{-3}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	9.6×10^{-5}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.0×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	2.2×10^{-2}	0	0	100
^{228}Ra	8.4×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.2×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	2.0×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	1.0×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	6.0×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.7×10^{-4}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.6×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	7.4×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.5×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	5.4×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	3.9×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	2.0×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	2.4×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	3.0×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.6×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.0×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.4×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.0×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.6×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	4.1×10^{-6}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	1.5×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	3.7×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	3.2×10^{-6}	0	0	100

Table 19. Dose conversion coefficients for the following organism

Organism name : Flatfish egg
Habitat : aquatic
Biota : aquatic
Body mass (kg) : 4.19×10^{-6}
Body shape proportions : 1.0000 1.0000
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	2.2×10^{-9}	0	1	99
^{14}C	6.6×10^{-4}	0	1	99	2.6×10^{-5}	0	0	100
^{32}P	2.2×10^{-3}	0	0	100	7.5×10^{-3}	0	0	100
^{33}P	9.8×10^{-4}	0	1	99	8.6×10^{-5}	0	0	100
^{35}S	6.5×10^{-4}	0	2	98	2.8×10^{-5}	0	0	100
^{36}Cl	2.2×10^{-3}	0	0	100	1.7×10^{-3}	0	0	100
^{40}K	2.2×10^{-3}	0	0	100	8.0×10^{-3}	0	0	100
^{45}Ca	9.8×10^{-4}	0	1	99	9.0×10^{-5}	0	0	100
^{51}Cr	6.4×10^{-5}	0	82	18	4.4×10^{-4}	0	0	100
^{54}Mn	7.8×10^{-5}	0	71	29	1.2×10^{-2}	0	0	100
^{57}Co	2.8×10^{-4}	0	64	36	1.7×10^{-3}	0	0	100
^{58}Co	2.1×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.2×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{59}Ni	7.9×10^{-5}	0	80	20	1.7×10^{-5}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	1.7×10^{-6}	0	0	100
^{65}Zn	1.8×10^{-3}	0	4	96	8.4×10^{-3}	0	0	100
^{75}Se	2.2×10^{-4}	0	30	70	5.4×10^{-3}	0	0	100
^{79}Se	7.4×10^{-4}	0	1	99	3.4×10^{-5}	0	0	100
^{89}Sr	2.1×10^{-3}	0	0	100	5.9×10^{-3}	0	0	100
^{90}Sr	3.9×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{95}Zr	1.4×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{94}Nb	1.8×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	5.9×10^{-4}	0	2	98	1.1×10^{-2}	0	0	100
^{99}Tc	1.2×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{103}Ru	1.4×10^{-3}	0	3	97	6.7×10^{-3}	0	0	100
^{106}Ru	2.1×10^{-3}	0	2	98	2.0×10^{-2}	0	0	100
^{110m}Ag	8.3×10^{-4}	0	2	98	3.8×10^{-2}	0	0	100
^{109}Cd	1.1×10^{-3}	0	7	93	4.0×10^{-4}	0	0	100
^{124}Sb	1.9×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{125}Sb	1.1×10^{-3}	0	6	94	6.2×10^{-3}	0	0	100
^{129m}Te	4.5×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{132}Te	3.6×10^{-3}	0	2	98	4.1×10^{-2}	0	0	100
^{125}I	2.8×10^{-4}	0	52	48	5.7×10^{-4}	0	0	100

^{129}I	8.6×10^{-4}	0	14	86	3.6×10^{-4}	0	0	100
^{131}I	1.9×10^{-3}	0	0	100	6.1×10^{-3}	0	0	100
^{132}I	2.2×10^{-3}	0	0	100	3.6×10^{-2}	0	0	100
^{133}I	2.2×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{134}Cs	1.5×10^{-3}	0	1	99	2.2×10^{-2}	0	0	100
^{135}Cs	8.7×10^{-4}	0	1	99	6.0×10^{-5}	0	0	100
^{136}Cs	1.7×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	2.0×10^{-3}	0	0	100	9.2×10^{-3}	0	0	100
^{140}Ba	5.1×10^{-3}	0	3	97	4.7×10^{-2}	0	0	100
^{140}La	2.3×10^{-3}	0	0	100	3.7×10^{-2}	0	0	100
^{141}Ce	1.9×10^{-3}	0	1	99	1.5×10^{-3}	0	0	100
^{144}Ce	3.2×10^{-3}	0	1	99	1.6×10^{-2}	0	0	100
^{152}Eu	2.5×10^{-3}	0	3	97	1.8×10^{-2}	0	0	100
^{154}Eu	2.3×10^{-3}	0	2	98	1.9×10^{-2}	0	0	100
^{155}Eu	8.5×10^{-4}	0	8	92	8.6×10^{-4}	0	0	100
^{192}Ir	2.2×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{210}Pb	2.7×10^{-3}	0	4	96	3.3×10^{-3}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	98	0	2	3.3×10^{-2}	0	0	100
^{228}Ra	3.3×10^{-3}	0	7	93	1.7×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.6×10^{-3}	0	0	100
^{228}Th	4.5×10^{-1}	99	0	1	3.2×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.4×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	2.4×10^{-5}	0	0	100
^{231}Th	2.2×10^{-3}	0	10	90	4.6×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.9×10^{-5}	0	0	100
^{234}Th	2.9×10^{-3}	0	1	99	9.7×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.7×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.8×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	2.4×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	96	0	4	2.6×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.8×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	99	0	1	4.8×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	2.4×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	9.9×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	2.3×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	4.0×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.4×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	2.0×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.2×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100

Table 20. Dose conversion coefficients for the following organism

Organism name : Flatfish

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 1.31×10^0

Body shape proportions : 0.6250 0.0630

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	1.9×10^{-11}	0	1	99
^{14}C	6.8×10^{-4}	0	1	99	4.3×10^{-7}	0	0	100
^{32}P	9.1×10^{-3}	0	0	100	5.2×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	1.5×10^{-6}	0	0	100
^{35}S	6.8×10^{-4}	0	2	98	4.6×10^{-7}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	4.4×10^{-5}	0	0	100
^{40}K	7.9×10^{-3}	0	0	100	2.3×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.6×10^{-6}	0	0	100
^{51}Cr	1.1×10^{-4}	0	48	52	3.9×10^{-4}	0	0	100
^{54}Mn	1.0×10^{-3}	0	5	95	1.1×10^{-2}	0	0	100
^{57}Co	4.9×10^{-4}	0	38	62	1.5×10^{-3}	0	0	100
^{58}Co	4.0×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	4.0×10^{-3}	0	0	100	3.2×10^{-2}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	6.0×10^{-7}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	2.6×10^{-8}	0	0	100
^{65}Zn	2.7×10^{-3}	0	2	98	7.4×10^{-3}	0	0	100
^{75}Se	7.9×10^{-4}	0	8	92	4.9×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	5.7×10^{-7}	0	0	100
^{89}Sr	7.7×10^{-3}	0	0	100	3.6×10^{-4}	0	0	100
^{90}Sr	1.4×10^{-2}	0	0	100	1.2×10^{-3}	0	0	100
^{95}Zr	2.5×10^{-3}	0	0	100	9.4×10^{-3}	0	0	100
^{94}Nb	4.2×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{95}Nb	1.5×10^{-3}	0	1	99	9.7×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	3.0×10^{-6}	0	0	100
^{103}Ru	2.2×10^{-3}	0	2	98	5.9×10^{-3}	0	0	100
^{106}Ru	1.7×10^{-2}	0	0	100	5.2×10^{-3}	0	0	100
^{110m}Ag	4.3×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{109}Cd	1.3×10^{-3}	0	6	94	1.7×10^{-4}	0	0	100
^{124}Sb	7.0×10^{-3}	0	0	100	2.4×10^{-2}	0	0	100
^{125}Sb	2.0×10^{-3}	0	4	96	5.4×10^{-3}	0	0	100
^{129m}Te	1.3×10^{-2}	0	0	100	1.5×10^{-3}	0	0	100
^{132}Te	1.1×10^{-2}	0	1	99	3.3×10^{-2}	0	0	100
^{125}I	5.1×10^{-4}	0	29	71	3.4×10^{-4}	0	0	100

^{129}I	1.0×10^{-3}	0	12	88	2.2×10^{-4}	0	0	100
^{131}I	3.1×10^{-3}	0	0	100	4.8×10^{-3}	0	0	100
^{132}I	9.2×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{133}I	6.3×10^{-3}	0	0	100	7.8×10^{-3}	0	0	100
^{134}Cs	4.1×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	1.0×10^{-6}	0	0	100
^{136}Cs	4.4×10^{-3}	0	1	99	2.7×10^{-2}	0	0	100
^{137}Cs	4.1×10^{-3}	0	0	100	7.2×10^{-3}	0	0	100
^{140}Ba	1.6×10^{-2}	0	1	99	3.7×10^{-2}	0	0	100
^{140}La	9.6×10^{-3}	0	0	100	3.0×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	9.5×10^{-4}	0	0	100
^{144}Ce	1.6×10^{-2}	0	0	100	2.6×10^{-3}	0	0	100
^{152}Eu	5.4×10^{-3}	0	2	98	1.5×10^{-2}	0	0	100
^{154}Eu	5.4×10^{-3}	0	1	99	1.6×10^{-2}	0	0	100
^{155}Eu	9.9×10^{-4}	0	7	93	7.3×10^{-4}	0	0	100
^{192}Ir	4.2×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{210}Pb	5.8×10^{-3}	0	2	98	1.5×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	96	0	4	2.3×10^{-2}	0	0	100
^{228}Ra	7.8×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.3×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	2.1×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	1.1×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	6.7×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.8×10^{-4}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	4.2×10^{-6}	0	0	100
^{234}Th	1.1×10^{-2}	0	0	100	1.2×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.8×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	6.2×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	4.9×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	2.1×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	3.2×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	3.2×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	4.8×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.5×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	4.6×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.2×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.9×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	5.5×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	1.6×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	5.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	4.4×10^{-6}	0	0	100

Table 21. Dose conversion coefficients for the following organism

Organism name : Crab egg mass
Habitat : aquatic
Biota : aquatic
Body mass (kg) : 1.26×10^{-2}
Body shape proportions : 0.6670 0.1670
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	6.6×10^{-11}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	1.9×10^{-6}	0	0	100
^{32}P	8.4×10^{-3}	0	0	100	1.2×10^{-3}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	6.2×10^{-6}	0	0	100
^{35}S	6.7×10^{-4}	0	2	98	2.0×10^{-6}	0	0	100
^{36}Cl	3.7×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{40}K	7.3×10^{-3}	0	0	100	3.0×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	6.5×10^{-6}	0	0	100
^{51}Cr	8.0×10^{-5}	0	66	34	4.2×10^{-4}	0	0	100
^{54}Mn	3.6×10^{-4}	0	15	85	1.1×10^{-2}	0	0	100
^{57}Co	3.5×10^{-4}	0	52	48	1.6×10^{-3}	0	0	100
^{58}Co	3.2×10^{-3}	0	2	98	1.3×10^{-2}	0	0	100
^{60}Co	2.1×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{59}Ni	9.3×10^{-5}	0	67	33	3.0×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	1.2×10^{-7}	0	0	100
^{65}Zn	2.2×10^{-3}	0	3	97	7.9×10^{-3}	0	0	100
^{75}Se	4.1×10^{-4}	0	16	84	5.2×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	2.5×10^{-6}	0	0	100
^{89}Sr	7.2×10^{-3}	0	0	100	8.8×10^{-4}	0	0	100
^{90}Sr	1.3×10^{-2}	0	0	100	2.4×10^{-3}	0	0	100
^{95}Zr	1.9×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.8×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{95}Nb	8.8×10^{-4}	0	1	99	1.0×10^{-2}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	1.2×10^{-5}	0	0	100
^{103}Ru	1.7×10^{-3}	0	3	97	6.3×10^{-3}	0	0	100
^{106}Ru	1.5×10^{-2}	0	0	100	7.9×10^{-3}	0	0	100
^{110m}Ag	2.1×10^{-3}	0	1	99	3.7×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	2.9×10^{-4}	0	0	100
^{124}Sb	5.3×10^{-3}	0	0	100	2.5×10^{-2}	0	0	100
^{125}Sb	1.5×10^{-3}	0	5	95	5.8×10^{-3}	0	0	100
^{129m}Te	1.2×10^{-2}	0	1	99	2.4×10^{-3}	0	0	100
^{132}Te	8.7×10^{-3}	0	1	99	3.6×10^{-2}	0	0	100
^{125}I	3.6×10^{-4}	0	41	59	5.0×10^{-4}	0	0	100

^{129}I	9.2×10^{-4}	0	13	87	3.0×10^{-4}	0	0	100
^{131}I	2.7×10^{-3}	0	0	100	5.2×10^{-3}	0	0	100
^{132}I	6.9×10^{-3}	0	0	100	3.2×10^{-2}	0	0	100
^{133}I	5.5×10^{-3}	0	0	100	8.6×10^{-3}	0	0	100
^{134}Cs	2.7×10^{-3}	0	0	100	2.1×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	4.4×10^{-6}	0	0	100
^{136}Cs	2.6×10^{-3}	0	1	99	2.9×10^{-2}	0	0	100
^{137}Cs	3.5×10^{-3}	0	0	100	7.8×10^{-3}	0	0	100
^{140}Ba	1.3×10^{-2}	0	1	99	4.0×10^{-2}	0	0	100
^{140}La	7.4×10^{-3}	0	0	100	3.2×10^{-2}	0	0	100
^{141}Ce	2.4×10^{-3}	0	1	99	1.1×10^{-3}	0	0	100
^{144}Ce	1.4×10^{-2}	0	0	100	4.5×10^{-3}	0	0	100
^{152}Eu	4.3×10^{-3}	0	2	98	1.6×10^{-2}	0	0	100
^{154}Eu	4.2×10^{-3}	0	1	99	1.7×10^{-2}	0	0	100
^{155}Eu	9.0×10^{-4}	0	7	93	8.1×10^{-4}	0	0	100
^{192}Ir	3.4×10^{-3}	0	1	99	1.1×10^{-2}	0	0	100
^{210}Pb	5.6×10^{-3}	0	2	98	4.3×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	96	0	4	2.5×10^{-2}	0	0	100
^{228}Ra	6.7×10^{-3}	0	3	97	1.4×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.4×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	2.3×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.2×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{231}Th	2.4×10^{-3}	0	9	91	2.6×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	8.6×10^{-6}	0	0	100
^{234}Th	1.0×10^{-2}	0	0	100	2.2×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	5.6×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.0×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.1×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.3×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	8.4×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	4.0×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	5.3×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.8×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	3.7×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.8×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	9.8×10^{-6}	0	0	100

Table 22. Dose conversion coefficients for the following organism

Organism name : Crab larvae
Habitat : aquatic
Biota : aquatic
Body mass (kg) : 3.35×10^{-5}
Body shape proportions : 1.0000 1.0000
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	4.7×10^{-12}	0	0	100
^{14}C	6.7×10^{-4}	0	1	99	1.2×10^{-5}	0	0	100
^{32}P	4.0×10^{-3}	0	0	100	5.6×10^{-3}	0	0	100
^{33}P	1.0×10^{-3}	0	1	99	4.1×10^{-5}	0	0	100
^{35}S	6.6×10^{-4}	0	2	98	1.3×10^{-5}	0	0	100
^{36}Cl	3.0×10^{-3}	0	0	100	8.8×10^{-4}	0	0	100
^{40}K	4.0×10^{-3}	0	0	100	6.3×10^{-3}	0	0	100
^{45}Ca	1.0×10^{-3}	0	1	99	4.3×10^{-5}	0	0	100
^{51}Cr	6.7×10^{-5}	0	79	21	4.4×10^{-4}	0	0	100
^{54}Mn	1.0×10^{-4}	0	54	46	1.2×10^{-2}	0	0	100
^{57}Co	3.0×10^{-4}	0	62	38	1.7×10^{-3}	0	0	100
^{58}Co	2.6×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.3×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{59}Ni	8.3×10^{-5}	0	76	24	1.3×10^{-5}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	1.0×10^{-6}	0	0	100
^{65}Zn	1.9×10^{-3}	0	3	97	8.2×10^{-3}	0	0	100
^{75}Se	2.5×10^{-4}	0	26	74	5.4×10^{-3}	0	0	100
^{79}Se	7.6×10^{-4}	0	1	99	1.6×10^{-5}	0	0	100
^{89}Sr	3.8×10^{-3}	0	0	100	4.2×10^{-3}	0	0	100
^{90}Sr	6.2×10^{-3}	0	0	100	9.4×10^{-3}	0	0	100
^{95}Zr	1.5×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.1×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	6.3×10^{-4}	0	2	98	1.1×10^{-2}	0	0	100
^{99}Tc	1.3×10^{-3}	0	0	100	7.9×10^{-5}	0	0	100
^{103}Ru	1.5×10^{-3}	0	3	97	6.6×10^{-3}	0	0	100
^{106}Ru	4.0×10^{-3}	0	1	99	1.9×10^{-2}	0	0	100
^{110m}Ag	1.0×10^{-3}	0	2	98	3.8×10^{-2}	0	0	100
^{109}Cd	1.1×10^{-3}	0	7	93	3.7×10^{-4}	0	0	100
^{124}Sb	2.8×10^{-3}	0	0	100	2.8×10^{-2}	0	0	100
^{125}Sb	1.3×10^{-3}	0	5	95	6.1×10^{-3}	0	0	100
^{129m}Te	7.1×10^{-3}	0	1	99	7.5×10^{-3}	0	0	100
^{132}Te	5.1×10^{-3}	0	1	99	3.9×10^{-2}	0	0	100
^{125}I	2.9×10^{-4}	0	51	49	5.7×10^{-4}	0	0	100

^{129}I	8.8×10^{-4}	0	13	87	3.4×10^{-4}	0	0	100
^{131}I	2.3×10^{-3}	0	0	100	5.7×10^{-3}	0	0	100
^{132}I	3.6×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{133}I	3.5×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{134}Cs	1.9×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{135}Cs	9.1×10^{-4}	0	1	99	2.9×10^{-5}	0	0	100
^{136}Cs	1.9×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	2.7×10^{-3}	0	0	100	8.6×10^{-3}	0	0	100
^{140}Ba	7.7×10^{-3}	0	2	98	4.5×10^{-2}	0	0	100
^{140}La	3.9×10^{-3}	0	0	100	3.6×10^{-2}	0	0	100
^{141}Ce	2.1×10^{-3}	0	1	99	1.3×10^{-3}	0	0	100
^{144}Ce	5.2×10^{-3}	0	0	100	1.4×10^{-2}	0	0	100
^{152}Eu	3.2×10^{-3}	0	3	97	1.7×10^{-2}	0	0	100
^{154}Eu	3.0×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.7×10^{-4}	0	7	93	8.5×10^{-4}	0	0	100
^{192}Ir	2.7×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{210}Pb	3.9×10^{-3}	0	3	97	2.0×10^{-3}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	98	0	2	3.0×10^{-2}	0	0	100
^{228}Ra	4.5×10^{-3}	0	5	95	1.6×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.5×10^{-1}	98	0	2	3.0×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	2.0×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	10	90	3.8×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{234}Th	4.7×10^{-3}	0	1	99	7.9×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.4×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.5×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	99	0	1	4.6×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	2.2×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	8.9×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.4×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.3×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.3×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.9×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100

Table 23. Dose conversion coefficients for the following organism

Organism name : Crab

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 7.54×10^{-1}

Body shape proportions : 0.6000 0.3000

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	1.8×10^{-13}	0	0	100
^{14}C	6.8×10^{-4}	0	1	99	5.1×10^{-7}	0	0	100
^{32}P	9.3×10^{-3}	0	0	100	2.7×10^{-4}	0	0	100
^{33}P	1.1×10^{-3}	0	1	99	1.7×10^{-6}	0	0	100
^{35}S	6.8×10^{-4}	0	2	98	5.5×10^{-7}	0	0	100
^{36}Cl	3.8×10^{-3}	0	0	100	3.8×10^{-5}	0	0	100
^{40}K	8.1×10^{-3}	0	0	100	2.1×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.8×10^{-6}	0	0	100
^{51}Cr	1.2×10^{-4}	0	42	58	3.8×10^{-4}	0	0	100
^{54}Mn	1.4×10^{-3}	0	4	96	1.0×10^{-2}	0	0	100
^{57}Co	5.4×10^{-4}	0	34	66	1.5×10^{-3}	0	0	100
^{58}Co	4.5×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{60}Co	5.0×10^{-3}	0	0	100	3.1×10^{-2}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	7.0×10^{-7}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	3.8×10^{-8}	0	0	100
^{65}Zn	3.0×10^{-3}	0	2	98	7.2×10^{-3}	0	0	100
^{75}Se	9.7×10^{-4}	0	7	93	4.7×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	6.7×10^{-7}	0	0	100
^{89}Sr	7.9×10^{-3}	0	0	100	2.0×10^{-4}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	5.6×10^{-4}	0	0	100
^{95}Zr	2.9×10^{-3}	0	0	100	9.0×10^{-3}	0	0	100
^{94}Nb	4.9×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{95}Nb	1.9×10^{-3}	0	1	99	9.3×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	3.4×10^{-6}	0	0	100
^{103}Ru	2.4×10^{-3}	0	2	98	5.7×10^{-3}	0	0	100
^{106}Ru	1.9×10^{-2}	0	0	100	3.8×10^{-3}	0	0	100
^{110m}Ag	5.6×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{109}Cd	1.4×10^{-3}	0	6	94	1.4×10^{-4}	0	0	100
^{124}Sb	7.9×10^{-3}	0	0	100	2.3×10^{-2}	0	0	100
^{125}Sb	2.2×10^{-3}	0	3	97	5.1×10^{-3}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.2×10^{-3}	0	0	100
^{132}Te	1.3×10^{-2}	0	1	99	3.2×10^{-2}	0	0	100
^{125}I	5.7×10^{-4}	0	26	74	2.8×10^{-4}	0	0	100
^{129}I	1.0×10^{-3}	0	11	89	1.9×10^{-4}	0	0	100

^{131}I	3.3×10^{-3}	0	0	100	4.6×10^{-3}	0	0	100
^{132}I	1.0×10^{-2}	0	0	100	2.8×10^{-2}	0	0	100
^{133}I	6.6×10^{-3}	0	0	100	7.5×10^{-3}	0	0	100
^{134}Cs	4.8×10^{-3}	0	0	100	1.9×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	1.2×10^{-6}	0	0	100
^{136}Cs	5.4×10^{-3}	0	0	100	2.6×10^{-2}	0	0	100
^{137}Cs	4.4×10^{-3}	0	0	100	6.9×10^{-3}	0	0	100
^{140}Ba	1.7×10^{-2}	0	1	99	3.5×10^{-2}	0	0	100
^{140}La	1.1×10^{-2}	0	0	100	2.9×10^{-2}	0	0	100
^{141}Ce	2.5×10^{-3}	0	1	99	9.1×10^{-4}	0	0	100
^{144}Ce	1.7×10^{-2}	0	0	100	1.6×10^{-3}	0	0	100
^{152}Eu	5.9×10^{-3}	0	1	99	1.4×10^{-2}	0	0	100
^{154}Eu	6.0×10^{-3}	0	1	99	1.5×10^{-2}	0	0	100
^{155}Eu	1.0×10^{-3}	0	6	94	7.0×10^{-4}	0	0	100
^{192}Ir	4.6×10^{-3}	0	0	100	9.9×10^{-3}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	1.1×10^{-4}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.0×10^{-7}	0	0	100
^{226}Ra	3.5×10^{-1}	95	0	5	2.2×10^{-2}	0	0	100
^{228}Ra	8.3×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.3×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	96	0	4	2.0×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	97	0	2	1.0×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	6.2×10^{-6}	0	0	100
^{231}Th	2.5×10^{-3}	0	9	91	1.7×10^{-4}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.8×10^{-6}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	7.4×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	1	4.6×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	5.7×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	4.2×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	5	2.0×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	2.7×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	3.0×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.9×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.1×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.8×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.1×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	2.7×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	4.4×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	97	0	2	1.5×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	4.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	3.5×10^{-6}	0	0	100

Table 24. Dose conversion coefficients for the following organism

Organism name : Bee - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 5.89×10^{-4}
Body shape proportions : 0.3750 0.3750
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	7.0×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.0×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.5×10^{-3}	0	0	100	1.3×10^{-8}	0	0	100
^{40}K	6.3×10^{-3}	0	0	100	1.2×10^{-5}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.6×10^{-14}	0	0	100
^{51}Cr	7.2×10^{-5}	0	74	26	2.6×10^{-6}	0	0	100
^{54}Mn	1.9×10^{-4}	0	30	70	6.8×10^{-5}	0	0	100
^{57}Co	3.2×10^{-4}	0	57	43	8.9×10^{-6}	0	0	100
^{58}Co	2.9×10^{-3}	0	2	98	7.9×10^{-5}	0	0	100
^{60}Co	1.6×10^{-3}	0	0	100	1.9×10^{-4}	0	0	100
^{59}Ni	8.9×10^{-5}	0	71	29	4.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.1×10^{-3}	0	3	97	4.5×10^{-5}	0	0	100
^{75}Se	3.1×10^{-4}	0	21	79	3.1×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	6.1×10^{-3}	0	0	100	6.8×10^{-9}	0	0	100
^{90}Sr	1.0×10^{-2}	0	0	100	8.5×10^{-12}	0	0	100
^{95}Zr	1.7×10^{-3}	0	0	100	6.0×10^{-5}	0	0	100
^{94}Nb	2.4×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{95}Nb	7.2×10^{-4}	0	2	98	6.2×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.6×10^{-3}	0	3	97	3.9×10^{-5}	0	0	100
^{106}Ru	9.2×10^{-3}	0	0	100	1.7×10^{-5}	0	0	100
^{110m}Ag	1.4×10^{-3}	0	1	99	2.2×10^{-4}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	1.3×10^{-6}	0	0	100
^{124}Sb	4.2×10^{-3}	0	0	100	1.4×10^{-4}	0	0	100
^{125}Sb	1.4×10^{-3}	0	5	95	3.5×10^{-5}	0	0	100
^{129m}Te	1.1×10^{-2}	0	1	99	6.1×10^{-6}	0	0	100
^{132}Te	7.2×10^{-3}	0	1	99	2.1×10^{-4}	0	0	100
^{125}I	3.1×10^{-4}	0	47	53	2.7×10^{-6}	0	0	100

^{129}I	9.0×10^{-4}	0	13	87	1.6×10^{-6}	0	0	100
^{131}I	2.6×10^{-3}	0	0	100	3.2×10^{-5}	0	0	100
^{132}I	5.6×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{133}I	4.8×10^{-3}	0	0	100	5.0×10^{-5}	0	0	100
^{134}Cs	2.3×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{135}Cs	9.2×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.1×10^{-3}	0	1	99	1.7×10^{-4}	0	0	100
^{137}Cs	3.2×10^{-3}	0	0	100	4.6×10^{-5}	0	0	100
^{140}Ba	1.1×10^{-2}	0	1	99	2.2×10^{-4}	0	0	100
^{140}La	6.0×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	5.8×10^{-6}	0	0	100
^{144}Ce	1.0×10^{-2}	0	0	100	3.9×10^{-6}	0	0	100
^{152}Eu	3.9×10^{-3}	0	2	98	9.0×10^{-5}	0	0	100
^{154}Eu	3.7×10^{-3}	0	1	99	9.7×10^{-5}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	4.4×10^{-6}	0	0	100
^{192}Ir	3.1×10^{-3}	0	1	99	6.8×10^{-5}	0	0	100
^{210}Pb	5.1×10^{-3}	0	2	98	1.5×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.9×10^{-10}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	1.3×10^{-4}	0	0	100
^{228}Ra	5.9×10^{-3}	0	4	96	7.6×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	8.5×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	1.1×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	6.3×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	1.1×10^{-6}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{234}Th	8.3×10^{-3}	0	0	100	2.0×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	3.1×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	1.3×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.0×10^{-8}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.9×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.1×10^{-8}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.8×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	9.9×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100

Table 25. Dose conversion coefficients for the following organism

Organism name : Bee - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 5.89×10^{-4}
Body shape proportions : 0.3750 0.3750
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	7.0×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.0×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.5×10^{-3}	0	0	100	7.5×10^{-7}	0	0	100
^{40}K	6.3×10^{-3}	0	0	100	7.3×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.6×10^{-11}	0	0	100
^{51}Cr	7.2×10^{-5}	0	74	26	1.5×10^{-4}	0	0	100
^{54}Mn	1.9×10^{-4}	0	30	70	4.1×10^{-3}	0	0	100
^{57}Co	3.2×10^{-4}	0	57	43	4.7×10^{-4}	0	0	100
^{58}Co	2.9×10^{-3}	0	2	98	4.8×10^{-3}	0	0	100
^{60}Co	1.6×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{59}Ni	8.9×10^{-5}	0	71	29	2.5×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.1×10^{-3}	0	3	97	2.8×10^{-3}	0	0	100
^{75}Se	3.1×10^{-4}	0	21	79	1.8×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	6.1×10^{-3}	0	0	100	4.1×10^{-7}	0	0	100
^{90}Sr	1.0×10^{-2}	0	0	100	3.9×10^{-10}	0	0	100
^{95}Zr	1.7×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{94}Nb	2.4×10^{-3}	0	0	100	7.7×10^{-3}	0	0	100
^{95}Nb	7.2×10^{-4}	0	2	98	3.8×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.6×10^{-3}	0	3	97	2.3×10^{-3}	0	0	100
^{106}Ru	9.2×10^{-3}	0	0	100	1.0×10^{-3}	0	0	100
^{110m}Ag	1.4×10^{-3}	0	1	99	1.3×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	3.4×10^{-5}	0	0	100
^{124}Sb	4.2×10^{-3}	0	0	100	8.6×10^{-3}	0	0	100
^{125}Sb	1.4×10^{-3}	0	5	95	2.1×10^{-3}	0	0	100
^{129m}Te	1.1×10^{-2}	0	1	99	3.3×10^{-4}	0	0	100
^{132}Te	7.2×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{125}I	3.1×10^{-4}	0	47	53	4.7×10^{-5}	0	0	100

^{129}I	9.0×10^{-4}	0	13	87	2.8×10^{-5}	0	0	100
^{131}I	2.6×10^{-3}	0	0	100	1.9×10^{-3}	0	0	100
^{132}I	5.6×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{133}I	4.8×10^{-3}	0	0	100	3.0×10^{-3}	0	0	100
^{134}Cs	2.3×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{135}Cs	9.2×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.1×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{137}Cs	3.2×10^{-3}	0	0	100	2.8×10^{-3}	0	0	100
^{140}Ba	1.1×10^{-2}	0	1	99	1.3×10^{-2}	0	0	100
^{140}La	6.0×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	3.0×10^{-4}	0	0	100
^{144}Ce	1.0×10^{-2}	0	0	100	2.2×10^{-4}	0	0	100
^{152}Eu	3.9×10^{-3}	0	2	98	5.4×10^{-3}	0	0	100
^{154}Eu	3.7×10^{-3}	0	1	99	5.9×10^{-3}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	1.8×10^{-4}	0	0	100
^{192}Ir	3.1×10^{-3}	0	1	99	4.0×10^{-3}	0	0	100
^{210}Pb	5.1×10^{-3}	0	2	98	6.9×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.2×10^{-8}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	8.3×10^{-3}	0	0	100
^{228}Ra	5.9×10^{-3}	0	4	96	4.6×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.7×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	7.0×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	3.1×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	5.0×10^{-5}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}Th	8.3×10^{-3}	0	0	100	1.1×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	1.8×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.1×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	7.1×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.2×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	8.6×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.6×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	8.0×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.4×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.2×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	5.4×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.4×10^{-7}	0	0	100

Table 26. Dose conversion coefficients for the following organism

Organism name : Bee colony - plane

Habitat : terrestrial

Biota : animal

Body mass (kg) : 2.83×10^1

Body shape proportions : 0.5000 0.5000

External exposure : on-soil

Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.5×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	8.0×10^{-9}	0	0	100
^{40}K	8.7×10^{-3}	0	0	100	7.8×10^{-6}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	6.5×10^{-15}	0	0	100
^{51}Cr	2.5×10^{-4}	0	21	79	1.6×10^{-6}	0	0	100
^{54}Mn	4.3×10^{-3}	0	1	99	4.3×10^{-5}	0	0	100
^{57}Co	1.1×10^{-3}	0	17	83	5.2×10^{-6}	0	0	100
^{58}Co	7.9×10^{-3}	0	1	99	5.1×10^{-5}	0	0	100
^{60}Co	1.3×10^{-2}	0	0	100	1.3×10^{-4}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	4.2×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	4.9×10^{-3}	0	1	99	3.0×10^{-5}	0	0	100
^{75}Se	2.6×10^{-3}	0	2	98	1.9×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	4.4×10^{-9}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	4.3×10^{-12}	0	0	100
^{95}Zr	5.5×10^{-3}	0	0	100	3.9×10^{-5}	0	0	100
^{94}Nb	1.0×10^{-2}	0	0	100	8.2×10^{-5}	0	0	100
^{95}Nb	4.6×10^{-3}	0	0	100	4.0×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	4.2×10^{-3}	0	1	99	2.5×10^{-5}	0	0	100
^{106}Ru	2.0×10^{-2}	0	0	100	1.1×10^{-5}	0	0	100
^{110m}Ag	1.5×10^{-2}	0	0	100	1.4×10^{-4}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	6.7×10^{-7}	0	0	100
^{124}Sb	1.4×10^{-2}	0	0	100	9.2×10^{-5}	0	0	100
^{125}Sb	3.8×10^{-3}	0	2	98	2.2×10^{-5}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	3.8×10^{-6}	0	0	100
^{132}Te	2.2×10^{-2}	0	0	100	1.3×10^{-4}	0	0	100
^{125}I	7.5×10^{-4}	0	19	81	1.4×10^{-6}	0	0	100

^{129}I	1.2×10^{-3}	0	10	90	8.7×10^{-7}	0	0	100
^{131}I	4.8×10^{-3}	0	0	100	2.0×10^{-5}	0	0	100
^{132}I	1.8×10^{-2}	0	0	100	1.2×10^{-4}	0	0	100
^{133}I	8.9×10^{-3}	0	0	100	3.2×10^{-5}	0	0	100
^{134}Cs	1.0×10^{-2}	0	0	100	8.1×10^{-5}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	1.3×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{137}Cs	6.4×10^{-3}	0	0	100	2.9×10^{-5}	0	0	100
^{140}Ba	2.6×10^{-2}	0	1	99	1.4×10^{-4}	0	0	100
^{140}La	1.8×10^{-2}	0	0	100	1.2×10^{-4}	0	0	100
^{141}Ce	2.9×10^{-3}	0	1	99	3.4×10^{-6}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	2.5×10^{-6}	0	0	100
^{152}Eu	1.0×10^{-2}	0	1	99	5.8×10^{-5}	0	0	100
^{154}Eu	1.0×10^{-2}	0	0	100	6.3×10^{-5}	0	0	100
^{155}Eu	1.3×10^{-3}	0	5	95	2.5×10^{-6}	0	0	100
^{192}Ir	7.8×10^{-3}	0	0	100	4.3×10^{-5}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	8.2×10^{-8}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.4×10^{-10}	0	0	100
^{226}Ra	3.5×10^{-1}	94	0	6	8.9×10^{-5}	0	0	100
^{228}Ra	1.2×10^{-2}	0	2	98	4.9×10^{-5}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	5.2×10^{-6}	0	0	100
^{228}Th	4.7×10^{-1}	95	0	5	7.6×10^{-5}	0	0	100
^{229}Th	7.0×10^{-2}	97	0	3	3.6×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{231}Th	2.6×10^{-3}	0	9	91	5.9×10^{-7}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	9.6×10^{-9}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	1.2×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	1.9×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	9.8×10^{-9}	0	0	100
^{235}U	6.5×10^{-2}	94	0	6	7.7×10^{-6}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	5.3×10^{-9}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	1.1×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	9.0×10^{-9}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	5.9×10^{-9}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	8.7×10^{-9}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.9×10^{-11}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	9.7×10^{-7}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.2×10^{-8}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	5.9×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.1×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.2×10^{-8}	0	0	100

Table 27. Dose conversion coefficients for the following organism

Organism name : Bee colony - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 2.83×10^{1}
Body shape proportions : 0.5000 0.5000
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.5×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.8×10^{-3}	0	0	100	4.8×10^{-7}	0	0	100
^{40}K	8.7×10^{-3}	0	0	100	5.0×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.0×10^{-11}	0	0	100
^{51}Cr	2.5×10^{-4}	0	21	79	9.7×10^{-5}	0	0	100
^{54}Mn	4.3×10^{-3}	0	1	99	2.7×10^{-3}	0	0	100
^{57}Co	1.1×10^{-3}	0	17	83	2.8×10^{-4}	0	0	100
^{58}Co	7.9×10^{-3}	0	1	99	3.1×10^{-3}	0	0	100
^{60}Co	1.3×10^{-2}	0	0	100	8.1×10^{-3}	0	0	100
^{59}Ni	9.6×10^{-5}	0	66	34	1.1×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	4.9×10^{-3}	0	1	99	1.9×10^{-3}	0	0	100
^{75}Se	2.6×10^{-3}	0	2	98	1.1×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	2.7×10^{-7}	0	0	100
^{90}Sr	1.5×10^{-2}	0	0	100	1.7×10^{-10}	0	0	100
^{95}Zr	5.5×10^{-3}	0	0	100	2.4×10^{-3}	0	0	100
^{94}Nb	1.0×10^{-2}	0	0	100	5.0×10^{-3}	0	0	100
^{95}Nb	4.6×10^{-3}	0	0	100	2.5×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	4.2×10^{-3}	0	1	99	1.5×10^{-3}	0	0	100
^{106}Ru	2.0×10^{-2}	0	0	100	6.6×10^{-4}	0	0	100
^{110m}Ag	1.5×10^{-2}	0	0	100	8.8×10^{-3}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	1.8×10^{-5}	0	0	100
^{124}Sb	1.4×10^{-2}	0	0	100	5.8×10^{-3}	0	0	100
^{125}Sb	3.8×10^{-3}	0	2	98	1.3×10^{-3}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	2.1×10^{-4}	0	0	100
^{132}Te	2.2×10^{-2}	0	0	100	8.1×10^{-3}	0	0	100
^{125}I	7.5×10^{-4}	0	19	81	2.4×10^{-5}	0	0	100

^{129}I	1.2×10^{-3}	0	10	90	1.4×10^{-5}	0	0	100
^{131}I	4.8×10^{-3}	0	0	100	1.2×10^{-3}	0	0	100
^{132}I	1.8×10^{-2}	0	0	100	7.3×10^{-3}	0	0	100
^{133}I	8.9×10^{-3}	0	0	100	1.9×10^{-3}	0	0	100
^{134}Cs	1.0×10^{-2}	0	0	100	5.0×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	1.3×10^{-2}	0	0	100	6.9×10^{-3}	0	0	100
^{137}Cs	6.4×10^{-3}	0	0	100	1.8×10^{-3}	0	0	100
^{140}Ba	2.6×10^{-2}	0	1	99	9.1×10^{-3}	0	0	100
^{140}La	1.8×10^{-2}	0	0	100	7.4×10^{-3}	0	0	100
^{141}Ce	2.9×10^{-3}	0	1	99	1.8×10^{-4}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	1.4×10^{-4}	0	0	100
^{152}Eu	1.0×10^{-2}	0	1	99	3.6×10^{-3}	0	0	100
^{154}Eu	1.0×10^{-2}	0	0	100	3.9×10^{-3}	0	0	100
^{155}Eu	1.3×10^{-3}	0	5	95	1.1×10^{-4}	0	0	100
^{192}Ir	7.8×10^{-3}	0	0	100	2.5×10^{-3}	0	0	100
^{210}Pb	5.9×10^{-3}	0	2	98	2.9×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	2.7×10^{-8}	0	0	100
^{226}Ra	3.5×10^{-1}	94	0	6	5.6×10^{-3}	0	0	100
^{228}Ra	1.2×10^{-2}	0	2	98	3.1×10^{-3}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	2.9×10^{-4}	0	0	100
^{228}Th	4.7×10^{-1}	95	0	5	4.9×10^{-3}	0	0	100
^{229}Th	7.0×10^{-2}	97	0	3	1.8×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	8.8×10^{-7}	0	0	100
^{231}Th	2.6×10^{-3}	0	9	91	2.6×10^{-5}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	4.8×10^{-7}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	7.1×10^{-5}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	1.1×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	6.4×10^{-7}	0	0	100
^{235}U	6.5×10^{-2}	94	0	6	4.3×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	4.0×10^{-7}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	4.8×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	5.6×10^{-7}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	3.5×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	5.4×10^{-7}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.5×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	3.3×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	4.7×10^{-7}	0	0	100
^{243}Cm	8.3×10^{-2}	97	0	3	3.3×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	4.2×10^{-7}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	3.4×10^{-7}	0	0	100

Table 28. Dose conversion coefficients for the following organism

Organism name : Earthworm egg- soil
Habitat : Soil
Biota : Soil
Body mass (kg) : 6.54×10^{-5}
Body shape proportions : 1.0000 1.0000
External exposure : in-water
Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	3.8×10^{-12}	0	0	100
^{14}C	6.7×10^{-4}	0	1	99	1.0×10^{-5}	0	0	100
^{32}P	4.8×10^{-3}	0	0	100	4.8×10^{-3}	0	0	100
^{33}P	1.0×10^{-3}	0	1	99	3.3×10^{-5}	0	0	100
^{35}S	6.7×10^{-4}	0	2	98	1.1×10^{-5}	0	0	100
^{36}Cl	3.1×10^{-3}	0	0	100	7.2×10^{-4}	0	0	100
^{40}K	4.6×10^{-3}	0	0	100	5.6×10^{-3}	0	0	100
^{45}Ca	1.0×10^{-3}	0	1	99	3.5×10^{-5}	0	0	100
^{51}Cr	6.8×10^{-5}	0	78	22	4.4×10^{-4}	0	0	100
^{54}Mn	1.2×10^{-4}	0	48	52	1.2×10^{-2}	0	0	100
^{57}Co	3.0×10^{-4}	0	61	39	1.7×10^{-3}	0	0	100
^{58}Co	2.6×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.4×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{59}Ni	8.5×10^{-5}	0	74	26	1.2×10^{-5}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	8.4×10^{-7}	0	0	100
^{65}Zn	2.0×10^{-3}	0	3	97	8.2×10^{-3}	0	0	100
^{75}Se	2.6×10^{-4}	0	25	75	5.4×10^{-3}	0	0	100
^{79}Se	7.6×10^{-4}	0	1	99	1.3×10^{-5}	0	0	100
^{89}Sr	4.4×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{90}Sr	7.1×10^{-3}	0	0	100	8.5×10^{-3}	0	0	100
^{95}Zr	1.6×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.2×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	6.5×10^{-4}	0	2	98	1.1×10^{-2}	0	0	100
^{99}Tc	1.3×10^{-3}	0	0	100	6.4×10^{-5}	0	0	100
^{103}Ru	1.5×10^{-3}	0	3	97	6.5×10^{-3}	0	0	100
^{106}Ru	5.0×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{110m}Ag	1.1×10^{-3}	0	2	98	3.8×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	3.6×10^{-4}	0	0	100
^{124}Sb	3.1×10^{-3}	0	0	100	2.7×10^{-2}	0	0	100
^{125}Sb	1.3×10^{-3}	0	5	95	6.0×10^{-3}	0	0	100
^{129m}Te	8.1×10^{-3}	0	1	99	6.6×10^{-3}	0	0	100
^{132}Te	5.6×10^{-3}	0	1	99	3.9×10^{-2}	0	0	100
^{125}I	2.9×10^{-4}	0	50	50	5.6×10^{-4}	0	0	100

^{129}I	8.8×10^{-4}	0	13	87	3.4×10^{-4}	0	0	100
^{131}I	2.4×10^{-3}	0	0	100	5.6×10^{-3}	0	0	100
^{132}I	4.1×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{133}I	3.9×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{134}Cs	2.0×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{135}Cs	9.1×10^{-4}	0	1	99	2.3×10^{-5}	0	0	100
^{136}Cs	1.9×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	2.8×10^{-3}	0	0	100	8.4×10^{-3}	0	0	100
^{140}Ba	8.6×10^{-3}	0	2	98	4.4×10^{-2}	0	0	100
^{140}La	4.4×10^{-3}	0	0	100	3.5×10^{-2}	0	0	100
^{141}Ce	2.2×10^{-3}	0	1	99	1.2×10^{-3}	0	0	100
^{144}Ce	6.1×10^{-3}	0	0	100	1.3×10^{-2}	0	0	100
^{152}Eu	3.4×10^{-3}	0	2	98	1.7×10^{-2}	0	0	100
^{154}Eu	3.1×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.7×10^{-4}	0	7	93	8.4×10^{-4}	0	0	100
^{192}Ir	2.8×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{210}Pb	4.3×10^{-3}	0	2	98	1.7×10^{-3}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	3.0×10^{-2}	0	0	100
^{228}Ra	4.8×10^{-3}	0	5	95	1.5×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.5×10^{-1}	98	0	2	2.9×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.9×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	10	90	3.6×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100
^{234}Th	5.5×10^{-3}	0	1	99	7.1×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.4×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	2.0×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.5×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	99	0	1	4.6×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	2.1×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	8.6×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	2.0×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.3×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.2×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.2×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.9×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.0×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100

Table 29. Dose conversion coefficients for the following organism

Organism name : Earthworm - in soil
Habitat : terrestrial
Biota : animal
Body mass (kg) : 5.24×10^{-3}
Body shape proportions : 0.1000 0.1000
External exposure : in-soil
Source geometry : 50-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	8.0×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.6×10^{-3}	0	0	100	1.9×10^{-6}	0	0	100
^{40}K	7.0×10^{-3}	0	0	100	1.9×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	6.5×10^{-11}	0	0	100
^{51}Cr	7.6×10^{-5}	0	69	31	3.7×10^{-4}	0	0	100
^{54}Mn	2.8×10^{-4}	0	20	80	1.1×10^{-2}	0	0	100
^{57}Co	3.4×10^{-4}	0	54	46	9.7×10^{-4}	0	0	100
^{58}Co	3.0×10^{-3}	0	2	98	1.2×10^{-2}	0	0	100
^{60}Co	1.8×10^{-3}	0	0	100	3.1×10^{-2}	0	0	100
^{59}Ni	9.2×10^{-5}	0	69	31	2.5×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.2×10^{-3}	0	3	97	7.3×10^{-3}	0	0	100
^{75}Se	3.6×10^{-4}	0	18	82	4.1×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	6.9×10^{-3}	0	0	100	1.1×10^{-6}	0	0	100
^{90}Sr	1.3×10^{-2}	0	0	100	3.7×10^{-9}	0	0	100
^{95}Zr	1.8×10^{-3}	0	0	100	9.5×10^{-3}	0	0	100
^{94}Nb	2.6×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{95}Nb	8.0×10^{-4}	0	2	98	9.9×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.7×10^{-3}	0	3	97	5.9×10^{-3}	0	0	100
^{106}Ru	1.3×10^{-2}	0	0	100	2.6×10^{-3}	0	0	100
^{110m}Ag	1.8×10^{-3}	0	1	99	3.5×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	8.4×10^{-5}	0	0	100
^{124}Sb	4.9×10^{-3}	0	0	100	2.3×10^{-2}	0	0	100
^{125}Sb	1.5×10^{-3}	0	5	95	5.3×10^{-3}	0	0	100
^{129m}Te	1.2×10^{-2}	0	1	99	8.6×10^{-4}	0	0	100
^{132}Te	8.1×10^{-3}	0	1	99	3.2×10^{-2}	0	0	100
^{125}I	3.3×10^{-4}	0	44	56	1.3×10^{-4}	0	0	100

^{129}I	9.1×10^{-4}	0	13	87	8.4×10^{-5}	0	0	100
^{131}I	2.7×10^{-3}	0	0	100	4.6×10^{-3}	0	0	100
^{132}I	6.5×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{133}I	5.2×10^{-3}	0	0	100	7.7×10^{-3}	0	0	100
^{134}Cs	2.6×10^{-3}	0	0	100	2.0×10^{-2}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.4×10^{-3}	0	1	99	2.7×10^{-2}	0	0	100
^{137}Cs	3.4×10^{-3}	0	0	100	7.3×10^{-3}	0	0	100
^{140}Ba	1.2×10^{-2}	0	1	99	3.5×10^{-2}	0	0	100
^{140}La	6.9×10^{-3}	0	0	100	2.9×10^{-2}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	6.5×10^{-4}	0	0	100
^{144}Ce	1.3×10^{-2}	0	0	100	5.5×10^{-4}	0	0	100
^{152}Eu	4.1×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{154}Eu	4.0×10^{-3}	0	1	99	1.5×10^{-2}	0	0	100
^{155}Eu	9.0×10^{-4}	0	7	93	3.8×10^{-4}	0	0	100
^{192}Ir	3.2×10^{-3}	0	1	99	9.8×10^{-3}	0	0	100
^{210}Pb	5.4×10^{-3}	0	2	98	1.4×10^{-5}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	96	0	4	2.2×10^{-2}	0	0	100
^{228}Ra	6.4×10^{-3}	0	3	97	1.2×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.1×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	1.9×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	6.7×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	5.0×10^{-6}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	1.1×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	3.5×10^{-6}	0	0	100
^{234}Th	9.9×10^{-3}	0	0	100	2.7×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	4.3×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	5.0×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	4.2×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	1.6×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	3.0×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.8×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	4.1×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.0×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	3.9×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.3×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.5×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	4.3×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.2×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	3.9×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	3.0×10^{-6}	0	0	100

Table 30. Dose conversion coefficients for the following organism

Organism name : Pine trunk   - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 4.71×10^2
Body shape proportions : 0.0300 0.0300
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.6×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.9×10^{-3}	0	0	100	3.9×10^{-9}	0	0	100
^{40}K	9.0×10^{-3}	0	0	100	4.3×10^{-6}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.8×10^{-15}	0	0	100
^{51}Cr	3.4×10^{-4}	0	15	85	7.9×10^{-7}	0	0	100
^{54}Mn	6.1×10^{-3}	0	1	99	2.2×10^{-5}	0	0	100
^{57}Co	1.5×10^{-3}	0	12	88	2.2×10^{-6}	0	0	100
^{58}Co	1.0×10^{-2}	0	1	99	2.5×10^{-5}	0	0	100
^{60}Co	1.8×10^{-2}	0	0	100	6.7×10^{-5}	0	0	100
^{59}Ni	9.6×10^{-5}	0	65	35	3.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	6.0×10^{-3}	0	1	99	1.5×10^{-5}	0	0	100
^{75}Se	3.8×10^{-3}	0	2	98	8.8×10^{-6}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	2.2×10^{-9}	0	0	100
^{90}Sr	1.6×10^{-2}	0	0	100	1.5×10^{-12}	0	0	100
^{95}Zr	7.2×10^{-3}	0	0	100	1.9×10^{-5}	0	0	100
^{94}Nb	1.4×10^{-2}	0	0	100	4.1×10^{-5}	0	0	100
^{95}Nb	6.3×10^{-3}	0	0	100	2.0×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	5.4×10^{-3}	0	1	99	1.2×10^{-5}	0	0	100
^{106}Ru	2.1×10^{-2}	0	0	100	5.3×10^{-6}	0	0	100
^{110m}Ag	2.1×10^{-2}	0	0	100	7.2×10^{-5}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	2.3×10^{-7}	0	0	100
^{124}Sb	1.8×10^{-2}	0	0	100	4.9×10^{-5}	0	0	100
^{125}Sb	4.9×10^{-3}	0	1	99	1.1×10^{-5}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.8×10^{-6}	0	0	100
^{132}Te	2.8×10^{-2}	0	0	100	6.6×10^{-5}	0	0	100
^{125}I	8.1×10^{-4}	0	18	82	4.7×10^{-7}	0	0	100

^{129}I	1.2×10^{-3}	0	10	90	2.9×10^{-7}	0	0	100
^{131}I	5.9×10^{-3}	0	0	100	9.7×10^{-6}	0	0	100
^{132}I	2.4×10^{-2}	0	0	100	5.9×10^{-5}	0	0	100
^{133}I	1.0×10^{-2}	0	0	100	1.6×10^{-5}	0	0	100
^{134}Cs	1.4×10^{-2}	0	0	100	4.0×10^{-5}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	1.8×10^{-2}	0	0	100	5.6×10^{-5}	0	0	100
^{137}Cs	7.8×10^{-3}	0	0	100	1.4×10^{-5}	0	0	100
^{140}Ba	3.2×10^{-2}	0	0	100	7.6×10^{-5}	0	0	100
^{140}La	2.2×10^{-2}	0	0	100	6.2×10^{-5}	0	0	100
^{141}Ce	3.1×10^{-3}	0	1	99	1.4×10^{-6}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	1.2×10^{-6}	0	0	100
^{152}Eu	1.2×10^{-2}	0	1	99	3.0×10^{-5}	0	0	100
^{154}Eu	1.3×10^{-2}	0	0	100	3.2×10^{-5}	0	0	100
^{155}Eu	1.5×10^{-3}	0	4	96	9.5×10^{-7}	0	0	100
^{192}Ir	1.0×10^{-2}	0	0	100	2.1×10^{-5}	0	0	100
^{210}Pb	6.0×10^{-3}	0	2	98	2.7×10^{-8}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	2.2×10^{-10}	0	0	100
^{226}Ra	3.6×10^{-1}	93	0	7	4.7×10^{-5}	0	0	100
^{228}Ra	1.4×10^{-2}	0	2	98	2.5×10^{-5}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	2.4×10^{-6}	0	0	100
^{228}Th	4.7×10^{-1}	95	0	5	4.2×10^{-5}	0	0	100
^{229}Th	7.0×10^{-2}	96	0	3	1.5×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	6.9×10^{-9}	0	0	100
^{231}Th	2.6×10^{-3}	0	8	92	2.2×10^{-7}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	3.5×10^{-9}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	5.8×10^{-7}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	8.9×10^{-7}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	7.5×10^{-9}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	3.5×10^{-9}	0	0	100
^{235}U	6.6×10^{-2}	93	0	7	3.4×10^{-6}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.8×10^{-9}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	4.1×10^{-7}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	3.0×10^{-9}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	2.3×10^{-9}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	2.9×10^{-9}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	2.8×10^{-11}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	3.4×10^{-7}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	4.2×10^{-9}	0	0	100
^{243}Cm	8.3×10^{-2}	96	0	4	2.6×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	3.7×10^{-9}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	4.1×10^{-9}	0	0	100

Table 31. Dose conversion coefficients for the following organism

Organism name : Pine trunk - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 4.71×10^2
Body shape proportions : 0.0300 0.0300
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	9.6×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.8×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.9×10^{-3}	0	0	100	2.4×10^{-7}	0	0	100
^{40}K	9.0×10^{-3}	0	0	100	2.8×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	2.7×10^{-12}	0	0	100
^{51}Cr	3.4×10^{-4}	0	15	85	4.7×10^{-5}	0	0	100
^{54}Mn	6.1×10^{-3}	0	1	99	1.3×10^{-3}	0	0	100
^{57}Co	1.5×10^{-3}	0	12	88	1.2×10^{-4}	0	0	100
^{58}Co	1.0×10^{-2}	0	1	99	1.6×10^{-3}	0	0	100
^{60}Co	1.8×10^{-2}	0	0	100	4.3×10^{-3}	0	0	100
^{59}Ni	9.6×10^{-5}	0	65	35	8.4×10^{-39}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	6.0×10^{-3}	0	1	99	9.7×10^{-4}	0	0	100
^{75}Se	3.8×10^{-3}	0	2	98	5.1×10^{-4}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	8.0×10^{-3}	0	0	100	1.4×10^{-7}	0	0	100
^{90}Sr	1.6×10^{-2}	0	0	100	5.6×10^{-11}	0	0	100
^{95}Zr	7.2×10^{-3}	0	0	100	1.2×10^{-3}	0	0	100
^{94}Nb	1.4×10^{-2}	0	0	100	2.5×10^{-3}	0	0	100
^{95}Nb	6.3×10^{-3}	0	0	100	1.2×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	5.4×10^{-3}	0	1	99	7.4×10^{-4}	0	0	100
^{106}Ru	2.1×10^{-2}	0	0	100	3.3×10^{-4}	0	0	100
^{110m}Ag	2.1×10^{-2}	0	0	100	4.5×10^{-3}	0	0	100
^{109}Cd	1.5×10^{-3}	0	6	94	6.0×10^{-6}	0	0	100
^{124}Sb	1.8×10^{-2}	0	0	100	3.1×10^{-3}	0	0	100
^{125}Sb	4.9×10^{-3}	0	1	99	6.5×10^{-4}	0	0	100
^{129m}Te	1.4×10^{-2}	0	0	100	1.1×10^{-4}	0	0	100
^{132}Te	2.8×10^{-2}	0	0	100	4.1×10^{-3}	0	0	100
^{125}I	8.1×10^{-4}	0	18	82	7.9×10^{-6}	0	0	100

^{129}I	1.2×10^{-3}	0	10	90	4.8×10^{-6}	0	0	100
^{131}I	5.9×10^{-3}	0	0	100	5.8×10^{-4}	0	0	100
^{132}I	2.4×10^{-2}	0	0	100	3.7×10^{-3}	0	0	100
^{133}I	1.0×10^{-2}	0	0	100	9.7×10^{-4}	0	0	100
^{134}Cs	1.4×10^{-2}	0	0	100	2.5×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	1.8×10^{-2}	0	0	100	3.5×10^{-3}	0	0	100
^{137}Cs	7.8×10^{-3}	0	0	100	8.9×10^{-4}	0	0	100
^{140}Ba	3.2×10^{-2}	0	0	100	4.9×10^{-3}	0	0	100
^{140}La	2.2×10^{-2}	0	0	100	4.0×10^{-3}	0	0	100
^{141}Ce	3.1×10^{-3}	0	1	99	7.6×10^{-5}	0	0	100
^{144}Ce	1.8×10^{-2}	0	0	100	7.3×10^{-5}	0	0	100
^{152}Eu	1.2×10^{-2}	0	1	99	1.8×10^{-3}	0	0	100
^{154}Eu	1.3×10^{-2}	0	0	100	2.0×10^{-3}	0	0	100
^{155}Eu	1.5×10^{-3}	0	4	96	4.1×10^{-5}	0	0	100
^{192}Ir	1.0×10^{-2}	0	0	100	1.2×10^{-3}	0	0	100
^{210}Pb	6.0×10^{-3}	0	2	98	8.9×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.4×10^{-8}	0	0	100
^{226}Ra	3.6×10^{-1}	93	0	7	3.0×10^{-3}	0	0	100
^{228}Ra	1.4×10^{-2}	0	2	98	1.6×10^{-3}	0	0	100
^{227}Th	8.3×10^{-2}	98	0	2	1.4×10^{-4}	0	0	100
^{228}Th	4.7×10^{-1}	95	0	5	2.7×10^{-3}	0	0	100
^{229}Th	7.0×10^{-2}	96	0	3	7.5×10^{-5}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.3×10^{-7}	0	0	100
^{231}Th	2.6×10^{-3}	0	8	92	9.5×10^{-6}	0	0	100
^{232}Th	5.6×10^{-2}	100	0	0	1.7×10^{-7}	0	0	100
^{234}Th	1.2×10^{-2}	0	0	100	3.4×10^{-5}	0	0	100
^{231}Pa	7.0×10^{-2}	98	0	2	5.2×10^{-5}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	4.2×10^{-7}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	2.0×10^{-7}	0	0	100
^{235}U	6.6×10^{-2}	93	0	7	1.9×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	2	1.9×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.6×10^{-7}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.6×10^{-7}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.4×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.1×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.5×10^{-7}	0	0	100
^{243}Cm	8.3×10^{-2}	96	0	4	1.5×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.3×10^{-7}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.1×10^{-7}	0	0	100

Table 32. Dose conversion coefficients for the following organism

Organism name : Pine (layer) - plane
Habitat : terrestrial
Biota : vegetation
Vegetation type : tree
Layer density : 0.00×10^0
Body mass (kg) : 0.00×10^0
Body shape proportions : 0.0000 0.0000
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$1.\$\times10^0$	0	0	0	–	0	0	0
^{14}C	$1.\$\times10^0$	0	0	0	–	0	0	0
^{32}P	$1.\$\times10^0$	0	0	0	–	0	0	0
^{33}P	$1.\$\times10^0$	0	0	0	–	0	0	0
^{35}S	$1.\$\times10^0$	0	0	0	–	0	0	0
^{36}Cl	$1.\$\times10^0$	0	0	0	8.5×10^{-9}	0	0	100
^{40}K	$1.\$\times10^0$	0	0	0	8.1×10^{-6}	0	0	100
^{45}Ca	$1.\$\times10^0$	0	0	0	1.3×10^{-13}	0	0	100
^{51}Cr	$1.\$\times10^0$	0	0	0	1.8×10^{-6}	0	0	100
^{54}Mn	$1.\$\times10^0$	0	0	0	4.6×10^{-5}	0	0	100
^{57}Co	$1.\$\times10^0$	0	0	0	7.0×10^{-6}	0	0	100
^{58}Co	$1.\$\times10^0$	0	0	0	5.4×10^{-5}	0	0	100
^{60}Co	$1.\$\times10^0$	0	0	0	1.3×10^{-4}	0	0	100
^{59}Ni	$1.\$\times10^0$	0	0	0	1.9×10^{-10}	0	0	100
^{63}Ni	$1.\$\times10^0$	0	0	0	–	0	0	0
^{65}Zn	$1.\$\times10^0$	0	0	0	3.2×10^{-5}	0	0	100
^{75}Se	$1.\$\times10^0$	0	0	0	2.3×10^{-5}	0	0	100
^{79}Se	$1.\$\times10^0$	0	0	0	–	0	0	0
^{89}Sr	$1.\$\times10^0$	0	0	0	4.7×10^{-9}	0	0	100
^{90}Sr	$1.\$\times10^0$	0	0	0	9.0×10^{-11}	0	0	100
^{95}Zr	$1.\$\times10^0$	0	0	0	4.1×10^{-5}	0	0	100
^{94}Nb	$1.\$\times10^0$	0	0	0	8.7×10^{-5}	0	0	100
^{95}Nb	$1.\$\times10^0$	0	0	0	4.3×10^{-5}	0	0	100
^{99}Tc	$1.\$\times10^0$	0	0	0	–	0	0	0
^{103}Ru	$1.\$\times10^0$	0	0	0	2.7×10^{-5}	0	0	100
^{106}Ru	$1.\$\times10^0$	0	0	0	1.1×10^{-5}	0	0	100
^{110m}Ag	$1.\$\times10^0$	0	0	0	1.5×10^{-4}	0	0	100
^{109}Cd	$1.\$\times10^0$	0	0	0	2.7×10^{-6}	0	0	100
^{124}Sb	$1.\$\times10^0$	0	0	0	9.5×10^{-5}	0	0	100
^{125}Sb	$1.\$\times10^0$	0	0	0	2.5×10^{-5}	0	0	100
^{129m}Te	$1.\$\times10^0$	0	0	0	5.0×10^{-6}	0	0	100

^{132}Te	$1.\$ \times 10^0$	0	0	0	1.4×10^{-4}	0	0	100
^{125}I	$1.\$ \times 10^0$	0	0	0	4.9×10^{-6}	0	0	100
^{129}I	$1.\$ \times 10^0$	0	0	0	2.8×10^{-6}	0	0	100
^{131}I	$1.\$ \times 10^0$	0	0	0	2.2×10^{-5}	0	0	100
^{132}I	$1.\$ \times 10^0$	0	0	0	1.3×10^{-4}	0	0	100
^{133}I	$1.\$ \times 10^0$	0	0	0	3.4×10^{-5}	0	0	100
^{134}Cs	$1.\$ \times 10^0$	0	0	0	8.6×10^{-5}	0	0	100
^{135}Cs	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{136}Cs	$1.\$ \times 10^0$	0	0	0	1.2×10^{-4}	0	0	100
^{137}Cs	$1.\$ \times 10^0$	0	0	0	3.1×10^{-5}	0	0	100
^{140}Ba	$1.\$ \times 10^0$	0	0	0	1.5×10^{-4}	0	0	100
^{140}La	$1.\$ \times 10^0$	0	0	0	1.2×10^{-4}	0	0	100
^{141}Ce	$1.\$ \times 10^0$	0	0	0	4.7×10^{-6}	0	0	100
^{144}Ce	$1.\$ \times 10^0$	0	0	0	3.0×10^{-6}	0	0	100
^{152}Eu	$1.\$ \times 10^0$	0	0	0	6.4×10^{-5}	0	0	100
^{154}Eu	$1.\$ \times 10^0$	0	0	0	6.8×10^{-5}	0	0	100
^{155}Eu	$1.\$ \times 10^0$	0	0	0	3.9×10^{-6}	0	0	100
^{192}Ir	$1.\$ \times 10^0$	0	0	0	4.7×10^{-5}	0	0	100
^{210}Pb	$1.\$ \times 10^0$	0	0	0	1.8×10^{-7}	0	0	100
^{210}Po	$1.\$ \times 10^0$	0	0	0	4.7×10^{-10}	0	0	100
^{226}Ra	$1.\$ \times 10^0$	0	0	0	9.3×10^{-5}	0	0	100
^{228}Ra	$1.\$ \times 10^0$	0	0	0	5.3×10^{-5}	0	0	100
^{227}Th	$1.\$ \times 10^0$	0	0	0	6.4×10^{-6}	0	0	100
^{228}Th	$1.\$ \times 10^0$	0	0	0	7.8×10^{-5}	0	0	100
^{229}Th	$1.\$ \times 10^0$	0	0	0	5.4×10^{-6}	0	0	100
^{230}Th	$1.\$ \times 10^0$	0	0	0	6.4×10^{-8}	0	0	100
^{231}Th	$1.\$ \times 10^0$	0	0	0	1.6×10^{-6}	0	0	100
^{232}Th	$1.\$ \times 10^0$	0	0	0	5.1×10^{-8}	0	0	100
^{234}Th	$1.\$ \times 10^0$	0	0	0	1.6×10^{-6}	0	0	100
^{231}Pa	$1.\$ \times 10^0$	0	0	0	2.8×10^{-6}	0	0	100
^{233}U	$1.\$ \times 10^0$	0	0	0	6.6×10^{-8}	0	0	100
^{234}U	$1.\$ \times 10^0$	0	0	0	8.1×10^{-8}	0	0	100
^{235}U	$1.\$ \times 10^0$	0	0	0	1.1×10^{-5}	0	0	100
^{238}U	$1.\$ \times 10^0$	0	0	0	6.3×10^{-8}	0	0	100
^{237}Np	$1.\$ \times 10^0$	0	0	0	2.2×10^{-6}	0	0	100
^{238}Pu	$1.\$ \times 10^0$	0	0	0	1.0×10^{-7}	0	0	100
^{239}Pu	$1.\$ \times 10^0$	0	0	0	4.2×10^{-8}	0	0	100
^{240}Pu	$1.\$ \times 10^0$	0	0	0	9.8×10^{-8}	0	0	100
^{241}Pu	$1.\$ \times 10^0$	0	0	0	1.5×10^{-10}	0	0	100
^{241}Am	$1.\$ \times 10^0$	0	0	0	2.2×10^{-6}	0	0	100
^{242}Cm	$1.\$ \times 10^0$	0	0	0	1.2×10^{-7}	0	0	100
^{243}Cm	$1.\$ \times 10^0$	0	0	0	7.9×10^{-6}	0	0	100
^{244}Cm	$1.\$ \times 10^0$	0	0	0	1.1×10^{-7}	0	0	100
^{252}Cf	$1.\$ \times 10^0$	0	0	0	9.2×10^{-8}	0	0	100

Table 33. Dose conversion coefficients for the following organism

Organism name : Pine (layer) - volume
Habitat : terrestrial
Biota : vegetation
Vegetation type : tree
Layer density : 0.00×10^0
Body mass (kg) : 0.00×10^0
Body shape proportions : 0.0000 0.0000
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{14}C	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{32}P	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{33}P	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{35}S	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{36}Cl	$1.\$ \times 10^0$	0	0	0	5.9×10^{-7}	0	0	100
^{40}K	$1.\$ \times 10^0$	0	0	0	5.7×10^{-4}	0	0	100
^{45}Ca	$1.\$ \times 10^0$	0	0	0	9.4×10^{-14}	0	0	100
^{51}Cr	$1.\$ \times 10^0$	0	0	0	1.2×10^{-4}	0	0	100
^{54}Mn	$1.\$ \times 10^0$	0	0	0	3.2×10^{-3}	0	0	100
^{57}Co	$1.\$ \times 10^0$	0	0	0	3.9×10^{-4}	0	0	100
^{58}Co	$1.\$ \times 10^0$	0	0	0	3.7×10^{-3}	0	0	100
^{60}Co	$1.\$ \times 10^0$	0	0	0	9.3×10^{-3}	0	0	100
^{59}Ni	$1.\$ \times 10^0$	0	0	0	6.5×10^{-11}	0	0	100
^{63}Ni	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{65}Zn	$1.\$ \times 10^0$	0	0	0	2.2×10^{-3}	0	0	100
^{75}Se	$1.\$ \times 10^0$	0	0	0	1.4×10^{-3}	0	0	100
^{79}Se	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{89}Sr	$1.\$ \times 10^0$	0	0	0	3.2×10^{-7}	0	0	100
^{90}Sr	$1.\$ \times 10^0$	0	0	0	1.4×10^{-10}	0	0	100
^{95}Zr	$1.\$ \times 10^0$	0	0	0	2.8×10^{-3}	0	0	100
^{94}Nb	$1.\$ \times 10^0$	0	0	0	6.0×10^{-3}	0	0	100
^{95}Nb	$1.\$ \times 10^0$	0	0	0	2.9×10^{-3}	0	0	100
^{99}Tc	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{103}Ru	$1.\$ \times 10^0$	0	0	0	1.8×10^{-3}	0	0	100
^{106}Ru	$1.\$ \times 10^0$	0	0	0	7.9×10^{-4}	0	0	100
^{110m}Ag	$1.\$ \times 10^0$	0	0	0	1.0×10^{-2}	0	0	100
^{109}Cd	$1.\$ \times 10^0$	0	0	0	1.8×10^{-5}	0	0	100
^{124}Sb	$1.\$ \times 10^0$	0	0	0	6.8×10^{-3}	0	0	100
^{125}Sb	$1.\$ \times 10^0$	0	0	0	1.6×10^{-3}	0	0	100
^{129m}Te	$1.\$ \times 10^0$	0	0	0	2.6×10^{-4}	0	0	100

^{132}Te	$1.\$\times10^0$	0	0	0	9.8×10^{-3}	0	0	100
^{125}I	$1.\$\times10^0$	0	0	0	2.9×10^{-5}	0	0	100
^{129}I	$1.\$\times10^0$	0	0	0	2.1×10^{-5}	0	0	100
^{131}I	$1.\$\times10^0$	0	0	0	1.5×10^{-3}	0	0	100
^{132}I	$1.\$\times10^0$	0	0	0	8.7×10^{-3}	0	0	100
^{133}I	$1.\$\times10^0$	0	0	0	2.3×10^{-3}	0	0	100
^{134}Cs	$1.\$\times10^0$	0	0	0	6.0×10^{-3}	0	0	100
^{135}Cs	$1.\$\times10^0$	0	0	0	$-$	0	0	0
^{136}Cs	$1.\$\times10^0$	0	0	0	8.2×10^{-3}	0	0	100
^{137}Cs	$1.\$\times10^0$	0	0	0	2.2×10^{-3}	0	0	100
^{140}Ba	$1.\$\times10^0$	0	0	0	1.1×10^{-2}	0	0	100
^{140}La	$1.\$\times10^0$	0	0	0	8.5×10^{-3}	0	0	100
^{141}Ce	$1.\$\times10^0$	0	0	0	2.4×10^{-4}	0	0	100
^{144}Ce	$1.\$\times10^0$	0	0	0	1.7×10^{-4}	0	0	100
^{152}Eu	$1.\$\times10^0$	0	0	0	4.3×10^{-3}	0	0	100
^{154}Eu	$1.\$\times10^0$	0	0	0	4.6×10^{-3}	0	0	100
^{155}Eu	$1.\$\times10^0$	0	0	0	1.6×10^{-4}	0	0	100
^{192}Ir	$1.\$\times10^0$	0	0	0	3.1×10^{-3}	0	0	100
^{210}Pb	$1.\$\times10^0$	0	0	0	3.1×10^{-6}	0	0	100
^{210}Po	$1.\$\times10^0$	0	0	0	3.3×10^{-8}	0	0	100
^{226}Ra	$1.\$\times10^0$	0	0	0	6.5×10^{-3}	0	0	100
^{228}Ra	$1.\$\times10^0$	0	0	0	3.6×10^{-3}	0	0	100
^{227}Th	$1.\$\times10^0$	0	0	0	3.8×10^{-4}	0	0	100
^{228}Th	$1.\$\times10^0$	0	0	0	5.5×10^{-3}	0	0	100
^{229}Th	$1.\$\times10^0$	0	0	0	2.6×10^{-4}	0	0	100
^{230}Th	$1.\$\times10^0$	0	0	0	1.1×10^{-6}	0	0	100
^{231}Th	$1.\$\times10^0$	0	0	0	3.2×10^{-5}	0	0	100
^{232}Th	$1.\$\times10^0$	0	0	0	5.0×10^{-7}	0	0	100
^{234}Th	$1.\$\times10^0$	0	0	0	8.8×10^{-5}	0	0	100
^{231}Pa	$1.\$\times10^0$	0	0	0	1.4×10^{-4}	0	0	100
^{233}U	$1.\$\times10^0$	0	0	0	1.1×10^{-6}	0	0	100
^{234}U	$1.\$\times10^0$	0	0	0	4.3×10^{-7}	0	0	100
^{235}U	$1.\$\times10^0$	0	0	0	5.7×10^{-4}	0	0	100
^{238}U	$1.\$\times10^0$	0	0	0	1.7×10^{-7}	0	0	100
^{237}Np	$1.\$\times10^0$	0	0	0	6.7×10^{-5}	0	0	100
^{238}Pu	$1.\$\times10^0$	0	0	0	2.5×10^{-7}	0	0	100
^{239}Pu	$1.\$\times10^0$	0	0	0	2.7×10^{-7}	0	0	100
^{240}Pu	$1.\$\times10^0$	0	0	0	2.5×10^{-7}	0	0	100
^{241}Pu	$1.\$\times10^0$	0	0	0	4.8×10^{-9}	0	0	100
^{241}Am	$1.\$\times10^0$	0	0	0	4.5×10^{-5}	0	0	100
^{242}Cm	$1.\$\times10^0$	0	0	0	3.1×10^{-7}	0	0	100
^{243}Cm	$1.\$\times10^0$	0	0	0	4.3×10^{-4}	0	0	100
^{244}Cm	$1.\$\times10^0$	0	0	0	2.6×10^{-7}	0	0	100
^{252}Cf	$1.\$\times10^0$	0	0	0	2.9×10^{-7}	0	0	100

Table 34. Dose conversion coefficients for the following organism

Organism name : Grass meristem -plane
Habitat : terrestrial
Biota : vegetation
Vegetation type : herbs
Layer density : 0.00×10^0
Body mass (kg) : 0.00×10^0
Body shape proportions : 0.0000 0.0000
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{14}C	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{32}P	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{33}P	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{35}S	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{36}Cl	$1.\$ \times 10^0$	0	0	0	3.9×10^{-8}	0	0	100
^{40}K	$1.\$ \times 10^0$	0	0	0	2.6×10^{-5}	0	0	100
^{45}Ca	$1.\$ \times 10^0$	0	0	0	3.5×10^{-10}	0	0	100
^{51}Cr	$1.\$ \times 10^0$	0	0	0	1.4×10^{-5}	0	0	100
^{54}Mn	$1.\$ \times 10^0$	0	0	0	1.6×10^{-4}	0	0	100
^{57}Co	$1.\$ \times 10^0$	0	0	0	6.4×10^{-5}	0	0	100
^{58}Co	$1.\$ \times 10^0$	0	0	0	1.9×10^{-4}	0	0	100
^{60}Co	$1.\$ \times 10^0$	0	0	0	4.3×10^{-4}	0	0	100
^{59}Ni	$1.\$ \times 10^0$	0	0	0	2.5×10^{-5}	0	0	100
^{63}Ni	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{65}Zn	$1.\$ \times 10^0$	0	0	0	1.4×10^{-4}	0	0	100
^{75}Se	$1.\$ \times 10^0$	0	0	0	1.5×10^{-4}	0	0	100
^{79}Se	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{89}Sr	$1.\$ \times 10^0$	0	0	0	1.5×10^{-8}	0	0	100
^{90}Sr	$1.\$ \times 10^0$	0	0	0	7.9×10^{-9}	0	0	100
^{95}Zr	$1.\$ \times 10^0$	0	0	0	1.4×10^{-4}	0	0	100
^{94}Nb	$1.\$ \times 10^0$	0	0	0	2.9×10^{-4}	0	0	100
^{95}Nb	$1.\$ \times 10^0$	0	0	0	1.4×10^{-4}	0	0	100
^{99}Tc	$1.\$ \times 10^0$	0	0	0	–	0	0	0
^{103}Ru	$1.\$ \times 10^0$	0	0	0	9.4×10^{-5}	0	0	100
^{106}Ru	$1.\$ \times 10^0$	0	0	0	3.8×10^{-5}	0	0	100
^{110m}Ag	$1.\$ \times 10^0$	0	0	0	4.9×10^{-4}	0	0	100
^{109}Cd	$1.\$ \times 10^0$	0	0	0	4.6×10^{-5}	0	0	100
^{124}Sb	$1.\$ \times 10^0$	0	0	0	3.1×10^{-4}	0	0	100
^{125}Sb	$1.\$ \times 10^0$	0	0	0	9.4×10^{-5}	0	0	100
^{129m}Te	$1.\$ \times 10^0$	0	0	0	2.6×10^{-5}	0	0	100

^{132}Te	$1.\$\times10^0$	0	0	0	4.9×10^{-4}	0	0	100
^{125}I	$1.\$\times10^0$	0	0	0	4.6×10^{-5}	0	0	100
^{129}I	$1.\$\times10^0$	0	0	0	2.2×10^{-5}	0	0	100
^{131}I	$1.\$\times10^0$	0	0	0	7.4×10^{-5}	0	0	100
^{132}I	$1.\$\times10^0$	0	0	0	4.1×10^{-4}	0	0	100
^{133}I	$1.\$\times10^0$	0	0	0	1.1×10^{-4}	0	0	100
^{134}Cs	$1.\$\times10^0$	0	0	0	2.9×10^{-4}	0	0	100
^{135}Cs	$1.\$\times10^0$	0	0	0	–	0	0	0
^{136}Cs	$1.\$\times10^0$	0	0	0	3.9×10^{-4}	0	0	100
^{137}Cs	$1.\$\times10^0$	0	0	0	1.1×10^{-4}	0	0	100
^{140}Ba	$1.\$\times10^0$	0	0	0	5.0×10^{-4}	0	0	100
^{140}La	$1.\$\times10^0$	0	0	0	3.9×10^{-4}	0	0	100
^{141}Ce	$1.\$\times10^0$	0	0	0	1.6×10^{-5}	0	0	100
^{144}Ce	$1.\$\times10^0$	0	0	0	1.1×10^{-5}	0	0	100
^{152}Eu	$1.\$\times10^0$	0	0	0	2.2×10^{-4}	0	0	100
^{154}Eu	$1.\$\times10^0$	0	0	0	2.3×10^{-4}	0	0	100
^{155}Eu	$1.\$\times10^0$	0	0	0	1.7×10^{-5}	0	0	100
^{192}Ir	$1.\$\times10^0$	0	0	0	1.6×10^{-4}	0	0	100
^{210}Pb	$1.\$\times10^0$	0	0	0	2.7×10^{-5}	0	0	100
^{210}Po	$1.\$\times10^0$	0	0	0	1.6×10^{-9}	0	0	100
^{226}Ra	$1.\$\times10^0$	0	0	0	3.2×10^{-4}	0	0	100
^{228}Ra	$1.\$\times10^0$	0	0	0	2.1×10^{-4}	0	0	100
^{227}Th	$1.\$\times10^0$	0	0	0	5.8×10^{-5}	0	0	100
^{228}Th	$1.\$\times10^0$	0	0	0	2.8×10^{-4}	0	0	100
^{229}Th	$1.\$\times10^0$	0	0	0	8.5×10^{-5}	0	0	100
^{230}Th	$1.\$\times10^0$	0	0	0	7.3×10^{-6}	0	0	100
^{231}Th	$1.\$\times10^0$	0	0	0	6.7×10^{-5}	0	0	100
^{232}Th	$1.\$\times10^0$	0	0	0	7.2×10^{-6}	0	0	100
^{234}Th	$1.\$\times10^0$	0	0	0	1.3×10^{-5}	0	0	100
^{231}Pa	$1.\$\times10^0$	0	0	0	7.1×10^{-5}	0	0	100
^{233}U	$1.\$\times10^0$	0	0	0	5.5×10^{-6}	0	0	100
^{234}U	$1.\$\times10^0$	0	0	0	8.8×10^{-6}	0	0	100
^{235}U	$1.\$\times10^0$	0	0	0	1.2×10^{-4}	0	0	100
^{238}U	$1.\$\times10^0$	0	0	0	7.3×10^{-6}	0	0	100
^{237}Np	$1.\$\times10^0$	0	0	0	5.5×10^{-5}	0	0	100
^{238}Pu	$1.\$\times10^0$	0	0	0	8.6×10^{-6}	0	0	100
^{239}Pu	$1.\$\times10^0$	0	0	0	3.2×10^{-6}	0	0	100
^{240}Pu	$1.\$\times10^0$	0	0	0	8.2×10^{-6}	0	0	100
^{241}Pu	$1.\$\times10^0$	0	0	0	5.1×10^{-9}	0	0	100
^{241}Am	$1.\$\times10^0$	0	0	0	5.4×10^{-5}	0	0	100
^{242}Cm	$1.\$\times10^0$	0	0	0	7.8×10^{-6}	0	0	100
^{243}Cm	$1.\$\times10^0$	0	0	0	6.5×10^{-5}	0	0	100
^{244}Cm	$1.\$\times10^0$	0	0	0	7.2×10^{-6}	0	0	100
^{252}Cf	$1.\$\times10^0$	0	0	0	4.3×10^{-6}	0	0	100

Table 35. Dose conversion coefficients for the following organism

Organism name : Grass meristem -volume

Habitat : terrestrial

Biota : vegetation

Vegetation type : herbs

Layer density : 0.00×10^0

Body mass (kg) : 0.00×10^0

Body shape proportions : 0.0000 0.0000

External exposure : on-soil

Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	$1.\$\times10^0$	0	0	0	–	0	0	0
^{14}C	$1.\$\times10^0$	0	0	0	–	0	0	0
^{32}P	$1.\$\times10^0$	0	0	0	–	0	0	0
^{33}P	$1.\$\times10^0$	0	0	0	–	0	0	0
^{35}S	$1.\$\times10^0$	0	0	0	–	0	0	0
^{36}Cl	$1.\$\times10^0$	0	0	0	7.4×10^{-7}	0	0	100
^{40}K	$1.\$\times10^0$	0	0	0	7.0×10^{-4}	0	0	100
^{45}Ca	$1.\$\times10^0$	0	0	0	6.8×10^{-11}	0	0	100
^{51}Cr	$1.\$\times10^0$	0	0	0	1.5×10^{-4}	0	0	100
^{54}Mn	$1.\$\times10^0$	0	0	0	4.0×10^{-3}	0	0	100
^{57}Co	$1.\$\times10^0$	0	0	0	4.9×10^{-4}	0	0	100
^{58}Co	$1.\$\times10^0$	0	0	0	4.6×10^{-3}	0	0	100
^{60}Co	$1.\$\times10^0$	0	0	0	1.1×10^{-2}	0	0	100
^{59}Ni	$1.\$\times10^0$	0	0	0	3.1×10^{-6}	0	0	100
^{63}Ni	$1.\$\times10^0$	0	0	0	–	0	0	0
^{65}Zn	$1.\$\times10^0$	0	0	0	2.7×10^{-3}	0	0	100
^{75}Se	$1.\$\times10^0$	0	0	0	1.8×10^{-3}	0	0	100
^{79}Se	$1.\$\times10^0$	0	0	0	–	0	0	0
^{89}Sr	$1.\$\times10^0$	0	0	0	4.0×10^{-7}	0	0	100
^{90}Sr	$1.\$\times10^0$	0	0	0	3.0×10^{-9}	0	0	100
^{95}Zr	$1.\$\times10^0$	0	0	0	3.5×10^{-3}	0	0	100
^{94}Nb	$1.\$\times10^0$	0	0	0	7.5×10^{-3}	0	0	100
^{95}Nb	$1.\$\times10^0$	0	0	0	3.7×10^{-3}	0	0	100
^{99}Tc	$1.\$\times10^0$	0	0	0	–	0	0	0
^{103}Ru	$1.\$\times10^0$	0	0	0	2.3×10^{-3}	0	0	100
^{106}Ru	$1.\$\times10^0$	0	0	0	9.9×10^{-4}	0	0	100
^{110m}Ag	$1.\$\times10^0$	0	0	0	1.3×10^{-2}	0	0	100
^{109}Cd	$1.\$\times10^0$	0	0	0	5.2×10^{-5}	0	0	100
^{124}Sb	$1.\$\times10^0$	0	0	0	8.3×10^{-3}	0	0	100
^{125}Sb	$1.\$\times10^0$	0	0	0	2.0×10^{-3}	0	0	100
^{129m}Te	$1.\$\times10^0$	0	0	0	3.3×10^{-4}	0	0	100

^{132}Te	$1.\$\times10^{0}$	0	0	0	1.2×10^{-2}	0	0	100
^{125}I	$1.\$\times10^{0}$	0	0	0	7.6×10^{-5}	0	0	100
^{129}I	$1.\$\times10^{0}$	0	0	0	4.6×10^{-5}	0	0	100
^{131}I	$1.\$\times10^{0}$	0	0	0	1.8×10^{-3}	0	0	100
^{132}I	$1.\$\times10^{0}$	0	0	0	1.1×10^{-2}	0	0	100
^{133}I	$1.\$\times10^{0}$	0	0	0	2.9×10^{-3}	0	0	100
^{134}Cs	$1.\$\times10^{0}$	0	0	0	7.4×10^{-3}	0	0	100
^{135}Cs	$1.\$\times10^{0}$	0	0	0	–	0	0	0
^{136}Cs	$1.\$\times10^{0}$	0	0	0	1.0×10^{-2}	0	0	100
^{137}Cs	$1.\$\times10^{0}$	0	0	0	2.7×10^{-3}	0	0	100
^{140}Ba	$1.\$\times10^{0}$	0	0	0	1.3×10^{-2}	0	0	100
^{140}La	$1.\$\times10^{0}$	0	0	0	1.0×10^{-2}	0	0	100
^{141}Ce	$1.\$\times10^{0}$	0	0	0	3.1×10^{-4}	0	0	100
^{144}Ce	$1.\$\times10^{0}$	0	0	0	2.2×10^{-4}	0	0	100
^{152}Eu	$1.\$\times10^{0}$	0	0	0	5.3×10^{-3}	0	0	100
^{154}Eu	$1.\$\times10^{0}$	0	0	0	5.7×10^{-3}	0	0	100
^{155}Eu	$1.\$\times10^{0}$	0	0	0	2.0×10^{-4}	0	0	100
^{192}Ir	$1.\$\times10^{0}$	0	0	0	3.9×10^{-3}	0	0	100
^{210}Pb	$1.\$\times10^{0}$	0	0	0	9.6×10^{-6}	0	0	100
^{210}Po	$1.\$\times10^{0}$	0	0	0	4.0×10^{-8}	0	0	100
^{226}Ra	$1.\$\times10^{0}$	0	0	0	8.0×10^{-3}	0	0	100
^{228}Ra	$1.\$\times10^{0}$	0	0	0	4.5×10^{-3}	0	0	100
^{227}Th	$1.\$\times10^{0}$	0	0	0	4.8×10^{-4}	0	0	100
^{228}Th	$1.\$\times10^{0}$	0	0	0	6.8×10^{-3}	0	0	100
^{229}Th	$1.\$\times10^{0}$	0	0	0	3.4×10^{-4}	0	0	100
^{230}Th	$1.\$\times10^{0}$	0	0	0	3.4×10^{-6}	0	0	100
^{231}Th	$1.\$\times10^{0}$	0	0	0	6.4×10^{-5}	0	0	100
^{232}Th	$1.\$\times10^{0}$	0	0	0	2.6×10^{-6}	0	0	100
^{234}Th	$1.\$\times10^{0}$	0	0	0	1.1×10^{-4}	0	0	100
^{231}Pa	$1.\$\times10^{0}$	0	0	0	1.9×10^{-4}	0	0	100
^{233}U	$1.\$\times10^{0}$	0	0	0	3.1×10^{-6}	0	0	100
^{234}U	$1.\$\times10^{0}$	0	0	0	3.3×10^{-6}	0	0	100
^{235}U	$1.\$\times10^{0}$	0	0	0	7.4×10^{-4}	0	0	100
^{238}U	$1.\$\times10^{0}$	0	0	0	2.5×10^{-6}	0	0	100
^{237}Np	$1.\$\times10^{0}$	0	0	0	1.0×10^{-4}	0	0	100
^{238}Pu	$1.\$\times10^{0}$	0	0	0	3.3×10^{-6}	0	0	100
^{239}Pu	$1.\$\times10^{0}$	0	0	0	1.5×10^{-6}	0	0	100
^{240}Pu	$1.\$\times10^{0}$	0	0	0	3.1×10^{-6}	0	0	100
^{241}Pu	$1.\$\times10^{0}$	0	0	0	7.7×10^{-9}	0	0	100
^{241}Am	$1.\$\times10^{0}$	0	0	0	7.9×10^{-5}	0	0	100
^{242}Cm	$1.\$\times10^{0}$	0	0	0	3.3×10^{-6}	0	0	100
^{243}Cm	$1.\$\times10^{0}$	0	0	0	5.6×10^{-4}	0	0	100
^{244}Cm	$1.\$\times10^{0}$	0	0	0	3.0×10^{-6}	0	0	100
^{252}Cf	$1.\$\times10^{0}$	0	0	0	2.2×10^{-6}	0	0	100

Table 36. Dose conversion coefficients for the following organism

Organism name : Grass spike - plane
Habitat : terrestrial
Biota : animal
Body mass (kg) : 2.62×10^{-3}
Body shape proportions : 0.2000 0.2000
External exposure : on-soil
Source geometry : planar @0.5 g/sq.cm

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	7.9×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.6×10^{-3}	0	0	100	1.3×10^{-8}	0	0	100
^{40}K	6.9×10^{-3}	0	0	100	1.2×10^{-5}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.6×10^{-14}	0	0	100
^{51}Cr	7.5×10^{-5}	0	70	30	2.6×10^{-6}	0	0	100
^{54}Mn	2.6×10^{-4}	0	22	78	6.7×10^{-5}	0	0	100
^{57}Co	3.3×10^{-4}	0	55	45	8.9×10^{-6}	0	0	100
^{58}Co	3.0×10^{-3}	0	2	98	7.9×10^{-5}	0	0	100
^{60}Co	1.8×10^{-3}	0	0	100	1.9×10^{-4}	0	0	100
^{59}Ni	9.1×10^{-5}	0	69	31	4.5×10^{-43}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.2×10^{-3}	0	3	97	4.5×10^{-5}	0	0	100
^{75}Se	3.5×10^{-4}	0	19	81	3.1×10^{-5}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	6.8×10^{-3}	0	0	100	6.8×10^{-9}	0	0	100
^{90}Sr	1.2×10^{-2}	0	0	100	8.4×10^{-12}	0	0	100
^{95}Zr	1.8×10^{-3}	0	0	100	6.0×10^{-5}	0	0	100
^{94}Nb	2.6×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{95}Nb	7.8×10^{-4}	0	2	98	6.2×10^{-5}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.7×10^{-3}	0	3	97	3.9×10^{-5}	0	0	100
^{106}Ru	1.2×10^{-2}	0	0	100	1.7×10^{-5}	0	0	100
^{110m}Ag	1.7×10^{-3}	0	1	99	2.2×10^{-4}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	1.3×10^{-6}	0	0	100
^{124}Sb	4.8×10^{-3}	0	0	100	1.4×10^{-4}	0	0	100
^{125}Sb	1.5×10^{-3}	0	5	95	3.5×10^{-5}	0	0	100
^{129m}Te	1.2×10^{-2}	0	1	99	6.0×10^{-6}	0	0	100
^{132}Te	8.0×10^{-3}	0	1	99	2.1×10^{-4}	0	0	100
^{125}I	3.3×10^{-4}	0	44	56	2.7×10^{-6}	0	0	100

^{129}I	9.1×10^{-4}	0	13	87	1.6×10^{-6}	0	0	100
^{131}I	2.6×10^{-3}	0	0	100	3.2×10^{-5}	0	0	100
^{132}I	6.3×10^{-3}	0	0	100	1.8×10^{-4}	0	0	100
^{133}I	5.2×10^{-3}	0	0	100	5.0×10^{-5}	0	0	100
^{134}Cs	2.5×10^{-3}	0	0	100	1.3×10^{-4}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.3×10^{-3}	0	1	99	1.7×10^{-4}	0	0	100
^{137}Cs	3.4×10^{-3}	0	0	100	4.6×10^{-5}	0	0	100
^{140}Ba	1.2×10^{-2}	0	1	99	2.1×10^{-4}	0	0	100
^{140}La	6.8×10^{-3}	0	0	100	1.7×10^{-4}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	5.8×10^{-6}	0	0	100
^{144}Ce	1.3×10^{-2}	0	0	100	3.9×10^{-6}	0	0	100
^{152}Eu	4.1×10^{-3}	0	2	98	9.0×10^{-5}	0	0	100
^{154}Eu	4.0×10^{-3}	0	1	99	9.7×10^{-5}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	4.4×10^{-6}	0	0	100
^{192}Ir	3.2×10^{-3}	0	1	99	6.8×10^{-5}	0	0	100
^{210}Pb	5.4×10^{-3}	0	2	98	1.5×10^{-7}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	6.9×10^{-10}	0	0	100
^{226}Ra	3.4×10^{-1}	96	0	4	1.3×10^{-4}	0	0	100
^{228}Ra	6.3×10^{-3}	0	3	97	7.6×10^{-5}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	8.5×10^{-6}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	1.1×10^{-4}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	6.3×10^{-6}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	1.1×10^{-6}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{234}Th	9.6×10^{-3}	0	0	100	2.0×10^{-6}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	3.1×10^{-6}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	3.2×10^{-8}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.8×10^{-8}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	1.3×10^{-5}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.0×10^{-8}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	1.9×10^{-6}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	1.1×10^{-8}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.7×10^{-8}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	1.2×10^{-10}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	1.8×10^{-6}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	9.9×10^{-6}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	2.2×10^{-8}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	2.4×10^{-8}	0	0	100

Table 37. Dose conversion coefficients for the following organism

Organism name : Grass spike - volume
Habitat : terrestrial
Biota : animal
Body mass (kg) : 2.62×10^{-3}
Body shape proportions : 0.2000 0.2000
External exposure : on-soil
Source geometry : 10-cm-depth volume

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	–	0	0	0
^{14}C	6.8×10^{-4}	0	1	99	–	0	0	0
^{32}P	7.9×10^{-3}	0	0	100	–	0	0	0
^{33}P	1.1×10^{-3}	0	1	99	–	0	0	0
^{35}S	6.7×10^{-4}	0	2	98	–	0	0	0
^{36}Cl	3.6×10^{-3}	0	0	100	7.5×10^{-7}	0	0	100
^{40}K	6.9×10^{-3}	0	0	100	7.3×10^{-4}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	3.5×10^{-11}	0	0	100
^{51}Cr	7.5×10^{-5}	0	70	30	1.5×10^{-4}	0	0	100
^{54}Mn	2.6×10^{-4}	0	22	78	4.1×10^{-3}	0	0	100
^{57}Co	3.3×10^{-4}	0	55	45	4.7×10^{-4}	0	0	100
^{58}Co	3.0×10^{-3}	0	2	98	4.8×10^{-3}	0	0	100
^{60}Co	1.8×10^{-3}	0	0	100	1.2×10^{-2}	0	0	100
^{59}Ni	9.1×10^{-5}	0	69	31	2.5×10^{-38}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	–	0	0	0
^{65}Zn	2.2×10^{-3}	0	3	97	2.8×10^{-3}	0	0	100
^{75}Se	3.5×10^{-4}	0	19	81	1.8×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	–	0	0	0
^{89}Sr	6.8×10^{-3}	0	0	100	4.1×10^{-7}	0	0	100
^{90}Sr	1.2×10^{-2}	0	0	100	3.9×10^{-10}	0	0	100
^{95}Zr	1.8×10^{-3}	0	0	100	3.6×10^{-3}	0	0	100
^{94}Nb	2.6×10^{-3}	0	0	100	7.7×10^{-3}	0	0	100
^{95}Nb	7.8×10^{-4}	0	2	98	3.7×10^{-3}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	–	0	0	0
^{103}Ru	1.7×10^{-3}	0	3	97	2.3×10^{-3}	0	0	100
^{106}Ru	1.2×10^{-2}	0	0	100	1.0×10^{-3}	0	0	100
^{110m}Ag	1.7×10^{-3}	0	1	99	1.3×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	3.4×10^{-5}	0	0	100
^{124}Sb	4.8×10^{-3}	0	0	100	8.6×10^{-3}	0	0	100
^{125}Sb	1.5×10^{-3}	0	5	95	2.1×10^{-3}	0	0	100
^{129m}Te	1.2×10^{-2}	0	1	99	3.3×10^{-4}	0	0	100
^{132}Te	8.0×10^{-3}	0	1	99	1.2×10^{-2}	0	0	100
^{125}I	3.3×10^{-4}	0	44	56	4.7×10^{-5}	0	0	100

^{129}I	9.1×10^{-4}	0	13	87	2.7×10^{-5}	0	0	100
^{131}I	2.6×10^{-3}	0	0	100	1.9×10^{-3}	0	0	100
^{132}I	6.3×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{133}I	5.2×10^{-3}	0	0	100	3.0×10^{-3}	0	0	100
^{134}Cs	2.5×10^{-3}	0	0	100	7.6×10^{-3}	0	0	100
^{135}Cs	9.3×10^{-4}	0	1	99	–	0	0	0
^{136}Cs	2.3×10^{-3}	0	1	99	1.0×10^{-2}	0	0	100
^{137}Cs	3.4×10^{-3}	0	0	100	2.8×10^{-3}	0	0	100
^{140}Ba	1.2×10^{-2}	0	1	99	1.3×10^{-2}	0	0	100
^{140}La	6.8×10^{-3}	0	0	100	1.1×10^{-2}	0	0	100
^{141}Ce	2.3×10^{-3}	0	1	99	3.0×10^{-4}	0	0	100
^{144}Ce	1.3×10^{-2}	0	0	100	2.2×10^{-4}	0	0	100
^{152}Eu	4.1×10^{-3}	0	2	98	5.4×10^{-3}	0	0	100
^{154}Eu	4.0×10^{-3}	0	1	99	5.9×10^{-3}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	1.8×10^{-4}	0	0	100
^{192}Ir	3.2×10^{-3}	0	1	99	4.0×10^{-3}	0	0	100
^{210}Pb	5.4×10^{-3}	0	2	98	6.9×10^{-6}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	4.2×10^{-8}	0	0	100
^{226}Ra	3.4×10^{-1}	96	0	4	8.3×10^{-3}	0	0	100
^{228}Ra	6.3×10^{-3}	0	3	97	4.6×10^{-3}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	4.7×10^{-4}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	7.0×10^{-3}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	3.1×10^{-4}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	5.0×10^{-5}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{234}Th	9.6×10^{-3}	0	0	100	1.1×10^{-4}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	1.8×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	2.1×10^{-6}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.7×10^{-6}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	7.1×10^{-4}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.2×10^{-6}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	8.6×10^{-5}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	8.0×10^{-7}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.5×10^{-6}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	6.4×10^{-9}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	6.2×10^{-5}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.1×10^{-6}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	5.4×10^{-4}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.0×10^{-6}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	7.4×10^{-7}	0	0	100

Table 38. Dose conversion coefficients for the following organism

Organism name : Brown seaweed- aquatic

Habitat : aquatic

Biota : aquatic

Body mass (kg) : 6.54×10^{-3}

Body shape proportions : 0.0100 0.0100

External exposure : in-water

Source geometry : infinite

Nuclide	Internal exposure				External exposure			
	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3	DCC (μGy d^{-1} per Bq kg^{-1})	f_1	f_2	f_3
^{3}H	7.9×10^{-5}	0	75	25	5.3×10^{-10}	0	9	91
^{14}C	6.8×10^{-4}	0	1	99	3.8×10^{-6}	0	0	100
^{32}P	6.9×10^{-3}	0	0	100	2.7×10^{-3}	0	0	100
^{33}P	1.0×10^{-3}	0	1	99	1.6×10^{-5}	0	0	100
^{35}S	6.7×10^{-4}	0	2	98	4.1×10^{-6}	0	0	100
^{36}Cl	3.3×10^{-3}	0	0	100	5.5×10^{-4}	0	0	100
^{40}K	6.1×10^{-3}	0	0	100	4.2×10^{-3}	0	0	100
^{45}Ca	1.1×10^{-3}	0	1	99	1.7×10^{-5}	0	0	100
^{51}Cr	7.2×10^{-5}	0	73	27	4.3×10^{-4}	0	0	100
^{54}Mn	2.1×10^{-4}	0	27	73	1.1×10^{-2}	0	0	100
^{57}Co	3.2×10^{-4}	0	57	43	1.7×10^{-3}	0	0	100
^{58}Co	2.8×10^{-3}	0	2	98	1.4×10^{-2}	0	0	100
^{60}Co	1.6×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{59}Ni	8.9×10^{-5}	0	70	30	6.9×10^{-6}	0	0	100
^{63}Ni	2.4×10^{-4}	0	12	88	1.7×10^{-7}	0	0	100
^{65}Zn	2.1×10^{-3}	0	3	97	8.0×10^{-3}	0	0	100
^{75}Se	3.1×10^{-4}	0	21	79	5.3×10^{-3}	0	0	100
^{79}Se	7.7×10^{-4}	0	1	99	5.1×10^{-6}	0	0	100
^{89}Sr	6.0×10^{-3}	0	0	100	2.1×10^{-3}	0	0	100
^{90}Sr	1.1×10^{-2}	0	0	100	4.8×10^{-3}	0	0	100
^{95}Zr	1.7×10^{-3}	0	0	100	1.0×10^{-2}	0	0	100
^{94}Nb	2.4×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{95}Nb	7.3×10^{-4}	0	2	98	1.0×10^{-2}	0	0	100
^{99}Tc	1.4×10^{-3}	0	0	100	3.6×10^{-5}	0	0	100
^{103}Ru	1.6×10^{-3}	0	3	97	6.5×10^{-3}	0	0	100
^{106}Ru	1.1×10^{-2}	0	0	100	1.2×10^{-2}	0	0	100
^{110m}Ag	1.5×10^{-3}	0	1	99	3.8×10^{-2}	0	0	100
^{109}Cd	1.2×10^{-3}	0	7	93	3.3×10^{-4}	0	0	100
^{124}Sb	4.2×10^{-3}	0	0	100	2.6×10^{-2}	0	0	100
^{125}Sb	1.4×10^{-3}	0	5	95	5.9×10^{-3}	0	0	100
^{129m}Te	1.0×10^{-2}	0	1	99	4.3×10^{-3}	0	0	100
^{132}Te	7.1×10^{-3}	0	1	99	3.7×10^{-2}	0	0	100
^{125}I	3.1×10^{-4}	0	47	53	5.4×10^{-4}	0	0	100

^{129}I	9.0×10^{-4}	0	13	87	3.2×10^{-4}	0	0	100
^{131}I	2.5×10^{-3}	0	0	100	5.5×10^{-3}	0	0	100
^{132}I	5.5×10^{-3}	0	0	100	3.3×10^{-2}	0	0	100
^{133}I	4.6×10^{-3}	0	0	100	9.5×10^{-3}	0	0	100
^{134}Cs	2.3×10^{-3}	0	0	100	2.2×10^{-2}	0	0	100
^{135}Cs	9.2×10^{-4}	0	1	99	1.0×10^{-5}	0	0	100
^{136}Cs	2.2×10^{-3}	0	1	99	3.0×10^{-2}	0	0	100
^{137}Cs	3.1×10^{-3}	0	0	100	8.2×10^{-3}	0	0	100
^{140}Ba	1.1×10^{-2}	0	1	99	4.2×10^{-2}	0	0	100
^{140}La	5.9×10^{-3}	0	0	100	3.4×10^{-2}	0	0	100
^{141}Ce	2.2×10^{-3}	0	1	99	1.2×10^{-3}	0	0	100
^{144}Ce	1.1×10^{-2}	0	0	100	7.7×10^{-3}	0	0	100
^{152}Eu	3.7×10^{-3}	0	2	98	1.6×10^{-2}	0	0	100
^{154}Eu	3.6×10^{-3}	0	1	99	1.8×10^{-2}	0	0	100
^{155}Eu	8.9×10^{-4}	0	7	93	8.3×10^{-4}	0	0	100
^{192}Ir	3.0×10^{-3}	0	1	99	1.1×10^{-2}	0	0	100
^{210}Pb	4.9×10^{-3}	0	2	98	1.1×10^{-3}	0	0	100
^{210}Po	7.3×10^{-2}	100	0	0	1.2×10^{-7}	0	0	100
^{226}Ra	3.4×10^{-1}	97	0	3	2.7×10^{-2}	0	0	100
^{228}Ra	5.7×10^{-3}	0	4	96	1.5×10^{-2}	0	0	100
^{227}Th	8.2×10^{-2}	99	0	1	1.5×10^{-3}	0	0	100
^{228}Th	4.6×10^{-1}	97	0	3	2.6×10^{-2}	0	0	100
^{229}Th	6.9×10^{-2}	98	0	2	1.3×10^{-3}	0	0	100
^{230}Th	6.5×10^{-2}	100	0	0	1.5×10^{-5}	0	0	100
^{231}Th	2.3×10^{-3}	0	9	91	3.2×10^{-4}	0	0	100
^{232}Th	5.5×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{234}Th	8.5×10^{-3}	0	0	100	4.1×10^{-3}	0	0	100
^{231}Pa	7.0×10^{-2}	99	0	1	6.1×10^{-4}	0	0	100
^{233}U	6.7×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100
^{234}U	6.6×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{235}U	6.4×10^{-2}	95	0	4	2.4×10^{-3}	0	0	100
^{238}U	5.8×10^{-2}	100	0	0	1.2×10^{-5}	0	0	100
^{237}Np	6.7×10^{-2}	98	0	1	4.3×10^{-4}	0	0	100
^{238}Pu	7.6×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{239}Pu	7.1×10^{-2}	100	0	0	7.2×10^{-6}	0	0	100
^{240}Pu	7.2×10^{-2}	100	0	0	1.6×10^{-5}	0	0	100
^{241}Pu	7.4×10^{-5}	2	71	27	3.1×10^{-8}	0	0	100
^{241}Am	7.7×10^{-2}	99	0	1	4.0×10^{-4}	0	0	100
^{242}Cm	8.5×10^{-2}	100	0	0	1.8×10^{-5}	0	0	100
^{243}Cm	8.2×10^{-2}	98	0	2	1.8×10^{-3}	0	0	100
^{244}Cm	8.0×10^{-2}	100	0	0	1.7×10^{-5}	0	0	100
^{252}Cf	8.4×10^{-2}	100	0	0	1.3×10^{-5}	0	0	100