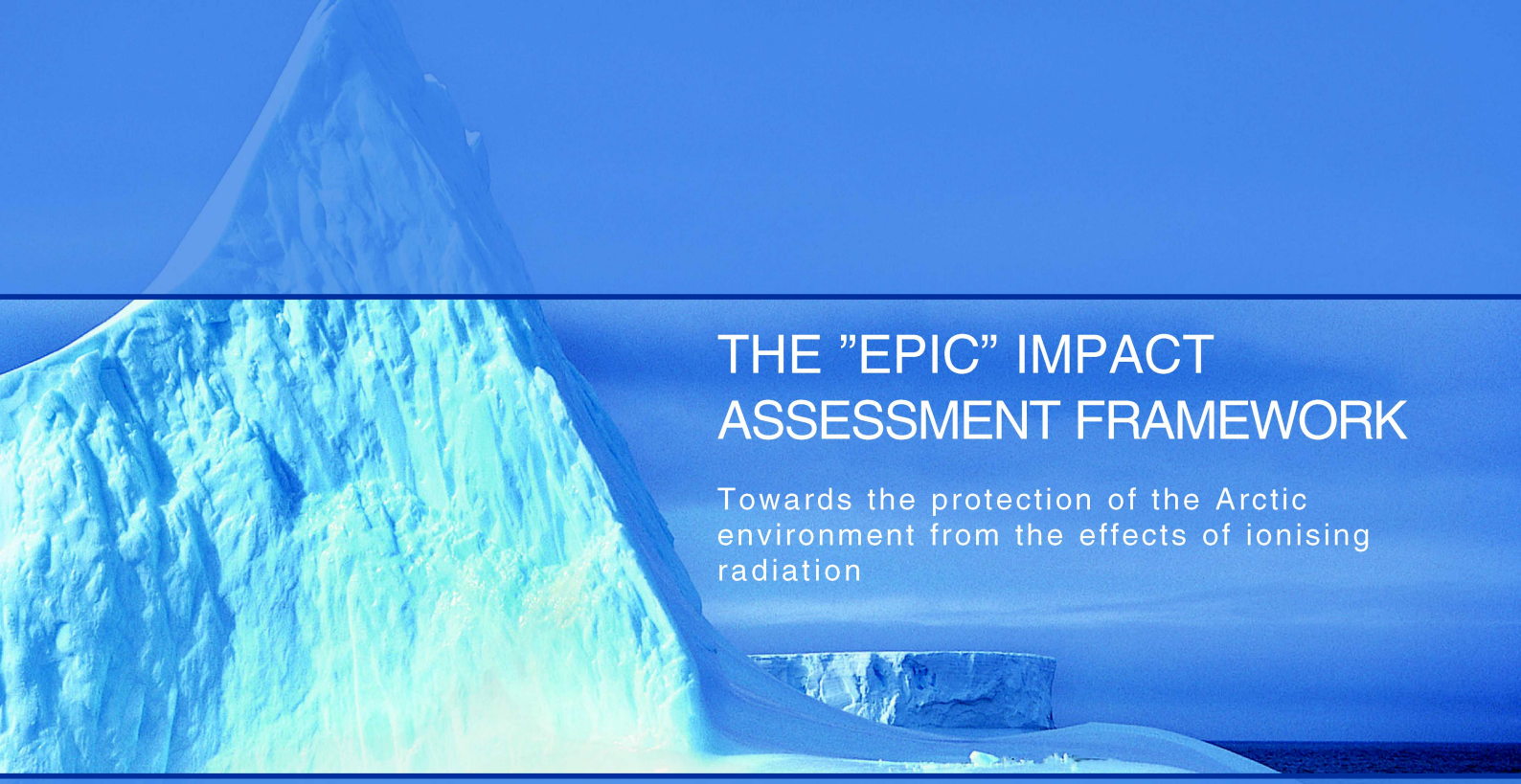

THE ”EPIC” IMPACT ASSESSMENT FRAMEWORK

Towards the protection of the Arctic environment from the effects of ionising radiation

A deliverable report for EPIC - Environmental Protection from Ionising Contaminants in the Arctic

Project ICA2-CT-2000-10032

Statens strålevern

Edited by
J. Brown, H. Thørring & A. Hosseini

December 2003

The "EPIC" impact assessment framework: Towards the protection of the Arctic environment from the effects of ionising radiation

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Contract No:
ICA2-CT-2000-10032

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Environmental Protection from Ionising Contaminants (EPIC)

To date, the protection of the environment from radiation is based on the premise that if Man is protected from harm, then all other components of the ecosystem will not be at risk. However, this has been increasingly questioned on the basis that it is not always true, it is inconsistent with environmental protection standards for other hazardous materials and conflicts with the recommendations of some international advisory bodies. The aim of the EPIC project is to develop a methodology for the protection of natural populations of organisms in Arctic ecosystems from radiation. This will be achieved by derivation of dose limits for different biota. The project therefore aims to (i) collate information relating to the environmental transfer and fate of selected radionuclides through aquatic and terrestrial ecosystems in the Arctic; (ii) identify reference Arctic biota that can be used to evaluate potential dose rates to biota in different terrestrial, freshwater and marine environments; (iii) model the uptake of a suite of radionuclides to reference Arctic biota; (iv) development of a reference set of dose models for reference Arctic biota; (v) compilation of data on dose-effects relationships and assessments of potential radiological consequences for reference Arctic biota; (vi) and integration of assessments of the environmental impact from radioactive contamination with those for other contaminants.

The EPIC project is funded under the EC Inco-Copernicus research programme and is co-ordinated by the Norwegian Radiation Protection Authority; project partners:

- Centre for Ecology & Hydrology, CEH-Merlewood, Grange-over-Sands, UK.
- Institute of Radiation Hygiene, St Petersburg, Russia.
- Scientific Production Association TYPHOON, Obninsk, Russia.

For further information on the EPIC project contact Dr. Per Strand (per.strand@nrpa.no).

EXECUTIVE SUMMARY

This report provides an overview of the EPIC environmental impact assessment framework in its entirety and explores how the advances made in the project may provide input towards the development of criteria and standards ensuring protection of the Arctic environment from ionising radiation. Where relevant, the methodologies employed by environmental impact assessment systems for non-radioactive contaminants are discussed from the perspective of compatibility. In the introductory part of the report, the requirement for environmental protection is considered through an analysis of international conventions, agreements and legal issues. The need to relate the system to established underlying principles including conservation, sustainability and maintenance of biodiversity is also emphasised.

The EPIC system consists of problem formulation stage and primarily of an assessment methodology that will allow an assessor to quantify the probable effect of radiation exposure to selected biota following a defined release of radionuclides. Pure decision and management issues fall beyond the scope of our assessment as these involve judgements of a societal, political etc. nature. The considerations afforded the system development have also been limited in a geographical context, i.e. to the European Arctic, and to a suite of 13 radionuclides selected to be broadly representative of (i) routine release scenarios from power plants and reprocessing facilities, (ii) accidental releases and (iii) naturally-occurring or technologically-enhanced naturally-occurring (TENORM) radionuclides. Three ecosystem types have been studied, i.e. terrestrial, freshwater and marine and the starting point for the assessment has been selected to be a unit concentration of a specified radionuclide in the environment with emphasis placed upon food chain transfer as oppose to physical transport processes.

Earlier in the EPIC project, lists of reference organisms were constructed based on the application of selection criteria including: Ecological niche, intrinsic radiosensitivity, radioecological sensitivity, distribution and amenability to research and monitoring. The generic reference organism lists have been used as a basis for deriving appropriate environmental transfer data information and selecting suitable target geometries/phantoms for dosimetric modelling. With respect to these points, it became apparent that the identification of actual species (or in some cases families or classes of organisms) representing each of the broadly defined groups would be helpful in some instances. Basic ecological information needs to be collated for each of the selected flora and fauna. The specific organism attributes that should be considered relate directly to the subsequent assessment of exposure. For example, information should be provided on habitat and, where applicable, the fractional occupancy of various organisms in their habitats. Guidance on the types of ecological information required for reference fauna has been provided in this report. For the purpose of illustration Life History data sheets have been presented in Appendix 1.

Several approaches have been employed in order to consider the transfer of radionuclides in the Arctic environment. In the first instance, datasets providing information on concentration ratios/factors (CR/CF) have been collated for reference organism types and the suite of EPIC radionuclides. This exercise has allowed data gaps to be identified. In cases where data coverage is poor or non-existent, other

methodologies have been employed in the process of providing estimates. Such methods have included the application of allometric relationships and the biokinetic models. Recommended values have been provided for terrestrial and marine environments in Appendices 3 and 4, respectively. Limitations in the application of concentration ratios have been explored. These essentially relate to problems in applying the method where sources to a compartment are numerous and the unsuitability of applying the approach to non-equilibrium situations. In light of these problems, further work was conducted in the development of fully dynamic models as exemplified by the modification of an existing radiological model "ECOMARC" to allow activity concentrations in a herbivorous (reindeer) and carnivorous mammal (nominally a wolf) to be derived.

The method for deriving absorbed doses is based on an approximation describing the dose distribution defined using Dose attenuation function and Chord distribution functions. External doses to organisms from radionuclides present in soil or in the water column are calculated using a variant of a simple formula for a uniformly contaminated isotropic infinite absorbing medium: This approach neglects density differences between the organism and the medium. A two-step method has been used for the estimation of external exposures at the interface of environments with different densities. In the first step, the kerma in a specified location (above the soil/air interface, in soil at the given depth) is derived. In the second step, the ratio of the dose in an organism and the kerma is calculated for the different organisms and radionuclides. A computer model with a user-friendly interface has been developed to allow such calculations to be conducted. Radionuclide specific Dose Conversion Factors (DCFs) have been generated for all reference organism groups and a large suite of radionuclides including the 13 radionuclides selected within EPIC and radionuclides from ^{238}U and ^{232}Th decay series. Within this report, weighted DCFs have been derived using provisional weighting factors of 3 for ^{3}H and 10 for alpha radiation. These DCF values are presented in Appendix 2 of this report.

The approach taken within EPIC with regards to analyses of dose-effects relationships was to collate and organise data around the reference organism categories and to focus on dose-rates and biological endpoints that are of relevance from the perspective of environmental protection. Data of dose-effects relationships on radiation effects in biota available from Russian and other former Soviet Union sources have been collated. The compiled data are concentrated on the effects in radiosensitive species in terrestrial and aquatic ecosystems, such as mammals, fish, and sensitive groups of plants (e.g. pines). Data have been organised under "umbrella" end-point categories, namely: morbidity, reproduction, mortality, cytogenetic effects, ecological effects, stimulation effects and adaptation effects. A general conclusion can be made, that the threshold for deterministic radiation effects in wildlife lies somewhere in the range 0.5-1 mGy d^{-1} for chronic low-LET radiation. However, although minor effects on morbidity in sensitive vertebrate animals are observed at the dose range specified above, populations of highly productive vertebrate organisms are viable at dose rates in the order 10 mGy d^{-1}. Preliminary scales defining the severity of radiation effects at different levels of chronic exposure for different organisms groups have been constructed. In addition, background dose-rates have been calculated for reference organisms in terrestrial, freshwater and marine ecosystems although some of the values generated have been based on very limited data sets.

There are currently no radiation dose limits in place for Arctic environments. In order to assess the potential consequences of exposures to radiation on non-human biota, arguably, two points of reference may be used. These are (a) natural background dose rates and (b) dose rates known to have specific biological effects on individual organisms. The information collated within the EPIC project is consistent with this and, therefore, allows an evaluation of potential effects from a given dose-rate to be made without explicitly providing dose-limits. Furthermore, the generalised conclusions, within EPIC, regarding the threshold dose-rates at which various effects are observed are consistent with earlier studies. From the available information it is, therefore, not possible to justify any Arctic specific dose-standards at the present time. It should be noted, however, that the data set upon which such a conclusion is drawn is limited in scope and the hypothesis relating to whether there is a unique expression of radiation-induced biological damage under Arctic conditions remains to be properly tested.

The EPIC environmental impact assessment framework is generally compatible with systems being developed elsewhere including those applicable for non-radioactive substances. The reference organism approach has now been advocated by a number of international authorities on this subject including the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and the International Union of Radioecology (IUR). Similar methodologies have also been applied in a recent EC study looking at impact of radionuclides in European marine areas, i.e. The Marina II study.

At the end of this report, areas of information deficiencies are identified and recommendation made for further development of this system. In particular, these relate to the development of better transfer data, through empirical data collation and modelling, in the Arctic environment, dose reconstruction of numerous data entries in the EPIC dose-effects database and the more detailed exploration of dose-effects on Arctic species (at present most of the available information relates to boreal species).

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1 Introduction

The main part of this report is concerned with a presentation of the EPIC impact assessment framework. This methodology is a key part of a system of protection that has been developed for ionising radiation, largely based on the Ecological Risk Assessment (ERA) approach. Specifically, ERA is built on the three phases of problem formulation, exposure and effects analysis and risk characterisation (Suter, 1993), and a discussion of the EPIC framework with respect to these three steps can be found in the following chapters. The results of any environmental impact or risk assessment (i.e., the qualitative or quantitative evaluation of the risk posed to the environment by the actual or potential presence of pollutants) will feed into risk management policy (i.e., the selection and practical implementation of regulatory and non-regulatory responses to that risk).

Although risk management is not specifically considered within the EPIC project, management decisions such as actions or policies to mitigate, reduce, remove or monitor environmental risks, and the legal requirements to implement such procedures will, in turn, dictate the need for assessment and influence the type of framework that is required. Thus before discussing the EPIC assessment methodology explicitly it is useful to consider some of the emerging, underlying principles of environmental protection, generally, that have led to the requirement for a system of environmental protection from ionising radiation.

1.1 Requirement for environmental protection

There are already numerous multi-lateral environmental agreements (MEAs) that legally frame the conservation aspects of environmental protection. Initially, these were designed to regulate the exploitation of wildlife and to maintain their economic utility. More recently, as attitudes and scientific understanding have developed; the focus has changed from protection of endangered species, to conservation of both species and their habitats. A major shift in conservation agreements occurred at the1992 UNCED Earth Summit in Rio de Janeiro, with the introduction of the Convention on Biological Diversity (CBD). The summit sought to bring together issues of human use and management of land and sea, nature conservation and the requirement for sustainability (Larsson *et al*., 2002a) and several relevant documents emerged in which a number of general principles for environmental protection were laid down. An example can be found in The Rio Declaration (UNCED, 1992) which emphasises in Principle 4 the issue of sustainable development, stating that '*In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it*.' The issue of sustainable development was the key subject of the successor to the Rio Earth Summit: the UNCED World Summit on Sustainable Development held in Johannesburg, August-September 2002.

The trend in environmental protection MEAs, has been reflected in international agreements relating to the management of radioactivity in a specific manner. Examples include the protection of the marine environment (OSPAR, 1998) and conventions on waste safety (e.g. the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (UN, 1996)). The

second principle of the IAEA Safety Fundamentals for the Management of Radioactive Waste (IAEA, 1995) states that, '*Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment*'.

From these and other considerations, five basic principles, which reflect a world view or overlapping consensus, have been identified by the International Atomic Energy Agency (IAEA, 2002) as being relevant to the issue of environmental protection, including from ionising radiation. These are:

(i) Conservation and preservation. The recognition that certain species are threatened or endangered (e.g. IUCN, 2000) and thus require protection from human activities. This applies not only to the conservation of wild species themselves but extend to their habitat.

(ii) Sustainability. This includes the right to economic development; the integration of development with environment protection, the sustainable use of natural resources and equity for future generations

(iii) Maintenance of biodiversity. Although agreement on the exact meaning of the word biodiversity has not been achieved, the term is generally accepted to cover the diversity of habitats, the diversity of species and the genetic variability within species

(iv) Environmental justice. This addresses issues of liability, compensation and distribution. The principle accounts for the fact that inequity can and does arise from the distribution of environmental benefits and harms and attempts to redress this imbalance by redistributing benefits or compensating from harm caused.

(v) Human dignity. This principle concerns a respect for human-dignity, rights and self-determination.

Translation of these vague "political" aspirations into a legal framework and quantitative assessment system is not entirely straight-forward. Although a certain amount of consensus on the principles has emerged from various meetings and conferences (e.g., Strand and Oughton, 2002; Oughton and Strand, 2003), there can be different interpretations and applications of the principles. For example, one implication that might be derived from the principle of conservation, as normally applied, but not restricted, to endangered species, is the requirement to protect selected flora and fauna at the individual level. Indeed, in the UK for instance, many species, including common as well as threatened or endangered ones, are protected at the individual level against deliberate harm being inflicted on them (Pentreath, 1999). This is in contrast to the basic axiom of other assessment systems (e.g. USDoE, 2002) where the "population", with all the concomitant difficulties in characterising such a group, is the entity of concern. The principle of biodiversity also implies the protection of individual organisms not just populations, in some cases. The loss of even one member from an endangered species might lead to a significant loss from the gene pool. Trans-generational equity (sustainability principle) might be addressed by ensuring that the end-points selected in the assessment system are appropriate for demonstrating the viability of organisms and their habitat in the foreseeable future. It follows that any assessment framework should therefore be compatible with such considerations allowing assessments to be made for individual organisms where

necessary but being flexible enough to allow assessment of impacts at higher levels of the biological hierarchy (e.g. populations, communities etc.).

Other matters relating to *sustainability*, *environmental justice* and *human dignity* are broader issues that will need to be addressed at an overarching management level (Robinson, 2002). These include assessment of economic, social and ethical issues, including decisions about the role of stakeholders and the acceptability of risk distribution over time and space (Oughton 2001, 2003). It is not possible to envisage how such principles might be directly addressed within an assessment system other than to say that the application of such principles may help to define the limits of our system. Issues of conflict could arise from an evaluation of human requirements *vis-à-vis* pure environmental protection considerations. For example, it may be possible to demonstrate "scientifically" that a particular species is not suffering any observable biological harm from current or prospective contamination levels, but broader issues impacting upon the ideal of protection, such as the exploitation of the organism by indigenous peoples (which could be linked to the principle of *human dignity*), can only be addressed using value judgements.

Finally, MEAs can be termed "soft laws" in the sense that they are not strictly enforceable. There enforcement is instead via national legislation that draws up the regulatory measures necessary to meet the objectives of the MEAs and these in turn usually result in "hard" law (Larsson *et al.*, 2002a). A system allowing quantitative impact assessments to be conducted should enable the assessor to robustly and transparently demonstrate that national legislation is being enforced (or being violated as the case may be).

1.2 Special considerations for the protection of the Arctic environment

The term "conservation" is often taken to be synonymous with "preservation", but in environmental policy important distinctions are made between the two. Conservation usually implies some active form of human interference in order to achieve protection of either a species or habitat, and can often result in conditions somewhat far removed from what one might see as "natural". Preservation is more often reserved for habitats and nature where human interference has been reduced to a minimum in order to keep a pristine environment in its original state. In the public perception, the Arctic might be considered as such an "untouched" environment and, in many areas, one where any introduction of pollutants would be seen as adverse (Oughton 2002).

At the scientific level, other considerations make the Arctic an interesting study case. There is evidence to suggest that the *in situ* physical conditions in the Arctic may hypothetically alter radionuclide transfer to biota (Kryshev and Sazykina, 1986, 1990; Sazykina, 1995, 1998), at least in the case of poikilotherms. Indeed, the slower digestion and metabolism of cold water animals resulting in slower efflux rates than in warm water species has been cited as a possible reason that differences may be observed in biological uptake within Arctic marine environments (Fisher *et al*., 1999). The modifying influence of Arctic climatic conditions upon the expression of radiation induced effects has been considered in some detail in Section 6.6 and by Sazkyina *et al.* (2003). The development of radiation effects in poikilothermic Arctic

organisms is expected to occur more slowly because of low environmental temperatures. However, low temperatures, extreme seasonal variations in incoming solar radiation and lack of nutrients are physical and chemical environmental stressors of Arctic organisms which limit biodiversity. These also make Arctic ecosystems potentially more vulnerable to contaminants than organisms in other European climatic regions (AMAP 1998). In addition, the Arctic contains several potential radionuclide sources. A full discussion of the potential sources of anthropogenic radioactive pollution in the Arctic is given by Strand *et al*. (1997).

1.3 Environmental protection - Arctic legal regime

The Arctic consists of territories of various nations, and as such has no overall and binding legal regime. As elsewhere, the framework for environmental protection of the Arctic is constituted by national laws. However, global treaties and norms to a larger and larger extent influence the national laws – something that is undoubtedly linked to the special status of the Arctic environment discussed above. In particular, marine treaties have influenced the domestic laws, and much of the focus of environmental protection of the Arctic has therefore been marine conservation.

The Arctic legal system consists of a collection of agreements and the guiding body is the Arctic Council. The council was emerged from the Arctic Environmental Protection Strategy (AEPS), which was adopted by the eight Arctic countries[1] in 1991. The AEPS was one of two agreements on protection of the Arctic environment produced in 1991: the other being the Declaration on Protection of the Environment Five years later, in 1996, Foreign Ministers of the Arctic states agreed in the Ottawa Declaration to form the Arctic Council to be a "*high-level forum intended to provide a means for promoting co-operation among Arctic states… on common Arctic issues, in particular issues of sustainable development and environmental protection in the Arctic*."

The objectives of the AEPS were:

(i) to protect the Arctic ecosystems, including humans,

(ii) to provide for the protection, enhancement and restoration of environmental quality and the sustainable utilization of natural resources including their use by local populations and indigenous peoples in the Arctic,

(iii) to recognize and to the extent possible, seek to accommodate the traditional and cultural needs, values and practices of the indigenous peoples, as determined by themselves, related to the protection of the environment,

(iv) to review regularly the state of the Arctic environment, and

(v) to identify, reduce, and as a final goal, eliminate pollution.

The AEPS proposed six priorities for action: persistent organic contaminants, oil pollution, heavy metals, noise, radioactivity, and acidification. The Arctic Council is

[1] Iceland, Canada, USA, Norway, Sweden, Russia, Finland and Denmark.

assessing the environmental impact of these six pollutants through different working groups such as Arctic Monitoring and Assessment Programme (AMAP), Conservation of Arctic Flora and Fauna (CAFF), Protection of the Arctic Marine Environment (PAME), and Emergency Preparedness and Response (EPPR) Programme.

Several existing global agreements apply in the Arctic. For the marine environment, these are the 1973 International Convention for the Prevention of Pollution from Ships (MARPOL), 1972 Convention on the Prevention of Marine Pollution by dumping of waste and other matter (London Convention) and the Law of the Sea Convention. The major international treaty on trans-boundary air pollution is the 1979 Convention on Long-Range Trans-boundary Air Pollution (LRTAP). Other significant global treaties to protect the atmosphere include the ozone regime, consisting of the 1985 Vienna Convention for the Protection of the Ozone Layer and the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer; the climate change treaty, including the 1992 United Nations Framework Convention on Climate Change and its 1997 Kyoto Protocol, and the new POPS treaty, 2000.

Biodiversity is covered on a global scale by the 1992 Convention on Biological Diversity, Protection of marine mammals and fish on a global scale is considered by the 1946 International Convention for the Regulation of Whaling (ICRW), and the UN Convention on Straddling Stocks and Highly Migratory Stocks. Furthermore, polar bears are protected through the 1973 Agreement on the Conservation of Polar Bears and Their Habitats. In addition the Arctic states have concluded a number of agreements bilaterally and regionally to conserve specific species.

All Arctic states are parties to the Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat; the World Heritage Convention (with the exception of Iceland), the Biodiversity Convention (with the exception of the USA). Norway and Sweden are parties to the Convention on the Conservation of Migratory Species or Wild Animals (the Bonn Convention).

The 1989 Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal has as a guiding principle that hazardous wastes should be treated as close to where they are produced as possible. In the Arctic area this convention has relevance in connection with imports of wastes for economic gains.

In the area of radioactive pollution, a number of treaties are of importance to the Arctic such as the 1986 Convention on Early Notification of a Nuclear Accident, the 1994 Convention on Nuclear Safety, and the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Specific environmental issues such as control of environmental impacts of mining and biodiversity protection are areas for which the Arctic legal regime is incomplete. Furthermore, despite indigenous rights and land claims, the indigenous peoples of the Arctic have not been fully integrated into the legal regime. The regime also suffers from being unenforceable, lacking specific commitments, targets and timetables for action, and under-funding.

1.4 Framework and scope of a system for environmental protection

A number of recent publications (Pentreath 1998; Pentreath, 1999; Strand *et al*., 2000; Strand & Larsson, 2001) have called for the development of a system for protecting the environment from ionising radiation. Discussion within the scientific community has led to the formalisation of the proposed framework within the present project, EPIC, and a larger EURATOM project entitled **F**ramework for **ASS**essment of **E**nvironmental Impac**T** "FASSET" (Contract FIGE-CT-2000-00102). Larsson *et al.* (2002a) provide an overview of the elements typical of an environmental assessment and management procedure (Figure 1.1). The overall system is typical of the Ecological Risk Assessment (ERA) approach promoted by US Environmental Protection Agency (EPA), based primarily on pathway based assessment systems (Suter, 1993). The system is divided into five different steps: planning; problem formulation (to guide further assessment, i.e. to define the assessment context); assessment, using the appropriate methods according to the assessment context; risk characterisation; and decision and management. In FASSET, the assessment framework was limited to the process from problem formulation through to characterisation of the effects of radiation on individuals. Risk characterisation was limited to a synthesis of exposure and effects data obtained during the assessment to inform management decisions. Pure decision and management issues were deemed to fall beyond the scope of the assessment as these involve judgements of a societal, political etc. nature.

A similar approach was developed within EPIC where the scope of the assessment methodology consists of the problem formulation stage and an assessment methodology that should enable an assessor to quantify the probable effect of radiation exposure to selected biota following a defined release of radionuclides. Although aspects of planning, (e.g. compatibility check with underlying principles and international regulation), were deemed necessary in order to facilitate compatibility with legislative requirements at national levels, it was recognised that any system needs to be generic enough to allow broad applicability. Thus, standards and limits have not been integrated into the system, since these are likely to be imposed through national regulation. However, a system may be used to structure information in a way that could allow standards to be developed – as will be attempted in this report.

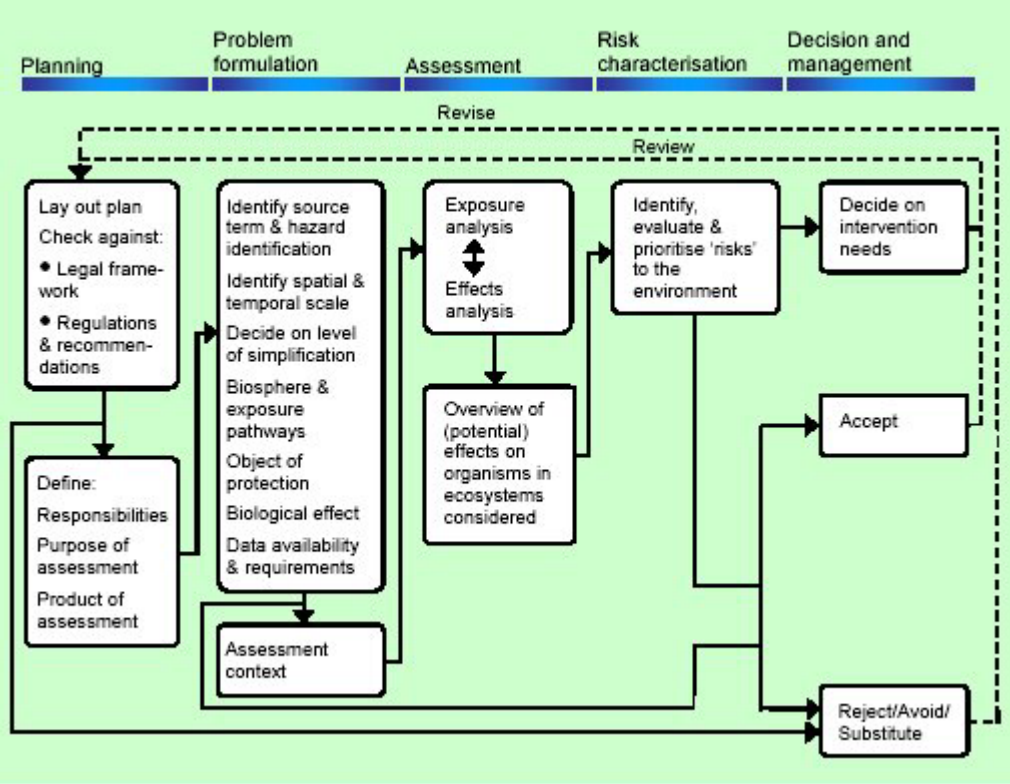

Figure 1.1 *Elements in a stepwise environmental assessment and management procedure (Larsson et al., 2002b).*

Efforts have been made to ensure compatibility between the approaches taken within the two projects. Whereas FASSET has focussed primarily on the development of a generic system or at least a system that has utility within a broad European setting, EPIC has centred on the development of common ideas using the example case of the European Arctic with the advantage of being able to utilise Russian expertise and extensive data sets from the former Soviet Union relating to environmental exposure from radiation.

1.5 Basic elements of an "exposure assessment" system for environmental protection

The exposure assessment part of the protection framework refers to the process of measuring or estimating the intensity, frequency, and duration of exposures to radionuclides currently present in the environment or of estimating hypothetical exposures that might arise from future releases. A system based on this approach would allow the considerable volume of available data pertaining to radioactive contamination of and, radiation effects on, the environment to be organised in a systematic manner. Basic, and therefore essential, components of this system include a reference set of organisms that could act as representative of the larger ecosystem, a set of quantities and units allowing consistent comparison of the effects from different radiation types, a set of dose models to allow calculation of absorbed dose and tabulated dose-effects relationships to allow interpretation of the doses received. Within this system a transparent, defendable impact assessment could be performed.

The FASSET definition of "reference organism" is: "a series of entities that provides a basis for the estimation of the radiation dose rate to a range of organisms that are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects." (Larsson *et al*., 2002b).The selection of suitable Arctic reference organisms is discussed in Section 3.1.

The basic unit for expressing exposure information to flora and fauna is the absorbed dose (or dose rate) in units of Gy. The practical application of the system of dosimetry based around the absorbed dose forces consideration of the empirical observation that the same absorbed dose of differing radiations can produce differing degrees of effect in the same biological endpoint. That is, the radiations can differ in their *qualitative effect*. For example, there is a very substantial body of experimental evidence to indicate that the absorbed dose of high linear energy transfer (LET) radiation (α-particles) required to produce a given biological effect is less than that of low LET radiation (β-particles and γ-rays) - the relative biological effectiveness (RBE) phenomenon. For human radiological protection practice, this phenomenon is taken into account by applying dimensionless radiation weighting factors (w_r) to the absorbed doses from the different radiations, and summing, to give a quantity called the *equivalent dose.* It should be emphasized, however, that values of w_r defined for the purpose of human radiation protection cannot be applied without reservation to other organisms and biological endpoints.

The whole system has been built around the objective to assess doses and effects for individual organisms. This is a pragmatic approach, based on the observation that the great preponderance of exposure data relate to effects on individual organisms, and is also compatible with the underlying principles of conservation and biodiversity, where the focus is often placed on the protection of individual organisms. Furthermore, there is no evidence to suggest that radiation effects can be expressed at high levels of biological organisation such as populations without first being observable at the individual level (Larsson *et al*., 2002a).

A common feature of FASSET and EPIC has been the categorisation of effects data under "umbrella" end-points. These have followed the guidance presented by Pentreath, (1999) and others (e.g. IUR, 2002) to consider mortality, morbidity, reproductive success and scoreable cytogenetic damage. The biological endpoint "reproductive success" is of particular interest because this tends to be the most radiosensitive endpoint that ultimately influences the viability of a defined population and relates the assessment to the underlying principle of sustainability.

1.6 Scope of the EPIC assessment system

The geographical extent of the study is presented in Figure 1.2 and described in more details in Beresford *et al.* (2003).

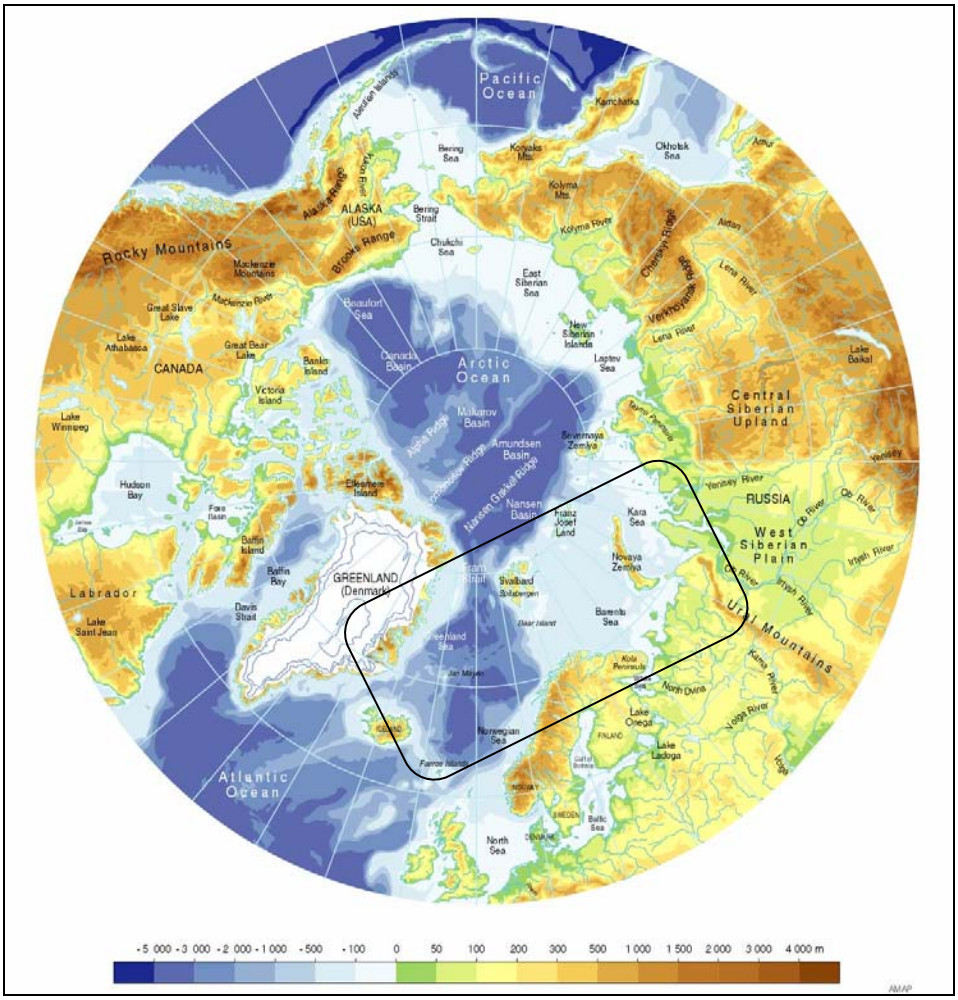

Figure 1.2 *Topography and bathymetry of the Arctic (taken from AMAP 1998); the box delimits the approximate area of the European Arctic as defined within EPIC.*

The assessment methodology, as presented here, is limited in terms of radionuclides considered for reasons of practicability within project time constraints. The initial list of 13 radionuclides (radioisotopes of caesium, strontium, iodine, technetium, plutonium, americium, carbon, hydrogen, uranium, radium, thorium and polonium) is broadly representative of (i) routine release scenarios from power plants and reprocessing facilities, (ii) accidental releases and (iii) naturally-occurring or technologically-enhanced naturally-occurring (TENORM) radionuclides. The selected radionuclides cover a broad range of environmental mobility and biological uptake and hence the system should be flexible enough to allow other radionuclides to be assessed with the provision of appropriate parameters. For aquatic systems, radioisotopes of P, Mn, Co and Zn were also considered for biological transfer as they are routinely released into waters of the study area. With respect to the derivation of "background" exposures arising from naturally-occurring radionuclides in soils, water and sediment, dose conversion factors were derived for members of ^{238}U and ^{232}Th decay chains (see Golikov & Brown, 2003).

In relation to the analyses of the transfer of radionuclides from the point of release/input to the resultant activity concentration observed within reference flora and fauna, a decision was made to focus mainly on the biological uptake. This was

made with a view to the generic applicability of the system, assuming that reference media concentrations would be predictable or measurable. This removed the requirement for a consideration of environmental (physical) transport models

Three broad ecosystem categories were selected for further consideration, namely: terrestrial, freshwater and marine. The starting point for the assessment has been selected to be a unit concentration in the organisms' habitat, e.g., unit activity concentration per litre of water in the case of the aquatic environment and a unit activity concentration per kg of soil or unit deposition per m^2 in terrestrial environments. In the absence of monitoring data, it is assumed that the assessor will have access to appropriate models to allow activity concentrations in abiotic compartments of the environment to be calculated.

1.7 Aims and structure of report

This report aims to describe how the developments presented by Beresford *et al.* (2001) (selection criteria for reference organisms/species), Beresford *et al.* (2003) (radionuclide transfer), Golikov & Brown (2003) (dose models) and Sazykina *et al.* (2003) (dose-effects relationships) can be combined to form a complete system to allow an environmental impact assessment for ionising radiation in the Arctic. The report also aims to provide recommendation towards the development of Arctic radiological standards and draw on information for other assessment systems (including those for non-radioactive contaminants where applicable).

In Chapter 2 of this report the assessment methodology is presented in its entirety. Thereafter, guidance on the selection of reference organism and representative groups (chapter 3), transfer factors appropriate for Arctic conditions (Chapter 4), dosimetric models relevant for the derivation of absorbed doses to Arctic biota (Chapter 5) and effects data pertaining to the assessment of effects arising from exposure to boreal/Arctic species (Chapter 6) are presented. Examples of the exposure assessment methodology are provided in Chapter 7. The development of numeric standards (e.g. dose limits) for Arctic biota is explored in Chapter 8. Furthermore, Russian environmental protection criteria will be considered in terms of their utility within an Arctic context. Comparisons have been made with other assessment methodologies (including non-radioactive substances) in Chapter 9. Finally, in Chapter 10, conclusions and recommendations for future work are presented.

1.8 Non-radioactive contaminants

In addition to radionuclides, a large number of potentially harmful contaminants are present in the Arctic as a result of anthropogenic activity. High levels of contamination are often found in areas influenced by technogenic activities, such as oil/gas fields along the coast of the Arctic seas; Ni-Cu mining industry on the Kola Peninsula; lumber industry; large sea ports, etc. Besides local sources, dispersed contamination caused by long-distance transport of toxicants from industrial and agricultural areas of temperate/warm climate also contributes to non-radioactive contamination in the Arctic.

Levels and possible effects of various anthropogenic pollutants in the Arctic (including radioactive and non-radioactive contaminants) are monitored and assessed within the Arctic Monitoring and Assessment Programme (AMAP). Among the types of non-radioactive contaminants included in AMAP, heavy metals and persistent organic pollutants (i.e. POPs) have been selected for comparison with radionuclides in this report.

The heavy metals of most concern in AMAP are mercury, cadmium, and lead. However, metals (and metalloids) such as arsenic, chromium, copper, nickel, and zinc are also relevant for the Arctic. A large number of POPs are considered in AMAP: Industrial products such as PCBs; chlorinated pesticides (e.g. DDT, toxaphene); and other (non-chlorinated) pesticides like tributyltin (TBT). In addition, brominated flame retardants such as PBDEs seem to be of growing importance.

Detailed information on (specific) heavy metals and POPs in the Arctic will not be given in this report – for such information the reader is referred to AMAP (1998, 2002).

2 Assessment approach

2.1 Stages in the assessment

The stages in the EPIC assessment are depicted in Figure 2.1. The initial stage of the assessment requires the selection of appropriate reference biota and suitable representative organisms (normally defined at the species level) with concomitant collation of life history data sheets. Following this step, the exposure assessment is conducted using the basic methodology outlined in this chapter. Methods for deriving the transfer and fate of radionuclides in Arctic ecosystems are necessary during this procedure as are methods for deriving (weighted or unweighted) dose-rates. Once exposures for reference biota have been derived, they need to be interpreted in terms of biological effects. The assessment approach presented here has been compared, where appropriate, to the approaches taken for non-radioactive contaminants.

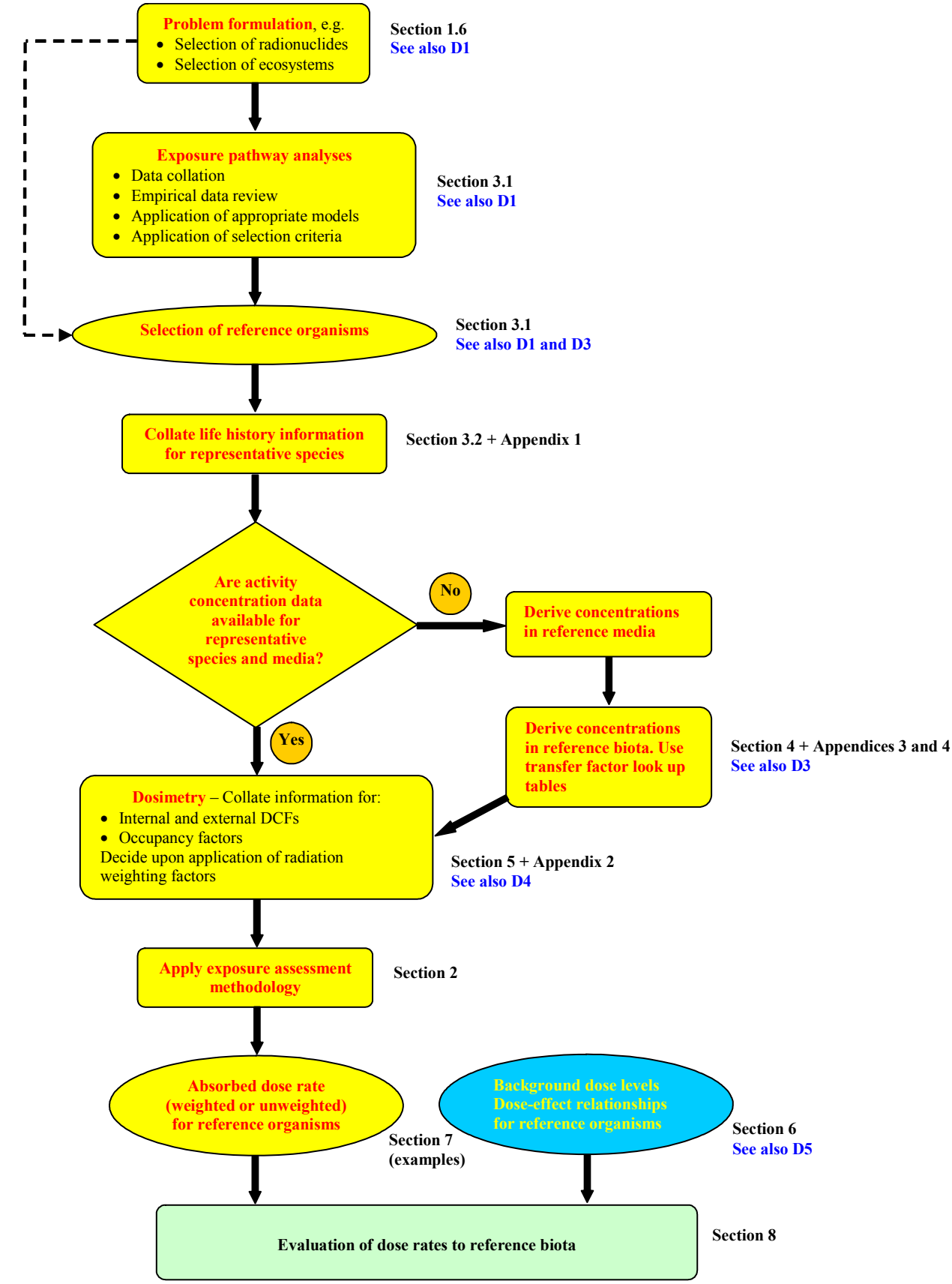

Figure 2.1 *Flow diagram showing stages in the EPIC exposure assessment*

D1: Beresford *et al*. (2001); D3: Beresford *et al*. (2003); D4: Golikov & Brown (2003); D5: Sazykina *et al*. (2003)

2.2 Exposure assessment methodology

For the main EPIC assessment, the basic components of information that are required to derive dose-rates to organisms are: (i) the activity concentrations of radionuclides in (selected) reference biota and their habitat; (ii) Dose Conversion Factors (DCFs) mapping these activity concentrations onto a dose rate and (iii) occupancy factors defining the time spent by biota in various habitats for the parameterisation of external dose calculations.

2.2.1 Deriving total exposure

The whole-body absorbed dose-rate is used as a measure of the reference organism exposure to ionising radiation, expressed in units of Gy per year, and is the sum of internal and external absorbed dose rates:

$$\dot{D}^{j}_{total} = \dot{D}^{j}_{\text{int}} + \dot{D}^{j}_{ext} \tag{2.1}$$

where,

$\dot{D}^{j}_{total}$ is the total absorbed dose rate received by organism *j* (Gy a^{-1}),
$\dot{D}^{j}_{\text{int}}$ is the internal absorbed dose rate received by organism *j* (Gy a^{-1}),
$\dot{D}^{j}_{ext}$ is the external absorbed dose rate received by organism *j* (Gy a^{-1}).

It may be appropriate to introduce radiation weighting factors to take account of the differing biological effectiveness of different types of ionising radiation. For this reason, the radiation emission types for each radionuclide have been split into the categories of α, β and γ. Introduction of weighting factors leads to the weighted absorbed dose:

$$\begin{aligned}
\dot{D}^{j}_{total,weighted} &= \dot{D}^{j}_{\text{int},weighted} + \dot{D}^{j}_{ext,weighted} \\
\dot{D}^{j}_{\text{int},weighted} &= w_{\beta}\dot{D}^{j}_{\text{int},\beta} + \dot{D}^{j}_{\text{int},\gamma} + w_{\alpha}\dot{D}^{j}_{\text{int},\alpha} \\
\dot{D}^{j}_{ext,weighted} &= w_{\beta}\dot{D}^{j}_{ext,\beta} + \dot{D}^{j}_{ext,\gamma} + w_{\alpha}\dot{D}^{j}_{ext,\alpha}
\end{aligned} \tag{2.2}$$

where,
w_{β} and w_{α} are the radiation weighting factors for beta radiation, and alpha radiation, respectively and the subscripts *β, γ,* and *α* denote the contributions to absorbed dose rate from beta particles, gamma ray photons, and alpha particles, respectively.

Contributions from low energy beta particles and alpha particles to external radiation will usually be negligible, but may need to be considered for organisms whose dimensions are of the same order as the range of these radiation types in tissue - typically, in the sub-millimetre range.

For simplicity of explanation, the following sections describe the methods for calculation of (unweighted) absorbed dose rates to organisms. Extension of the method to calculate weighted absorbed dose rates is described in Section 2.2.4

2.2.2 Assessment of external exposure

The external dose rate, averaged over different habitats, can be determined by the following equation:

$$\dot{D}_{ext}^{j} = \sum_{z} v_z \sum_{i} C_{zi}^{ref} * DCF_{ext,zi}^{j} \quad (2.3)$$

where,

C_{zi}^{ref} is the average concentration of the radionuclide *i* in the reference media of a given habitat z (Bq kg^{-1} (soil or sediment) or Bq m^{-3} (water)),

$DCF^{j}_{ext,zi}$ is the dose conversion factor for external exposure defined as the ratio between the average concentration of the radionuclide *i* in the reference media corresponding to the habitat *z* and the dose rate to the organism *j* (Gy a^{-1} per Bq kg^{-1} or Bq m^{-3})

v_z is the occupancy factor, i.e. fraction of the time that the organism *j* expends in habitat *z*. Information about the habitat of reference organisms can be found in Appendix 1.

The derivation of external unweighted DCFs for reference terrestrial biota are discussed in Chapter 5 of this report and presented in numerical form in EPIC Deliverable Report 4, Appendix 1 (Golikov & Brown, 2003).

2.2.3 Assessment of internal exposure

The internal dose rate (for biota in both aquatic and terrestrial environments) can be derived from the activity concentration in the selected reference organism using the following equation:

$$\dot{D}_{\text{int}}^{j} = \sum_{i} C_{i}^{j} * DCF_{\text{int},i}^{j} \quad (2.4)$$

where,

C_i^j is the average concentration of the radionuclide *i* in the reference organism *j* (Bq kg^{-1} fresh weight),

$DCF_{\text{int},i}^{j}$ is the radionuclide-specific dose conversion factor (DCF) for internal exposure defined as the ratio between the average concentration of the radionuclide *i* in the organism *j* and the dose rate to the organism (Gy a^{-1} per Bq kg^{-1} fresh weight).

The derivation of internal unweighted DCFs for reference terrestrial biota are discussed in Chapter 5 of this report and presented in numerical form in EPIC Deliverable Report 4, Appendix 1 (Golikov & Brown, 2003).

If no data are available on the activity concentrations in reference organisms, methodologies are available to allow these values to be estimated. This is discussed in more detail in Chapter 4.

2.2.4 Weighted absorbed dose-rate calculation

In EPIC Deliverable Report 2 (Golikov & Brown, 2002), the issue of appropriate radiation weighting factors was discussed. It was noted that the final choice of radiation weighting factor for alpha particles will depend on the selection of reference organism, end-point and dose (or dose-rate) range. It was considered appropriate that calculations of absorbed dose should be split into low LET and high LET components in order to facilitate the incorporation of a radiation weighting factor once consensus has been achieved.

A provisional recommendation concerning the application of an α-radiation weighting factor in the range of 5-20 was made. Furthermore, a weighting factor of 3 was recommended for application to low energy β. In view of the way in which DCFs have been presented in EPIC Deliverable Report 4 (Golikov & Brown, 2003), i.e. into components of α, β and γ radiation, it has not been possible to apply a weighting factor for low β in most cases. However, ^{3}H is known to emit a large component of low beta radiation and earlier studies (e.g. Straume & Carsten, 1993) have shown that a radiation weighting factor in excess of unity might be appropriate for this particular radionuclide.

The weighted internal DCFs for a given radionuclide and reference organism become:

$$\left[DCF^{j}_{\text{int},i,low\beta}\right]_w = DCF^{j}_{\text{int},i,\beta} * w_\beta \tag{2.5}$$

$$\left[DCF^{j}_{\text{int},i,\alpha}\right]_w = DCF^{j}_{\text{int},i,\alpha} * w_\alpha \tag{2.6}$$

$$\left[DCF^{j}_{\text{int},i,Total}\right]_w = \left[DCF^{j}_{\text{int},i,\beta}\right]_w + \left[DCF^{j}_{\text{int},i,\alpha}\right]_w + DCF^{j}_{\text{int},i,\gamma} \tag{2.7}$$

where,

$\left[DCF^{j}_{\text{int},i,\beta}\right]_w$; $\left[DCF^{j}_{\text{int},i,\alpha}\right]_w$ and $\left[DCF^{j}_{\text{int},i,Total}\right]_w$ are "weighted" DCFs for low β, α and all radiation types respectively. They are specific to radionuclide *i* and reference organism *j*.

w_β; w_α are radiation weighting factors

$DCF^{j}_{\text{int},i,\gamma}$ is the DCF for γ radiation for radionuclide *i* and reference organism *j*.

It should be noted that these weighted DCFs have not been included in the look-up tables presented in EPIC Deliverable Report 4, Appendix (Golikov & Brown, 2003). Therefore, weighted DCFs have been presented in Appendix 2 of this report. By way of example a w_α of 10 has been applied to alpha radiation components. In the exceptional case of tritium, ^{3}H, a weighting factor of 3 has been applied. For all other β, and γ, the radiation weighting factor has been set to unity.

2.2.5 Issues related to selection of data for use in the assessment

In some cases, it will be necessary to predefine the evaluation area, i.e. site boundary or area of elevated contamination, and then collate data from within these boundaries. The subsequent method of "averaging" data or selecting which data are appropriate for the assessment is currently a point for contention and will depend upon the purpose of the assessment. For example, in the context of an assessment to demonstrate compliance in line with the IAEA criterion of protecting a population of organisms, the *maximally exposed individual* is chosen as the point of reference (IAEA, 1992): the dose rate to this individual must not exceed the defined dose limit. In such a case, it may be necessary to characterise the distribution of values from an empirical data set (e.g. field sampled values of activity concentrations, CFs etc.) and then derive a model generated population from which an appropriate percentile can be selected (see Wilson & Hinton, 2002). Such an approach might be limited by assumptions required about the form of the distribution and the fact that the distribution of absorbed dose rates to individual organisms will not necessarily be the same as the distribution of results for environmental contamination based on samples taken within a particular area - because mobile organisms will receive absorbed dose rates which reflect a spatial average over their home range. Alternatively, the average absorbed dose rates to a relatively small subset of the population (in line with the critical group approach for humans) would be more tractable, and would be equally valid as an approach to protecting population of wild organisms. This latter approach is advocated within the EPIC framework.

In both cases, choices will have to be made about what fraction of population is appropriate for assessment: in the first, the size of the percentile, in the second the size of the chosen subset. However, here, flexibility should be seen as an advantage since what is appropriate will in turn be dependent on other factors such as the size of population, number of offspring, etc.

A direct consideration of the uncertainties involved in the exposure assessment have not been addressed within the EPIC assessment framework, although it is acknowledged that there are many sources and that such considerations are recognised as being important.

Specifically, however, it is recommended that both the Range and Best estimate values (e.g. transfer factors, activity concentrations in reference media and biota etc.) be tabulated. Such data may have utility not only in compliance situations (where maximum values may be required) but also within sensitivity and uncertainty analyses.

2.3 Interpretation of exposure estimates

There are currently no dose limits in place that can be appealed to when evaluating whether biota within Arctic environments are being protected from exposure to ionising radiation. In order to assess the potential consequences of exposures to radiation on non-human biota, arguably, two points of reference may be used. These are (a) natural background dose rates and (b) dose rates known to have specific

biological effects on individual organisms. This dual approach is in line with that discussed by Pentreath (2002).

With regard to natural background dose rates information on expected levels in Arctic and/or related environments are discussed in EPIC Deliverable Report 5 (Sazykina *et al*., 2003) and reconsidered from the perspective of dose standards in Chapter 8 of this report. With regard to the second point of reference, dose-effects relationships for reference (or related) Arctic biota have also been considered in great detail in EPIC Deliverable Report 5. An overview of this work in the context of the EPIC assessment framework is provided in Chapter 6. Furthermore, possible implications for the development of dose limits for the Arctic, based on these findings, are discussed in Chapter 8.

The information provided in these chapters and earlier deliverable reports (i.e. Sazykina *et al*., 2003), should allow the significance of derived dose-rates to be evaluated, albeit in a preliminary way, in terms of their implications for environmental impact. At this stage, and within the remit of the present project, it would be premature to derive concrete dose limits, although it is hoped that the results could provide relevant guidance and input to decision making processes.

3 Reference organisms

3.1 Selection of reference organisms

The EPIC approach requires the selection of reference organisms during the initial stages of the assessment. This subject has been addressed in EPIC Deliverable Report 1 (Beresford *et al*. 2001). For freshwater, marine and terrestrial environments, selection criteria have been applied in order to select a reference organism suite although this forms only a subset of numerous other criteria that could be applied (see for example Pentreath & Woodhead, 2001). The criteria applied in EPIC Deliverable Report 1 (Beresford *et al*. 2001) were:

- **Ecological niche**. This was simply applied as a requirement to have at least one representative from each trophic level.
- **Intrinsic radiosensitivity**. In this case comparison was made between the acute lethal doses expressed by various organism groups.
- **Radioecological sensitivity**, i.e. identification of which organisms are likely to be most exposed either through an expression of relatively high radionuclide bioaccumulation or relatively high activity concentrations in their habitat.
- **Distribution**. Preference was given to those organisms that were year-round residents in the Arctic.
- **Amenability to research and monitoring**. This criterion involved an assessment of whether data sets documenting activity concentrations in various groups of organism were available from monitoring studies and whether future research might be conducted upon the various groups (e.g. exposure experiments etc.).

The resultant initial reference organism list (see Beresford *et al*. 2003) was subsequently slightly refined and is presented in Tables 3.1-3.3. The generic reference organism lists have been used as a basis for deriving appropriate environmental transfer data information and selecting suitable target geometries/phantoms for dosimetric modelling. With respect to these points, it became apparent that the identification of actual species (or in some cases families or classes of organisms) representing each of the broadly defined groups would be helpful in some instances. This was true in the case of deriving food-chain model parameters where detailed information was often required, beyond a generic consideration, with respect to organism characteristics. It was also true in the case of geometry construction where quantitative information on size, shape and density are required and can be derived, simply and transparently, from a consideration of real flora and fauna. Examples of suitable representative species of selected reference organisms were subsequently chosen giving preference to species ubiquitous throughout the European Arctic and the availability of appropriate data (Tables 3.1 -3.3).

Table 3.1 Reference organisms and representative families/species for terrestrial ecosystems

Reference organism	*Representative species*	*Availability of information*		
		Life history	*CR*	*DCF*
Soil micro-organism	Not applicable	No		No
Lichens & Bryophyte	*Cladonia* spp.	Yes	*	No
Gymnosperm	*Juniperus* spp., *Larix dahurica, Picea obovata*	Yes	*	Yes (plant roots)
Monocotyledon	*Carex* spp., *Luzula* spp., *Festuca* spp.	Yes	*	Yes (plant roots)
Dicotyledon	*Vaccinium* spp.	Yes	*	Yes (plant roots)
Soil invertebrate	Collembola & mites	Yes	*	Yes
Herbivorous mammal	'Lemmings and voles' (*Dicrostonyx* spp., *Myopus* spp., *Lemmus* spp., *Microtus* spp., *Clethrionomys* spp. & *Eothenomys* spp.)	Yes	*	Yes
	Reindeer (*Rangifer tarandus*)	Yes		Yes
Carnivorous mammal	'Foxes' (*Vulpes vulpes* & *Alopex lagopus*)	Yes	*	Yes
Herbivorous bird	*Lagopus* spp.	Yes	*	Yes
Egg from ground-nesting bird	*Lagopus* spp.	Yes		Yes

* CRs not available for all radionuclides

Table 3.2 Reference organisms and representative families/species for freshwater ecosystems

Reference organism	*Representative species*	*Availability of information*		
		Life history	*CF*	*DCF*
Benthic bacteria	Not applicable	No	No	No
Aquatic plants	'Freshwater monocotyledons' (e.g. *Carex* spp.)	No	No	No
Phytoplankton	Not applicable	No	No	No
Zooplankton	Rotifera	No	No	No
Insect larvae	*Chironomid* spp.	No	No	No
Pelagic planktotrophic fish	*Coregonus peled* (northern whitefish), *Coregonus laveretus* (cisco) & *Coregonus albula* (shallow-water cisco)	No	* *	No
Pelagic carnivorous fish	*Esox lucius* (pike)	No	*	No
Benthic fish	*Coregonus lavaretus* (cisco) & *Salvelinus alpinus* (Arctic char)	No	*	No
Carnivorous mammal	*Mustela lutrecla* (mink)	No	No	No
Fish egg	Not applicable	No	No	No

* Some information available in EPIC D3 (Beresford *et al.,* 2003)

Table 3.3 Reference organisms and representative families/species for marine ecosystems

Reference organism	*Representative species*	*Availability of information*		
		Life History	*CF*	*DCF*
Benthic bacteria	Not applicable	No	No	No
Phytoplankton	Not applicable	Yes	Yes	No
Macroalgae	*Fucus* spp.	Yes	Yes	No
Pelagic crustacean	*Pandalus borealis*	Yes	Yes	Yes
Benthic mollusc	*Mytilus edulis*	Yes	Yes	Yes
Polychaetes	*Arenicola marina Lumbrineris* spp.	Yes	Yes	No
Pelagic planktotrophic fish	*Boreogadus saida* (polar cod) *Mallotus villosus* (capelin) *Clupea harengus* (herring)	Yes	Yes	Yes
Benthic crustacean	*Cancer pagurus*	*	Yes	Yes
Pelagic carnivorous fish	*Gadus morhua* (cod)	Yes	Yes	Yes
Benthic fish	*Pleuronectes* spp. (e.g. *Pleuronectes platessa*, plaice)	Yes	Yes	Yes
Sea bird	*Larus spp.*	Yes	Yes	Yes
Carnivorous mammal	'Seals' *(Erignathus barbatus, Phoca hispida, Phoca groenlandica)*	Yes	Yes	Yes
Fish egg	Not applicable	No	No	No

* Life history data available for European Lobster (*Homarus gammarus*)

Life history data have been collated for most representative species in marine and terrestrial ecosystems. Recommended CR/CF values are provided in this report for both terrestrial and marine systems although in the case of the former system, data availability has limited this exercise to only a few radionuclides for many of the reference biota considered.

In the terrestrial ecosystem, DCFs for plant roots have been derived for *Vaccinium spp*. and these may be applied for Gymnosperms and Monocotyledons. No DCFs for freshwater have been derived. Phantoms that correspond in dimensional terms may be suitably adopted from the marine list. For example, the DCF for cod may suitably used as a proxy for pike. As shown in Tables 3.1 to 3.3 DCFs are not available for all reference organisms. For the case of micro-organisms/bacteria in both terrestrial and aquatic environments, it has been shown (Pröhl *et al.,* 2003) that absorbed dose will be dominated by the external component of dose. If dose rates to these organisms require calculation, simple assumptions can be made. For example it can be assumed that the organism resides in an infinite absorbing medium and that all radiation energies are absorbed by the organism. DCFs for phytoplankton, macroalgae and polycheates have not been derived. In view of the radioresistance of marine flora and the lack of data on polychaetes (uptake and dose-effect information), it was considered unlikely that these organism types would feature strongly in any environmental impact assessment.

It is not the intention to be overly-prescriptive here. The lists of both reference organisms and representative organisms can be adopted by those wishing to conduct an impact assessment in the Arctic but when specific information concerning a particular release of radioactivity is available it may be appropriate to conduct a new exposure pathways analysis. This may, of course, result in the selection of modified lists. Although the information presented in this report for dose conversion factors and transfer factors may not be compatible with these organisms. In such a case, transfer information would need to be re-collated and new modelling work (e.g. dosimetric models for the derivation of DCFs) conducted.

3.2 Life history data sheets

Basic ecological information needs to be collated for each of the selected flora and fauna. The specific organism attributes that should be considered relate directly to the subsequent assessment of exposure. For example, information should be provided on habitat and, where applicable, the fractional occupancy of various organisms in their habitats. This information is important for the weighting of external dose-rates in order to account for the behaviour of the organism (see Section 2.2.2). Guidance on the types of ecological information required for reference fauna is provided in Table 3.4.

Table 3.4 Ecological information required for reference fauna

Information	*Assessment*	*Comments*
(i) Latin and common English name of the selected species.	Simple[1]	
(ii) Biota dimensions (mass, dimensions)	Simple[1]	Dimension – represent as ellipsoid and defined length, width depth. Required for geometry configuration
(iii) Habitat – configuration and occupancy factors	Simple[1]	Required for target source configuration – external dose assessment. - Marine – e.g. pelagic, benthic; - Terrestrial – e.g. at soil surface, in soil (depth and orientation) Occupancy factors – fraction of time spent in different habitats – required for average dose-rate calculation
(iv) Habitat (dynamic)	Advanced[2]	Examples: - The animal spends parts of its life cycle in different habitats (e.g. meroplanktonic larvae) - The animal hibernates (where and when?) Information required in the calculation of integrated doses
(v) Distribution – Home range.	Advanced[2]	Information required in the calculation of integrated doses
(vi) Average life expectancy	Advanced[2]	Information required in the calculation of integrated doses
(vii) Feeding habits	Advanced[2]	e.g. main prey species Information required for input to ecological models
(viii) Additional information on lifecycle	Advanced[2]	e.g. viviparous fish, periods spent in freshwater Information required in the calculation of integrated doses; sensitive periods in life-cycle

[1]Simple assessment – basic information required for the calculation of dose-rates.
[2]Advanced assessment – possibly beyond the scope of initial EPIC aspirations. However, such information may prove useful in the parameterisation of food-chain and exposure models.

Life history data sheets for the representative reference biota are presented in Appendix 1.

It should be noted that some of the information specified in Table 3.4 and presented in Appendix 1, for selected biota, is redundant for the purpose of conducting the impact assessment described in this report. Essentially, only information on the dimensions and habitat of a particular organism are required to allow informed application of appropriate DCFs with occupancy factors being required to subsequently use these. Organism mass, life expectancy and feeding habits have been used in some cases to provide appropriate values for allometric relationships, which have subsequently been implemented within the dynamic radioecological models described in Section 4.2. The additional information, e.g. home range, special life-cycle data etc. may be useful in the application of a more detailed ecological risk assessment (e.g. Sample *et al*., 1997) or in the parameterisation of models simulating how populations might respond to radiation induced changes in individual attributes (e.g. Woodhead, 2003).

3.3 Approaches for non-radioactive substances

First, it needs to be mentioned that the term reference organism is not (in common) use in connection with POPs or heavy metal assessments. Instead, related terms, such as indicator organisms or critical organisms are employed.

The 5 main criteria that were used to select appropriate reference organisms for EPIC, outlined in section 3.1, cover a broad spectrum – and should (with slight modifications) be applicable as selection criteria for indicator organisms in impact assessments concerning non-radioactive, hazardous substances such as POPs and heavy metals. Beyond this, it is doubtful whether similar selection criteria can be used to derive a common set of reference/indicator organisms for radioactive and non-radioactive pollutants in the Arctic. One set of organisms is, of course, desirable from a simplification point of view, but must be looked upon as an ideal – a set virtually impossible to compile in practice, since the optimal set of organisms will vary considerably depending on objectives, ecosystem and impact of interest. Furthermore, there is considerable variability among species in their exposure and response to different contaminants, and also regarding their rate of recovery from the effects of exposure (AMAP, 1998; Larsson *et al*., 2002a).

4 Transfer - Deriving activity concentrations in the reference organisms

Several approaches have been explored in the process of deriving concentrations in the bodies of reference flora and fauna. These are addressed in detail in EPIC Deliverable Report 3 (Beresford *et al*., 2003) – an overview of how recommended values were derived is provided here.

4.1 Empirically-derived transfer factor approach

This approach assumes that information is available on activity concentrations in a predefined reference material, i.e. filtered water in aquatic environments (Bq l^{-1}) or surface soil in terrestrial environments (Bq kg^{-1}).

4.1.1 Overview of approach

When the concentrations in the reference organisms are not available, these can be calculated by multiplying the concentrations in the reference media with the appropriated Concentration Ratios (CR) or Concentration Factors (CFs).

For the terrestrial ecosystems the CRs are defined as:

$$CR_{b,i}\ (dimensionless) = C_{b,i}/C_{soil,i} \quad (4.1)$$

where,
$CR_{b,i}$ = Concentration ratio for reference organism b and radionuclide i;
$C_{b,i}$ = Activity concentration of radionuclide i in whole body of reference biota (Bq kg^{-1}, fresh weight);
C_{soil} = Activity concentration of radionuclide i in surface soil (Bq kg^{-1} d.w.)

For the aquatic ecosystems the transfer factor, commonly known as Concentration Factors (CF), are defined as:

$$CF_{b,i}\ (dimensionless\ or\ l\ kg^{-1}) = C_{b,i}/C_{aq} \quad (4.2)$$

Where
$CF_{b,i}$ = Concentration Factor for reference organism b and radionuclide i;
C_b = Activity concentration of radionuclide i in whole body of reference biota (Bq kg^{-1}, fresh weight);
C_{aq} = Activity concentration of radionuclide i in aqueous phase (Bq l^{-1} or Bq kg^{-1}) - normally filtered water.

4.1.2 CRs in Arctic terrestrial environments

A database of the transfer of the EPIC radionuclides from soil to reference organisms was generated predominantly from literature review of published data (western and Russian-language publications) and data provided by Russian partners in EPIC. More than 300 publications (refereed literature, books, institute reports and conference

proceedings) were reviewed. The species selected as representative of Arctic reference organisms were especially targeted within the literature review. The review was not restricted to studies conducted within European Arctic because of the paucity of data specific to this area. Many data were rejected from the review as the level of detail within the original publications was insufficient to enable their use with any degree of confidence. The review also provides statistical information (mean, maximum, minimum) for each radionuclide and reference organism category.

For animals whole-body fresh weight activity concentrations have been used. Where activity concentrations for organs were reported, this required assumptions to be made concerning the distributions of radionuclides within the body of the animal. For plants all values were converted to dry matter values (in some cases literature values are reported as fresh or ashed weights).

Both CRs and aggregated transfer factors (Tag; Bq kg^{-1} in organisms: Bq m^{-2} in soil) were reported in Beresford *et al.* (2003). However for the purposes of consistency and ease of use within the assessment values in Appendix 3 appear only as CRs, Tags having been converted by authors assuming a soil bulk density of 0.78 g DM cm^{-3} for Arctic soils (Batjes 1995) and a sampling depth of 10 cm.

An overview of the empirical transfer factor data coverage is presented in Table 4.1. It is apparent that very few transfer factor data are available for radionuclides other that radioacaesium and radiostrontium. Data were available for many of the reference organisms for natural radionuclides; these data were dominated by studies from within the EPIC area. No Arctic specific data for the transfer of actinide elements from soil–biota were found during this review. Even for these well-studied radionuclides, very little information is available on transfer to selected representative organism groups, e.g. see data coverage for lemmings and voles (*Microtus spp./Lemmus spp*.).

Table 4.1 Coverage of empirical transfer factors for terrestrial reference organisms (values given in columns show number of data (T_{ag} or CR) found for each radionuclide)

Reference organism	*Representative species*	*Cs*	*Sr*	*I*	*Tc*	*Pu*	*Am*	*C*	*H*	*U*	*Ra*	*Th*	*Po*
Lichens+bryophytes	*Cladonia spp.*	388	356	-	-	-	-	-	-	1	6	6	5
Gymnosperms		22	13	-	-	-	-	-	-	11	4	2	-
Dicotyledons	*Vaccinium spp.*	457	63	-	-	-	-	-	-	10	7	6	4
Monocotyledons		435	321	-	-	-	-	-	-	-	1	-	2
Herbivorous mammal	*Microtus spp. /Lemmus spp.*	4	-	-	-	-	-	-	-	2	17	2	-
Herbivorous mammal	*Rangifer tarrandus*	845	365	-	-	-	-	-	-	-	16	6	42
Carnovorous mammal		12	8	-	-	-	-	-	-	1	17	2	3
Herbivorous bird		56	51[a]	-	-	-	-	-	-	4	31	4	-

[a] *Lagopus spp.* only

Consequently there is only sufficient data to provide recommended transfer parameters for application in the exposure assessment for some of the radionuclide – reference organism combinations. The approach suggested by Higley *et al.* (2003) was used, in combination with suitable soil-plant transfer values for dietary components, to determine soil-biota transfer values for Arctic reference organisms by Beresford *et al.* (2003). Where comparison was possible, predicted values generally compared well to the available measurements for some radionuclides (e.g. Cs and U) but not for others (e.g. Pu, Am and Th). The initial model was simplistic and did not include soil ingestion which could result in underestimated values for those radionuclides with low plant uptakes. Beresford *et al.* (in press) revised these estimates assuming a soil ingestion rate of 10 % dry matter intake for herbivores (USDoE 2002) and 6 % for fox (Sample and Suter 1994). For Cs and Pu gastrointestinal absorption factors for soil associated radionuclides were taken from Beresford *et al.,* (2000), Am absorption was taken to be the same as Pu, and all other radionuclides were assumed to have the same bioavailability as herbage associated radionuclides; Beresford *et al.* (2000) suggest this is a valid assumption for Sr and I. Daily dry matter ingestion rates were predicted using the allometric relationships of Nagy (2001) for carnivorous mammals (fox), rodents (vole) and galliformes (*Lagopus* spp.); intakes of grass and lichen by reindeer were assumed from Golikov (2001). Voles were assumed to eat grass, *Lagopus* spp. to eat *Vaccinium* spp., and fox to consume the soft tissues of voles. Estimates were made for animals of average age for each species. Predicted transfer values for Cs, U and Sr were generally comparable with the range of observed data, although predicted values for Ra were high compared with observed data. The inclusion of soil ingestion improved comparisons with the observed data for Pu, Am and Th.

For ^{14}C a specific activity approach was used to derive transfer parameter (Galeriu *et al.,* 2003; Beresford et al 2003). For ^{3}H an approach was developed (including limited Arctic specific parameters) enabling (unlike other biota assessment frameworks) organically bound and body water ^{3}H concentrations to be derived (Galeriu *et al.,* 2003; Beresford *et al*., 2003). For both ^{14}C and ^{3}H CR values represent the ratio of activity concentration in biota to that in air (Bq m^{-3}).

4.1.3 CFs in Arctic freshwater environments

CF data for Arctic freshwater environments are limited to few species and few radionuclides. Mean values ± standard deviation pertaining to CFs for ^{137}Cs (water ➔muscle) and ^{90}Sr (water ➔bone) have been provided for 4 species of fish from Arctic Russian lakes. For all other radionuclides and organism types, other methodologies must be applied in the derivation of transfer information as discussed below (Section 4.2.2).

4.1.4 CFs in Arctic marine environments

Site-specific radionuclide CF values for Arctic marine biota have been collated within EPIC for European Arctic sea areas including the Norwegian, Barents, White, Kara, and Greenland Seas. CF values have been calculated for Arctic fish, birds, sea mammals, zoobenthos, and macroalgae for the following radionuclides ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, and ^{99}Tc based upon a number of literature reviews. Collated data are for the period 1961-

1999, and a summary is shown in Table 4.2. For some radionuclide-organism combinations, data for neighbouring sea regions (i.e. the North Sea and North Atlantic) were also used because of the scarcity of Arctic-specific data. For all other radionuclide-biota combinations very few data are available.

Table 4.2 Summarised information on number of data compiled from Arctic marine biota from Beresford *et al*., (2003)

Reference organism group	*Caesium-137*	*Strontium-90*	*Plutonium-239,240*	*Technecium-99*	*Total*
Fish	630	37	23	1	691
Bird	55	-	6	-	61
Mammal	175	17	15	-	207
Crustacea	41	7	8	8	64
Mollusc	31	-	10	5	46
Macroalgae	116	14	46	18	194
Invertebrate*	33	3	10	-	46
Total	1081	78	118	32	1309

*Includes data for species such as *Strongylocentrothus* spp., foraminefera and polychaetes.

Where there are no Arctic specific transfer data, generic information for the world's oceans (IAEA, 1985 and IAEA in press) will have to be used although it is recognised that such data are biased towards edible marine organisms and the edible parts of these organisms.

By comparing region specific data sets with recommended generic values for CFs (IAEA, 1985 and IAEA in press), the hypothesis that transfers to Arctic biota differs from what is observed in temperate areas, was tested for ^{90}Sr, ^{137}Cs, ^{239,240}Pu and ^{99}Tc. Despite the general paucity of data and large uncertainties regarding radionuclide CFs to reference biota, the use of Arctic-specific CFs for Sr, in the case of crustaceans and fish, and Pu, in the case of molluscs, is preferable because differences with generic CFs are apparent.

The review in EPIC Deliverable Report 3 (Beresford *et al*., 2003) provides mean CF values that may be applied in an exposure assessment. These values have been used in conjunction with other data derived from other literature sources and modelling methodologies in order to produce the Look-up tables, providing recommended radionuclide-specific CFs for reference organism groups, presented in Appendix 4 of this report.

4.1.5 Management of information gaps

Several approaches may be adopted in cases where no transfer factors are available (see Copplestone *et al*., 2003). These include:

(1) A transfer value (fresh weight activity concentration in organism: fresh weight activity concentration in soil) of 1 is recommended as being generally conservative for terrestrial environments. There will be exceptions where this

assumption is not conservative (e.g. for radiocaesium) but in these case data will generally be available for some organism groups for these radionuclides on which an expert judgement can be based.

(2) For aquatic systems, the highest available concentration factor for a specified radionuclide considering all reference organism types should be compared with the k_d for that radionuclide. The larger number can be selected for the assessment.

(3) Consider if transfer can be justifiably ignored. For some organisms exposed to beta/gamma emitters the total dose is likely to be dominated by external radiation (e.g. a worm inhabiting soil contaminated by gamma-emitters).

(4) For some radionuclides transfer values for radionuclides with a similar biogeochemical behaviour could be employed. For instance, transfer values for Pu could be used to estimate Am activity concentrations.

4.1.6 Limitations in the application of equilibrium transfer factors

The application of concentration ratios provides a simply implemented methodology to estimating radionuclide concentrations in biota. Similar approaches have been suggested by most other developers of assessment frameworks (e.g. USDoE 2002; Copplestone *et al*., 2001). However, we acknowledge that the CR/CF approach is open to criticism because:

(1) it provides no information concerning the types of processes/mechanisms in operation during biological uptake, (although the amalgamation of these processes into one parameter can conversely be considered to be an advantage),

(2) the relationship between the radionuclide concentration in an abiotic compartment (e.g. soil, water) and within (the organs or whole body of) a high trophic-level organism, deriving most of its contaminant load from ingested food, may not be a simple, linear one,

(3) the assumption that the system is under equilibrium, a requirement for CRs/CFs to be truly applicable, is often invalid,

In numerous cases, application of CR/CF recommended values would not provide robust prognoses for activity concentrations in biological compartments. A case in point was demonstrated by Jackson *et al.* (2001) who considered the implications of activity concentrations of ^{99}Tc in lobster following pulsed releases to the environment. The numerous limitations associated with CFs renders the application of dynamic models desirable. Furthermore, such models may help to fill numerous data gaps on radionuclide transfer for many biota types as described below.

4.2 Dynamic modelling approach

4.2.1 Terrestrial

The model ECOMARC (Golikov, 2001) has been adapted for predicting activity concentrations in Arctic terrestrial biota. The ECOMARC dynamic compartment model is an adaptation of the ECOSYS-87 model which was developed to assess the radiological consequences for agricultural ecosystems in temperate latitudes of short-term depositions of a wide range of radionuclides (Müller & Pröhl 1993). In ECOMARC, where possible, Arctic specific model parameters are used. Model inputs are the time-integrated concentration of radionuclide activity in air, the total activity deposited by wet deposition, the amount of precipitation occurring during the deposition event[2], and the month in which deposition occurs. From these, radionuclide deposition to soil and vegetation are estimated. Processes influencing the transfer between soils, plants, animals and humans (including interception, translocation, root uptake and animal diet) are considered. Within EPIC, we have developed the model to allow simulations of activity concentrations in a herbivorous (reindeer) and carnivorous mammal (nominally a wolf) foodchain. Simulations for radiocaesium and radiostrontium have been run by way of example. We suggest that the approach could be extended to estimate activity concentrations of radioactive elements of I, Zr, Nb, Te, Ru, Ba, Ce, Pu, Mn and Zn in grass and lichen consuming Arctic biota. Concentration ratios within ECOMARC could be derived for other herbage types from the recommended values presented with EPIC. However, we also recognised that many radionuclide specific parameters (e.g. weathering half-lives, deposition velocities) may not be available for these vegetation types in Arctic ecosystems.

4.2.2 Freshwater

For the purpose of conducting an environmental impact assessment in a lake, methods are required to derive activity concentrations in the abiotic components of the system. The application of a simple compartmental model has been explored to describe radionuclide distribution between water and bottom sediments using two compartments and includes the following processes: radionuclide adsorption onto suspended particles and subsequent transfer to bottom sediments; diffusion exchange between water and sediments; radionuclide removal via lake outflow; radionuclide sedimentation to deep sediment layers; and radioactive decay.

The dynamic model "ECOMOD" has been used, by way of demonstration, to simulate the behaviour of selected radionuclides in freshwater foodchains. For some radionuclides (Cs, Sr, P, Mn, Zn, I and Co) rates of uptake by fish are modelled using temperature dependent parameters and ECOMOD includes some parameters derived from northern Russian lakes. These aspects of ECOMOD can therefore be said to be applicable to the Arctic. However, for other radionuclides and for invertebrates and aquatic plants non-Arctic specific empirical transfer ratios have to be used. Aquatic mammals and birds are not considered within the existing model. Although these

[2] These parameters are likely to be measured during a contamination event or would be available from atmospheric dispersion and deposition models.

modelling approaches have only been applied in Arctic lakes they can theoretically be adapted to Arctic rivers in combination with an appropriate river transport model.

It is apparent that at the present time there are numerous gaps in the exposure assessment framework for freshwater ecosystem. For many of the reference organisms selected there is little or no information on transfer within Arctic systems. Further work, either by field observation model development and parameterisation is required before a robust exposure assessment is possible.

4.2.3 Marine

The ECOMOD model, as described above for freshwater ecosystems has been applied to a generic marine system. Metabolic rates for marine fish are modelled to vary as a function of temperature and masses derived from life history data sheets are used during model parameterisation. Model runs have been made for a coupled system using (i) a single box compartmental model to account for partitioning between water and sediments and losses due to outflow and (ii) the ECOMOD food-chain transfer model. The simulations have been run for selected acute release scenarios and for a suite of radionuclides in order to produce information on the variation in activity concentrations within reference organisms over time.

A second food-chain model, using allometric relationships to derive parameters for ingestion rates and biological half-lives, has been applied for the purpose of estimating equilibrium concentration factors for reference biota. Recourse to life history data sheets was required in the formulation of allometric equations. Results for Cs and Pu in various components of the food-chain appear to reflect observational data providing a preliminary corroboration of this modelling approach. Models have not been developed for other radionuclides at the present time. This should be achievable in theory although it is recognised that full parameterisation of the model may be difficult in some cases.

In order to demonstrate how the various components of an exposure assessment in the marine environment can be placed together, an Arctic seas compartmental model routinely used for human radiological assessments at the NRPA has been adapted for use within an environmental impact assessment. The model accounts for numerous processes including advection, sedimentation, pore-water diffusion, bioturbation, resuspension and deep sediment burial. Furthermore, in the context of Arctic environments, transport of radionuclides by ice is also considered. The model has been modified by applying the recommended CF data produced with EPIC Deliverable 3 (Beresford *et al*., 2003) in the process of deriving activity concentrations in the whole-body of reference organisms.

4.3 Similarities and differences with approaches employed for non-radioactive contaminants

Combining transfer models for radioactive and non-radioactive contaminants is no prerequisite for allowing integrated impact assessments to be conducted. The same is true when considering biological uptake and food-chain transfer - such an approach may not be practicable in any case. However, there should be an understanding at

least of the terminology and methodology employed if only for the sake of consistency. Furthermore, more closely coupled modelling methods may be advantageous from the perspective of cost effectiveness and may help in cases where modifications to the combined assessment are required.

In the following discussion, general terminology and common model parameters concerning heavy metals and POPs referred to in the AMAP report (AMAP, 1998) have been compared with parameters used in EPIC:

The approach for modelling transfer of heavy metals and radionuclides to biota is essentially quite similar in the sense that the transfer at equilibrium is considered, although slightly different methodologies are employed. For radionuclides, the term concentration ratio (CR) or concentration factor (CF) is used as considered above. The CR is an integrative expression that accounts for the uptake occurring from all possible pathways. In contrast, the commonly used terms for heavy metals make a distinction between uptake pathways. Bioconcentration factors (BCFs) are used to describe the concentration of a metal, derived only from water (through gills or epithelial tissue) in the body tissue of the organism relative to that in water (Macek *et al*., 1979). The term Bioaccumulation factor (BAF) is actually synonymous with a radionuclide CR, summing over all pathways. BAFs are applicable both for aquatic and terrestrial environments. The connection, however, between BAF and CR (and T_{ag}) used for radionuclides, is more complex for terrestrial systems, since BAFs apply to concentration in organism divided by the air concentration of a specified metal.

The majority of POPs, particularly the organochlorines, are – semi-volatile, have low water solubilities and are, in contrast to most forms/species of heavy metals and radionuclides, highly lipophilic. These characteristics, combined with their chemical stability, lead to the establishment of a steady state between concentrations in water and air and in organic phases such as organic carbon and lipids (Mackay and Patterson 1981, 1982). The terminology in relation with transfer modelling of POPs is somewhat similar to the terminology used for heavy metals - BCFs and BAFs are commonly used, and bioaccumulation is the term used to define the net accumulation of POPs from all exposure routes (Thomann 1989). However, bioaccumulation is usually expressed as the concentrations in the organism on a lipid weight basis divided by the concentration found in water (truly dissolved) or air (gas phase). Furthermore, due to the lipophilicity of POPs, bioaccumulation potential may be estimated using octanol-water partition coefficients (K_{ow}). This factor is not applicable for most heavy metals (and radionuclides) – an exception being some organo-metallic substances, such as methyl-mercury.

Another commonly used term for radionuclides, heavy metals and especially POPs is biomagnification, which describe the increase in (activity) concentration by progressive higher trophic levels. Biomagnification factors (BMFs) can be formally expressed by dividing the (activity) concentration in a trophic level $n+1$ by the (activity) concentration in a trophic level n. For POPs, biomagnification is expressed as the concentrations in the organism divided by the concentrations in its food, both on a lipid weight or organic carbon (sediments, soil) basis. For heavy metals (and radionuclides), it is important to compare concentrations from the same tissue compartments for both predator and prey in order to obtain consistent BMFs (AMAP,

1998).

Internal distribution and focus on critical tissues/organs is important in assessments of uptake for both POPs and heavy metals in biota, especially at higher trophic levels. In contrast, CRs as used in EPIC (Section 4.1.1) relate to whole organisms. This discrepancy has arisen primarily for methodological reasons, e.g. the empirical data available and allometic biokinetic models employed for radionuclides often relate to whole body concentrations. It is recognised, however, that more robust dose estimates may be attained through a more detailed description of the internal distribution of some types of radionuclides (i.e. alpha and beta emitters). This is considered an important issue for future work.

In an integrated system, whereby the assessor can consider the combined effects of multi-contaminants, the effects part of the assessment is the crucial stage. This will be considered in Section 6.7 of this report.

5 Dose models for Arctic environments

5.1 Introduction

Numerous models already exist for the purpose of deriving absorbed doses to individual organisms including the analyses and solution of dose distribution functions, conservative approaches (whereby all radiations emitted by radionuclides within the organism are absorbed) and Monte Carlo methodologies, (e.g. IAEA, 1979, Copplestone *et al*., 2001; USDoE, 2002, Pröhl *et al*., 2003). Dose conversion coefficients have been derived for generic biota (Amiro, 1997) and specific reference plants and animals (Pröhl *et al*., 2003). A review of some of these approaches was presented in EPIC Deliverable Report 2 (Golikov & Brown, 2002).

The EPIC approach has used reference organisms as the basis for further dosimteric modelling. The selection of appropriate reference phantoms has been addressed in Section 3.1 of this report. The actual dimensions of the organisms have been based, in most cases, on the adult form of representative organisms and have been specified in the Look-up tables presented in the Appendix of EPIC Deliverable Report 4 (Golikov & Brown, 2003). For the derivation of DCFs, ellipsoids have been used to represent the various geometric forms of representative plants and animals.

Due to the complexity of the processes involved and the enormous variability of organisms and their natural habitats, it was not possible to derive external dose conversion factors (DCFs) for all possible exposure conditions. Therefore, typical exposure situations appropriate to and based around the geometries for reference organisms were selected for detailed consideration. These are:

- For the DCFs pertaining to species living *in the soil*, two source descriptions were assumed: (a) uniformly contaminated volume source was for natural radionuclides and (b) a planar isotropic source, located at the depth 0.5 $g \cdot cm^{-2}$ in the soil[3], for artificial radionuclides.
- For the DCFs pertaining to species living *on the ground*, two source descriptions were assumed: (a) a semi - infinite volume source for natural radionuclides and (b) a planar isotropic source located at a depth of 0.5 $g \cdot cm^{-2}$ in the soil for artificial radionuclides.
- For the DCFs pertaining to aquatic species at the sediment/water interface, two source descriptions were assumed: (a) a volume source with a depth of 5 cm for artificial radionuclides[4] and (b) semi - infinite volume source for natural radionuclides.

[3] This represents a (thin) surface layer contamination selected to represent a period shortly after a deposition episode.
[4] A depth of 5 cm was arbitrarily selected to represent common artificial radionuclide profiles – bioturbation and post depositional migration of radionuclides often lead to the rapid development of a finite layer of contamination.

5.2 Methodology for deriving absorbed doses

The method for deriving absorbed doses is based on an approximation defining the dose distribution of radiation within an organism's body. This distribution can be defined using two functions:

1. Dose attenuation function describing the dose at any point along the path length for radiation travelling through matter. This can be solved using exact numerical methods.
2. Chord distribution function describing numerous possible path lengths within the body. This can be calculated using a Monte Carlo methodology for each specific geometry.

External doses to organisms from radionuclides present in soil or in the water column are calculated using a variant of the simple formula for uniformly contaminated isotropic infinite absorbing medium: This equation approximates the dose rate to an organism immersed in an infinite contaminated medium but neglects density differences between the organism and the medium. Furthermore, it allows for self shielding by the organism itself, and averages the dose rate throughout the volume of the organism. This approach has been used to calculate the external dose from β- γ-radiation for organisms buried in soil or free swimming in the water column; the relevant concentrations being those in the soil or water media as appropriate.

The estimation of external exposures at the interface of environments with different densities is more complex than cases pertaining to infinite, uniformly-contaminated environments. A two-step method has been used. In the first step, the kerma in a specified location (above the soil/air interface, in soil at the given depth) is derived. In the second step, the ratio of the dose in an organism and the kerma is calculated for the different organisms and radionuclides.

5.3 Computer model

A model, entitled DOSE3D, has been developed which can be used to calculate internal and external doses (dose-rates) for user-defined geometries (Fig 5.1).

The computer program is constructed from two component parts:

1. **Geometry module** – This part of the program allows the user to create a geometry and subsequently manipulate and view this object. The module deals with a variety of shapes including ellipsoids, spheres, cylinders, conical cylinders and egg-shaped (i.e. irregular ellipsoid) objects. A 3-dimensional solid array is generated from the original mesh. A Monte Carlo algorithm is subsequently employed in order to calculate chord/segment distributions.
2. **Dose module** – This part of the program uses chords data output from the geometry module, in the form of histograms, to derive absorbed fractions or dose rates. Absorbed fractions can be calculated for α, β and γ radiation types. The user is prompted to select the energy (monoenergetic α and γ or

maximum and average for β) Scaling factors allow calculations to be performed for a phantom of larger size but the same shape.

The program is currently available in 2 forms, one which can be used to carry out calculations for (1) simple situations whereby activity concentrations are uniformly and homogeneously distributed within the organisms and/or its environment and (2) more complex situations whereby differential activity concentrations between organs can be defined and absorbed fractions and dose rates calculated for the sets of organs involved.

Using this model it is possible to derive absorbed fractions and dose rates for a large suite of radionuclides for any user-defined geometry and target source configuration.

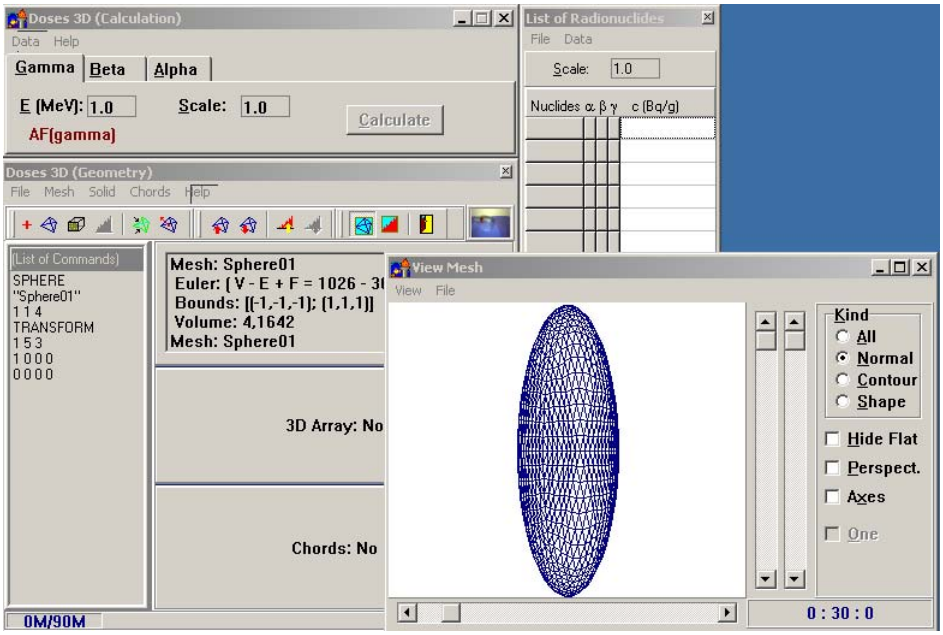

Figure 5.1 *The user interface of DOSE3D*

5.4 DCFs

In addition to the original list of 13 radionuclides originally selected within EPIC (Section 1.6), radionuclide specific DCFs have also been derived for ^{238}U and ^{232}Th decay series for the purpose of allowing background dose rates to be calculated. All radionuclides with half-lives greater than 1 day are treated separately and are presented with their own DCF. All progeny with half-lives less than 1 day are included within the DCF value of the parent. In cases where decay chains branch (e.g. ^{212}Bi and ^{234}Th), the DCF value is weighted according to the yield of daughters.

Further details concerning the models developed within the project and the derivation of DCFs can be found in EPIC Deliverable 4 (Golikov & Brown, 2003).

Within this report, weighted DCFs have been derived using provisional weighting factors of 3 for ^{3}H (all other β-emitters have been assigned a radiation weighting

factor of 1) and 10 for alpha radiation. These DCF values are presented in Appendix 2 of this report – for an overview see Tables 5.1 and 5.2.

Table 5.1 Aquatic reference organisms - exposure pathways considered. References to relevant look-up tables for DCFs in Appendix 2

Reference organism	*DFCs derived*	*Reference*
Pelagic planktotrophic fish	Internal External (from water column)	Section A2.1
Pelagic carnivorous fish	Internal External (from water column)	Section A2.2
Benthic crustacean	Internal External (from water column) External (from water bottom sediment)	Section A2.3
Benthic fish	Internal External (from water column) External (from water bottom sediment)	Section A2.4
Bivalve mollusc	Internal External (from water column) External (from water bottom sediment)	Section A2.5
Sea bird	Internal External (at air/water interface) External (on soil/air interface from source in soil)	Section A2.6
Pelagic crustacean	Internal External (from water column)	Section A2.7
Carnivorous mammal	Internal External (from water column) External (on soil/air interface from source in soil)	Section A2.8

Table 5.2 Terrestrial reference organisms - exposure pathways considered. Reference to relevant look-up tables for DCFs in Appendix 2

Reference organism	*DCFs derived*	*Reference*
Soil invertebrate (*Collembola*)	Internal External (on the soil/air interface)	Section A2.9
Soil invertebrate (mite)	Internal External (on the soil/air interface) External (100 cm underground)	Section A2.10
Herbivorous mammal (lemming)	Internal External (on the soil/air interface) External (100 cm underground)	Section A2.11
Herbivorous mammal (vole)	Internal External (on the soil/air interface) External (50 cm underground)	Section A2.12
Herbivorous mammal (reindeer)	Internal External (on the soil/air interface)	Section A2.13
Herbivorous bird	Internal External (on the soil/air interface)	Section A2.14
Bird egg	Internal External (on the soil/air interface)	Section A2.15
Carnivorous mammal	Internal External (on the soil/air interface) External (100 cm underground)	Section A2.16
Plant roots	Internal External (at the depth 0-30 cm)	Section A2.17

The application of a dose-rate within radiological assessments has a distinct advantage in the sense that it allows radiation exposures arising from numerous radionuclides and sources, i.e. internal and external, to be integrated within a single, unified measurement. A disadvantage with the application of absorbed dose(rate) relates to the observation that exposures to different radiation types cause varying degrees of biological damage (as discussed in Section 1.5) and thus a biological weighting factor needs to be applied to the various categories of radiations emitted by selected radionuclides to account for this. The methodology to circumvent this disadvantage is not difficult to implement as illustrated in Section 2.2. However, the fact that the relative biological effectiveness of different radiation types is dose-rate, species and end-point dependent means that consensus on appropriate radiation weighting factors is not easily attained.

5.5 Comment on approaches used for non-radioactive contaminants

The fact that radiation exposure assessment requires information concerning both internal and external sources of contamination is a point of divergence between assessment systems. Whereas radiation exposures require knowledge of habitat and occupancy factors for the derivation of external dose, heavy metals and POPs require information relating to internal body burden only. Information on the organism's habitat is required only in so far as this affects uptake pathways to the organism.

6 Dose-effects relationships

Full details concerning the analyses of dose-effects relationships for Arctic biota are provided in EPIC Deliverable Report 5 (Sazykina *et al*., 2003) and is summarised below.

6.1 General approach

The approach taken within EPIC with regards to analyses of dose-effects relationships was to collate and organise data around the reference organism categories defined earlier (Section 3.1) and to focus on dose-rates and biological endpoints that are of relevance from the perspective of environmental protection. For this purpose, the compilation of data focused on the effects of chronic radiation exposure at dose rates well below those that are known to cause mortality of organisms. And, from the wide variety of radiation effects reported in the open literature, emphasis was placed upon those which are important for the survival and reproduction of organisms *in the wild*. Furthermore, information was arranged in a form that would facilitate the development of appropriate Arctic dose limits, providing a scientific basis for the regulations in the radiation protection of the environment. To this end, a preliminary scale of the severity of radiation effects at different levels of chronic exposure to aid decision making was considered useful.

Data concerning dose-effects relationships on radiation effects in reference (or related) Arctic biota available from Russian and other former Soviet Union sources have been collated. The compiled data are concentrated on the effects in radiosensitive species in terrestrial and aquatic ecosystems, such as mammals, fish, and sensitive groups of plants (e.g. pines) less attention was given to radioresistent species. In line with approaches being taken elsewhere (e.g. Woodhead & Zinger, 2003) data have been organised under "umbrella" end-point categories, namely:

- Morbidity (worsening of physiological characteristics of organisms; effects on immune system, blood system, nervous system, etc.);
- Reproduction (negative changes in fertility and fecundity, resulting in reduced reproductive success);
- Mortality (shortening of lifetime as a result of combined effects on different organs and tissues of the organism);
- Cytogenetic effects;
- Ecological effects (changes in biodiversity, ecological successions, predator-prey relationships);
- Stimulation effects;
- Adaptation effects.

It should be noted, that the last three categories listed above are additions to those defined within the FASSET project (i.e. Woodhead & Zinger, 2003).

6.2 The EPIC database on radiation effects

In order to underpin the approach outlines above, a data-base in Microsoft ©EXCEL has been constructed. The EPIC database includes data on radiation effects in wild organisms, which were observed from field studies in the northern areas of Russia, including sub-Arctic. These areas include the Kyshtym radioactive trace, local areas with enhanced levels of natural radioactivity in Komi Autonomic Republic of Russia, and some others. Data on radiation effects in the Low Arctic refer mostly to cold-water fish. The database also includes data from laboratory experiments with boreal organisms, and data from several other relevant experimental studies. Considering the great importance of the radiobiological studies of wildlife in the Chernobyl contaminated areas, these data were also included in the EPIC database. In total, the EPIC database "Radiation effects on biota" contains approximately 1600 records from 435 papers and books. The structure of the database includes the following datasets (sub-databases):

- Radiation effects on terrestrial animals;
- Radiation effects on aquatic animals;
- Effects on terrestrial plants and herbaceous vegetation;
- Effects on soil fauna;
- Effects on micro-organisms;
- Table of lethal doses.

The EPIC database information covers a very wide range of radiation dose rates to wild flora and fauna: from below 10^{-5} Gy d^{-1} up to more than 1 Gy d^{-1}.

Dose reconstructions were made, in some cases, by the authors of the database using data on levels of radioactive contamination in the organism/environment and standard dose derivation methodologies (IAEA, 1976; IAEA, 1979; Kryshev & Sazykina, 1990; Kryshev *et al*., 2002).

6.3 Background dose-rates

As considered in Section 2.3, one reference point for assessing the significance of a particular level of radiation exposure may be defined by the natural background radiation. In the Arctic, as everywhere on the Earth, terrestrial and aquatic organisms are exposed to natural sources of ionising radiation, including cosmic rays, radionuclides produced by cosmic ray interactions in the atmosphere, and radiations from naturally-occurring radionuclides, which are ubiquitously distributed in all living and non-living components of the biosphere (Whicker & Schultz, 1982).

The typical dose rates of natural background exposure for different types of organisms in the Arctic are presented in EPIC Deliverable 5 (Sazykina *et al*., 2003).
These dose rates have been derived using data on the activity concentrations of natural radionuclides in the Arctic aquatic ecosystems for several reference organism groups and representative species. The doses have been estimated by the methods described in the earlier studies (IAEA, 1976, 1979; Kryshev & Sazykina, 1990,1995; Kryshev *et al*., 2001,2002), taking into account geometrical characteristics of

organisms and ionising radiation sources. Typical annual doses to terrestrial vertebrate under generic conditions have been taken from Whicker & Shultz (1982).

6.4 Preliminary relationships "dose rate – effects" for chronic low-LET radiation

The EPIC database "Radiation effects on biota" provides the extensive sets of data from Russian/FSU publications, which can substantially enlarge the knowledge of radiobiological effects in the northern wildlife (Sazykina *et al*., 2003). These data were found sufficient to develop the preliminary dose-effects relationships for northern biota in the terrestrial and aquatic environment as will be discussed in the context of Arctic dose limits (Section 8.3).

It may additionally be necessary, in the context of management, to develop specific scales documenting the likely effects of radiation exposure for selected reference organisms. An example is provided in Table 6.1. Further information, for other reference organism groups, can be found in Sazykina *et al.* (2003).

Table 6.1 Dose-effects relationships for developing roe of cold-water fish; chronic exposure from radionuclide in aquatic media during the whole period of fish eggs development (Sazykina *et al*., 2003).

Exposure	***Effects***
Chronic $5x10^{-8}$ Gy d^{-1}	Slight stimulation of salmon's eggs development
Chronic < 10^{-4} Gy d^{-1}	Effects are insignificant
Chronic (1-2)$x10^{-4}$ Gy d^{-1}	First effects appeared: some cytogenetic changes in blood of fore-larvae
Chronic (1-5)$x10^{-3}$ Gy d^{-1}	Decrease in survival of eggs, appearance of dead and abnormal embryos, in some cases damaged were 30-50% of eggs
Chronic $3x10^{-2}$ Gy d^{-1}	Considerable decrease in survival of roe, mortality about 50%
Chronic 0.13-0.33 Gy d^{-1}	Practically total death of roe

6.5 Effects of chronic high-LET radiation on wild organisms

In order to revisit the issue of relative biological effectiveness and the application of appropriate radiation weighting factors, data pertaining to biota exposure to high LET, i.e. α-radiation, were treated separately. The effects of high-LET radiation on wildlife, represented in the EPIC database, relate mainly to the areas of enhanced natural radioactivity (U, Th) in Komi Autonomous Region of Russia. The database also includes the results of some experiments with exposure of aquatic organisms to solutions of ^{238}U or ^{232}Th.

The comparison of dose-effects and concentration effects relationships for these radionuclides leads to the conclusion that high chemical toxicity of ^{238}U and ^{232}Th dominates over radiotoxicity. Alpha-emitting radionuclides, characterized by low specific activity and high chemical toxicity, are therefore not suitable for the purpose

of evaluating the radiation weighting factors for high-LET radiation. Further refinement of radiation weighting factors beyond the considerations afforded this topic previously (Section 5.4) has not been possible following the EPIC dose-effects review.

6.6 Radiation effects in the Arctic organisms

One of the hypotheses explored within EPIC, which has clear relevance to the derivation of Arctic specific dose limits, is that Arctic flora and fauna manifest effects quite differently, following exposure to radiation, compared to similar organisms under temperate conditions. Testing of this hypothesis is difficult because there are very few radiobiological studies that have relevance for the Arctic. Nonetheless some limited data are available.

For example, fish have been observed to survive for much longer time periods following high dose (i.e. approx 20 Gy) acute exposures at low temperatures, commensurate with those observed in Arctic environments, compared with higher temperatures, commensurate with those observed in temperate environments (Keiling *et al.,* 1958). On the other hand, other experimental studies have shown the repair of radiation damage in cells and tissues is not effective at very low temperatures (see references in Sazykina *et al.,* 2003).

From a further consideration of general radiobiological laws and peculiarities of metabolic processes in Arctic organisms, several further inferences may be derived. Anticipated impacts of ionising radiation, characteristic to Arctic conditions might include:

- Lesions in cooled animals (e.g. poikilothermic or hibernating animals) and plants might be expected to be latent. However, if the organisms become warm, lesions are rapidly revealed.
- Because the development of embryos and young poikilothermic organisms in the Arctic occurs slowly at low temperatures, Arctic organisms may receive much higher doses under conditions of chronic exposure, for a specified dose-rate, during the radiosensitive stages of ontogenesis when compared with similar species in the temperate climate.
- Low biodiversity of the Arctic ecosystems provides a more limited potential for compensatory replacement of damaged species by others.
- Long-distance migrations of many animals in the Arctic may result in mitigated exposure regimes because the animal will spend less time in contact with a localised hot-spot of contamination.

6.7 Combining effects assessments for radioactive and non-radioactive substances

Biological effects of hazardous substances, such as radionuclides, POPs and heavy metals, can be measured at different levels of biological organisation, from the molecular to the ecosystem level. Biomarkers[5] measurable at a molecular level respond early, but are not readily interpreted in terms of possible effects at higher levels of biological organisation (e.g. individual or populations). In contrast, biomarkers with clear ecological relevance, such as population declines or reduced reproductive rates, respond too late to have diagnostic or preventive value.

At the molecular or cellular level of organisation, effects of various substances may be crudely separated into genotoxic (i.e. act mainly by damaging DNA) and non-genotoxic substance categories. The former group includes chemically active species, or substances that can be activated, bind to or modify DNA directly, or indirectly *via* radicals. The non-genotoxic substances range from non-specific irritants and cytotoxins to natural hormones, growth factors, and their analogues (UNSCEAR, 2000). Most of the POPs referred to in AMAP (2002) are non-mutagenic (a common underlying mechanism seems to be disruption of the hormone system).

Even though the primary molecular and cellular effects of various POPs, heavy metals and radionuclides are often very diverse, comparison of toxicity may be performed using suitable (umbrella) end-points. The umbrella end-points used in EPIC have been described in Section 6.1. A similar, but more detailed approach is being developed for POPs using, in addition to mortality and reproduction effects, biological markers based on subtle, low dose effects (e.g. on liver enzymes). Carcinogenic effects are also considered – stating whether a POP is mutagenic or functions as a tumour promoter. In the Arctic, the major concern of POPs is long-term chronic exposures as organisms are exposed to low levels over their entire lifetime. In this context, the major effects of concern are those that may affect reproduction and survival at the individual and population level. An overview of toxic properties of important POPs is given in AMAP (2002).

End-points such as mortality and effects on reproduction are also important in connection with heavy metal studies - most experiments considered in AMAP, focus on "clinical signs and symptoms of lethal and sub-lethal toxicity" (AMAP, 1998). An overview of reported effects threshold levels in tissues of main animal groups are given in AMAP (1998).

In a "real" contamination situation, biota will be exposed to complex mixtures of various types of hazardous substances (and other environmental stressors). It is thus important to consider the possibility of combined effects[6] of toxicants in Arctic areas. Studies of interactions have indicated that, at least at high exposures, the action of one agent can be influenced by simultaneous exposures to other agents. The combined

[5] Almost any biological change, from molecular to ecological, can serve as a biomarker; however, the term most often refers to changes at sub-cellular level.

[6] Combined effects can be defined as: "The joint effects of two or more agents on the level of molecules, cells, organs, and organisms in the production of a biological effect" (UNSCEAR 2000)

effects may be greater or smaller than the sum of the effects from separate exposures to the individual agents (UNSCEAR 2000).

Even though interactions between non-radioactive contaminants and radionuclides/radiation exposure have not been extensively studied for non-human biota, two separate, but connected, general influences may be distinguished: (1) effects of co-exposure to non-radioactive contaminants on accumulation kinetics and internal tissue distribution of radionuclides; and (2) possible modifying influence of co-contaminants on the biological effects induced by the exposure to ionising radiation (Woodhead & Zinger, 2003).

A well balanced conclusion on the combined actions of two agents can only be given if the dose-effect relationship of both agents separately and of the combined exposure are known and can be analysed using a model in which the interactions can be consistently and quantitatively defined. The majority of studies on combined effect, including those with radiation, do not meet these conditions (UNSCEAR 2000).

7 Examples of assessment process

In order to facilitate the application of the exposure assessment methodology described in the preceding Sections of this report, two examples of application are provided.

7.1 Marine environment

7.1.1 Introduction

A "worst case" release scenario at the Kola NPP as described by Larsen *et al*. (1999) was selected for this example. A summary of the scenario and activities of ^{137}Cs, ^{134}Cs, and ^{90}Sr released to the atmosphere are presented below:

Source:	VVER-440/230	
Accident scenario:	Large Loss of Cool Cooling accident	
Release scenario:	Fission product release	45 min
	Reactor vessel melt-through	250 min
	End of scenario	1800 min
Nuclides:	^{137}Cs	14.0 PBq
	^{134}Cs	18.7 PBq
	^{90}Sr	1.7 PBq

It is assumed that the released radioactivity is deposited in the Barents Sea (*i.e*. box 27 in Figure 7.1). The NRPA marine box model has been employed to simulate sea water and sediment activity concentrations in the first 20 years after this hypothetical accident.

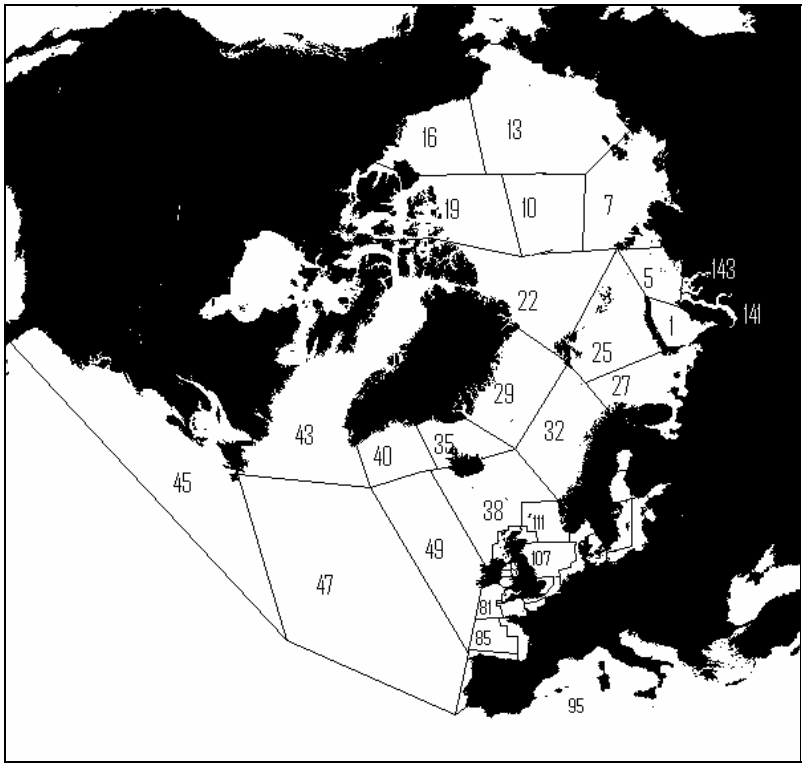

Figure 7.1 *The structure of the surface boxes in the NRPA marine box model*

7.1.2 Marine model description

The box model is an improved version of the compartmental model (Nielsen *et al.*, 1997). The model is based on the modified approach for box modelling (Iosjpe *et al.*, 2002), which includes dispersion of radionuclides during time (non-instantaneous mixing in oceanic space). This approach was created in order to provide a better and more realistic/physical approach comparing to traditional box modelling.

The NRPA model water boxes structure is developed with regards to improved description of Polar, Atlantic and Deep waters in the Arctic Ocean and the Northern Seas (Karcher & Harms, 2000).

The model ice module is available for description of radionuclides exchanges between water and ice phases, between the suspended sediment in the water column, bottom sediment and the ice sediment, the exchanges of radionuclides between the ice boxes.

7.1.3 Exposure assessment methodology

The list of reference organism, as specified in Section 3.1 (Table 3.3) has been adopted for further analyses. Simulations have been subsequently run for the following reference organisms (representative species in brackets): Carnivorous pelagic fish (Atlantic cod); benthic fish (plaice); bivalve mollusc (blue mussel); sea bird (herring gull); and carnivorous mammal (harp seal).

The activity concentrations of ^{137}Cs, ^{134}Cs, and ^{90}Sr associated with the reference organisms have been calculated (Eq. 4.2) by applying appropriate CFs, from Appendix 4, to radionuclide activity concentrations in (filtered) sea water derived using the marine box-model for a specified release scenario (as described in previous section). CFs for Sr and Cs are given in Tables A.4.3 and A4.6, respectively. As an example, calculated activity concentrations of ^{137}Cs in reference organisms for the specified scenario are plotted in Figure 7.2.

Simplifying assumptions have been made with respect to occupancy factors, *v*: For benthic biota (bivalve mollusc and benthic fish) it has been assumed that the organisms are continually present at the sediment-water interface at all times. For pelagic fish and sea mammals it has been assumed that the organisms are totally immersed in water at all times. For sea birds it was (somewhat arbitrarily) assumed that gulls spend 1/3 of their time on the water surface; 1/3 of their time in the inter-tidal zone; and the rest of their time in non-contaminated areas (e.g. in the air).

Internal and external dose conversion factors (DCFs) have been extracted from the relevant Tables in Appendix 2: Carnivorous pelagic fish (Table A2.2); benthic fish (Table A2.4); bivalve mollusc (Table A2.5); sea bird (Table A2.6); and carnivorous mammal (Table A2.8). To be able to calculate external doses to sea birds in the inter-tidal zone, it has been assumed that the external DCFs for soil also apply here. Sediment activity concentrations (Bq kg^{-1} DW) – predicted using the marine box model - have consequently been converted to kBq m^{-2} (assuming a density 0.78 g cm^{-3}, and a soil depth of 10 cm).

The exposure assessment methodology presented in Section 2.2 has been used to calculate doses to the selected reference organisms: external exposure (Eq. 2.3); internal exposure (Eq. 2.4) and total exposure (Eq.2.1), using activity concentrations, occupancy factors and internal and external DCFs. Distribution between external and internal exposure are visualised in Figure 7.3 using external dose rate fractions (i.e. external dose rate divided by total dose rate). Total dose rates from ^{137}Cs, ^{134}Cs, and ^{90}Sr are plotted in Figure 7.4.

From Life-history data sheets (see Section 3.2 and Appendix 1) it is evident that all of the representative species considered may live for 20 years or more. Consequently, integrated doses have been calculated for the whole simulation period (20 years). These integrated doses are presented in Table 7.1.

7.1.4 Results

Results from model simulations and methodology application are described below:

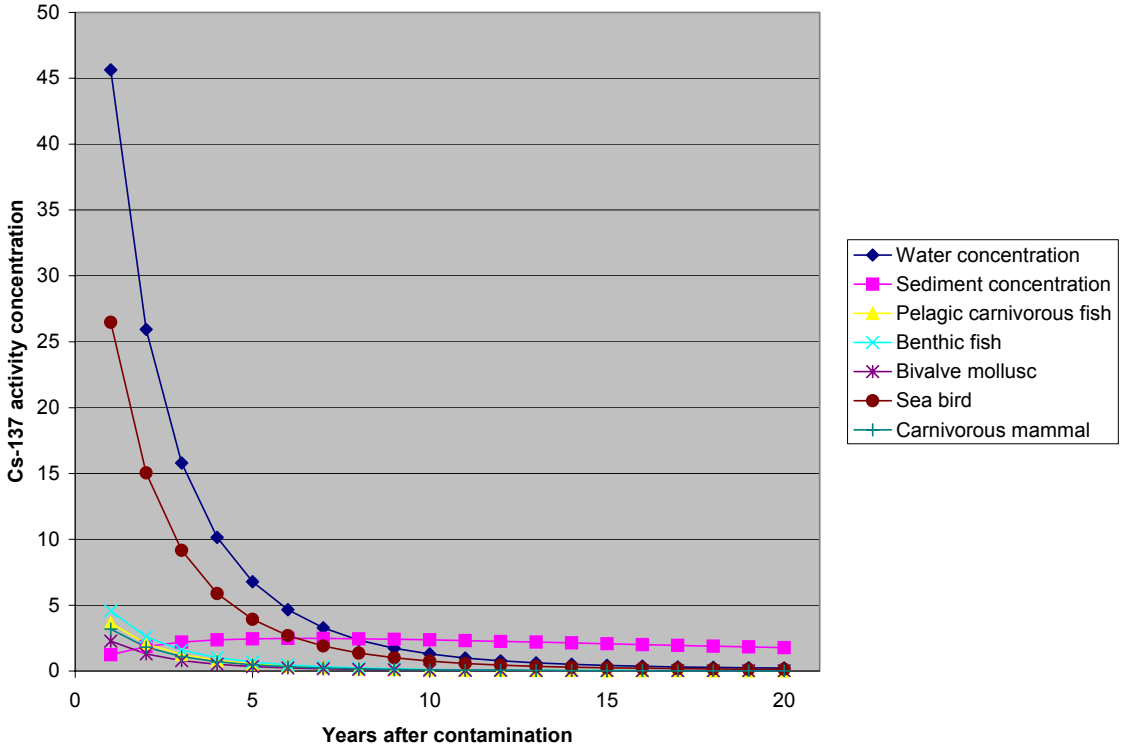

Figure 7.2 *Predicted ^{137}Cs activity concentrations in water (Bq m^{-3}), sediments (Bq kg^{-1} DW) and reference organisms (Bq kg^{-1} FW) from the Barents Sea*

According to Figure 7.2, activity concentrations of ^{137}Cs in sea water decrease rather rapidly, from 46, 6.8, and 1.3 Bq m^{-3} for years 1, 5, and 10, respectively. In contrast, sediment concentrations of ^{137}Cs seem to be rather stable for the whole simulation period, reaching the maximum about 6-7 years after the accident. Sea birds exhibit the highest activity concentrations within the reference organism group. This is due to large CF values for gulls.

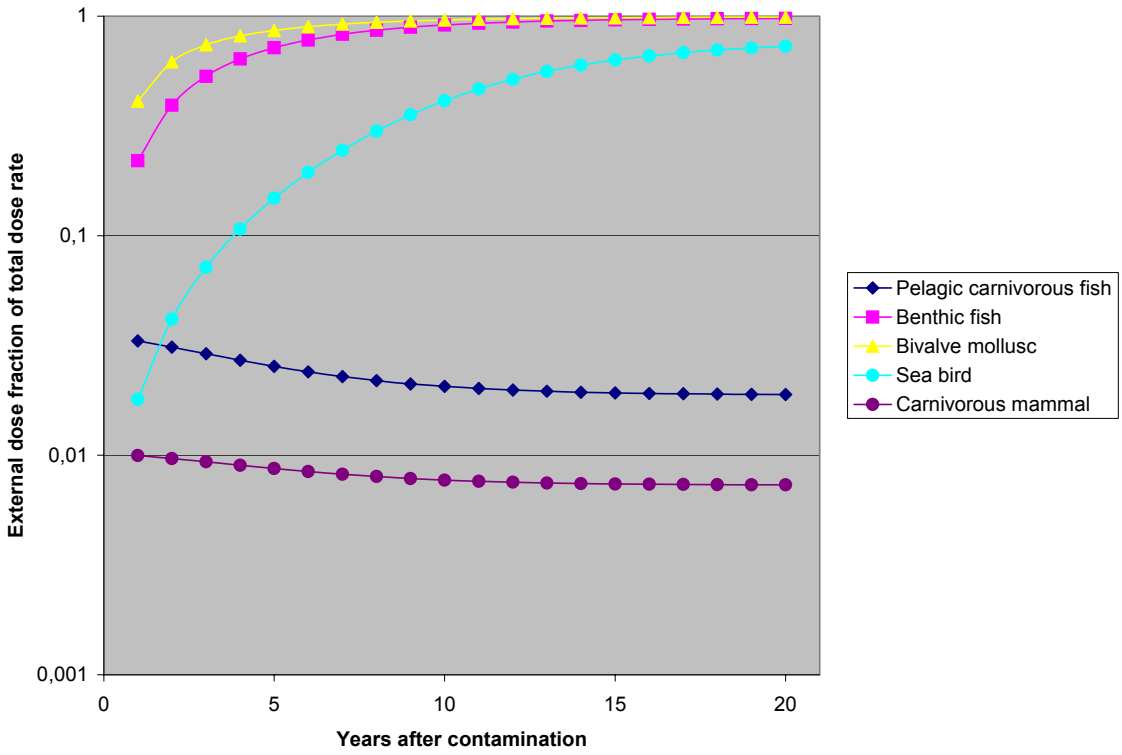

Figure 7.3 *External dose fractions of total dose rate (^{137}Cs, ^{134}Cs, and ^{90}Sr) to reference organisms from the Barents Sea.*

Excluding the first year, external doses (mainly from sediments) dominate predicted total doses to benthic organisms (i.e. bivalve molluscs and benthic fish). Internal doses, which varies as a function of bioaccumulation as defined by CFs, accounts for virtually the entire total dose rate to pelagic organisms (i.e. pelagic fish and sea mammals). Sea birds are in-between: The first 10 years internal exposure dominates, whereas external dose fractions increase to about ¾ of the total dose after 20 years.

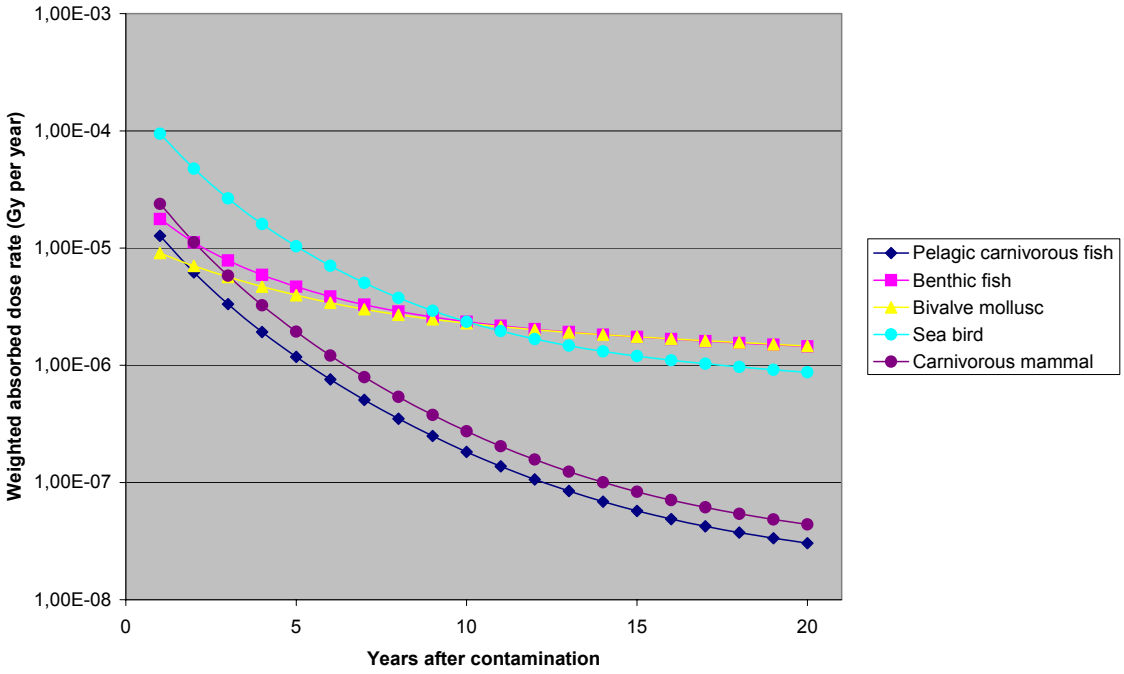

Figure 7.4 *Predicted weighted dose rates (^{137}Cs, ^{134}Cs, and ^{90}Sr) to reference organisms from the Barents Sea (Gy a^{-1})*

The concentration dynamics of radionuclides in the water column and sediment determine the dynamics of dose rates for all marine organisms. As shown in Figure 7.4, sea birds receive the highest predicted doses for the first 10 years after the hypothetical accident, whereas benthic organisms become the most exposed group for periods in excess of 10 years. Pelagic organisms receive total dose rates of comparable size to benthic organisms during the first years, but since doses to these organisms are only dependent on water concentrations, dose rates decrease quite rapidly (cf. Figure 7.2). In contrast, total doses to benthic organisms level off due to external exposure from sediments (cf. Figure 7.3).

Table 7.1 Total doses (^{137}Cs, ^{134}Cs, and ^{90}Sr) to reference organisms for the whole simulation period (20 years)

Reference organism	*Representative species*	*Integrated total dose (20 y) Gy*
Pelagic carnivorous fish	Cod	$2.8 \cdot 10^{-5}$
Benthic fish	Plaice	$8.0 \cdot 10^{-5}$
Bivalve mollusc	Blue mussel	$6.2 \cdot 10^{-5}$
Sea bird	Herring gull	$2.3 \cdot 10^{-4}$
Carnivorous mammal	Harp seal	$5.0 \cdot 10^{-5}$

In general, doses calculated for this example are low compared to natural background levels for marine reference organisms (see Section 8.3). Table 7.1 shows that sea birds receive the highest total dose (20 years), benthic organisms lie in-between and pelagic organisms receive the lowest doses from a hypothetical "worst case" accident at Kola NPP. The large CF of caesium for sea birds seems to be of most importance for the relatively high predicted dose for this reference organism.

7.2 Terrestrial ecosystems

For the purposes of demonstrating the assessment procedure for a terrestrial ecosystem we will assume two simple scenarios: (i) a deposition of 78 kBq m^{-2} of each of ^{137}Cs and ^{90}Sr at a depth of 0.5 g cm^{-2}; (ii) homogenous activity concentrations of ^{238}U in soil of 1 kBq kg^{-1} (dry weight). To demonstrate all stages of the assessment we will assume that no measurements of activity concentrations in representative species are available. Assessments will be made for best estimate (i.e. mean of observed data where available) and maximum exposures (as defined by the maximum CR value).

7.2.1 Selection of concentration ratios

The first step in calculating exposure is the selection of concentration ratios (CR) for representative species from Appendix 3. To use the CR values (a ratio of activity concentrations in biota to soil) we need to convert the deposition values for ^{137}Cs and ^{90}Sr to activity concentrations assuming a soil bulk density of 0.78 g DM cm^{-3} for Arctic soils and a sampling depth of 10 cm (i.e. as in section 4.1.2). This gives a soil activity concentration of 1 kBq kg^{-1} (dry weight) for both radionuclides.

For ^{137}Cs there are CR values available for all representative species with the exception of *Lagopus* spp. egg for which an estimate has been derived by Brown *et al.* (2003) by comparison of the transfer of Cs from diet to meat and eggs of domestic hens (IAEA, 1994) with soil-muscle CR values collated for wild herbivorous species (predominantly data for *Lagopus* spp.).

For ^{90}Sr no CR values are available for fox and vole, however, values are available for the reference organism groups carnivorous and herbivorous mammals (excluding reindeer) so these can be used. No value of the transfer of Sr to *Lagopus* spp. egg is available and data are not available to allow one to be estimated in the same manner

as for Cs and U. The transfer of Cs is greater than that of Sr both from feed to domestic hen egg (IAEA, 1994) and from soil to herbivorous bird (Beresford *et al.,* 2003). Therefore a pragmatic approach to estimate the transfer of Sr to *Lagpus* spp. egg is to assume the same CR value as for Cs.

Whilst there is a CR value for ^{238}U presented from data in Appendix 3 for carnivorous mammals this is based on one observation only. The maximum value presented in Table 7.2 is assumed to be an order of magnitude higher than this (as per recommendations in the aquatic sections). No observed CR values are available for reindeer and therefore we will use the allometrically derived estimate. A CR value for U transfer to *Lagopus* spp. egg has been estimated in the same manner as for ^{137}Cs by Brown *et al.,* (2003).

Maximum CR values for the transfer of all three radionuclides to eggs are assumed to be an order of magnitude higher than the derived CR values; allometrically derived values are treated similarly. An alternative to using reference organism group values would have been to use the allometrically derived values for representative species presented in Beresford *et al.* (in press). Concentration ratios for plants reference organisms are not required as we are estimating doses to the roots only. No CR values were collated for soil invertebrates within this project, the assumption having been made that external doses would predominate.

Whole-body activity concentrations can then be estimated by Eq. 4.1 (see Section 4.1.1).

Table 7.2 Best estimate (BE) and maximum CR values and predicted whole-body ^{137}Cs, ^{90}Sr and ^{238}U activity concentrations (FW) for the terrestrial assessment example.

Representative species		^{137}Cs		^{90}Sr		^{238}U	
		CR	*Estimated (Bq kg^{-1})*	*CR*	*Estimated (Bq kg^{-1})*	*CR*	*Estimated (Bq kg^{-1})*
Soil invertebrate	BE	n/a		n/a		n/a	
	Max	n/a		n/a			
Plant roots	BE	n/a		n/a		n/a	
	Max	n/a		n/a			
Vole	BE	3.49	3490	1.09[d]	1090	2.6x10^{-3}	2.6
	Max	4.43	4430	6.18	6180	2.8x10^{-3}	2.8
Reindeer	BE	9.91	9910	3.48	3480	9.4x10^{-3c}	9.4
	Max	45.1	45100	8.42	8420	9.4x10^{-2}	94
Fox	BE	0.65	650	0.72[d]	720	7.1x10^{-4d}	0.71
	Max	1.68	1680	1.86	1860	7.1x10^{-3}	7.1
Lagopus spp.	BE	0.76	760	3.5x10^{-2}	35	5.0x10^{-4}	0.50
	Max	3.22	3220	0.22	220	6.8x10^{-4}	0.68
Lagopus spp.	BE	6.4x10^{-2a}	64	6.4x10^{-2b}	64	2.0x10^{-3a}	2.0
egg	Max	0.64	640	0.64	640	2.0x10^{-2}	20

[a]Derived from feed to egg transfers for domestic hens and soil to tissue transfer for wild herbivorous species; [b]Assumed to be the same CR as for ^{137}Cs; [c]Allometrically derived; [d]CR value for reference organism group.

7.2.2 Estimation of dose rate

We need to select weighted dose conversion factors (DCFs) from Appendix 2, 2.9-2.17. The relevant DCFs (external dose rate to organisms on soil (DCF_{ext_on}), external dose to organisms in soil (DCF_{ext_in}) and internal dose (DCF_{int})) are summarised in Tables 7.3 and 7.4. Here we will assume that ^{90}Sr is in isotopic equilibrium with its daughter product ^{90}Y; given the long half-life of ^{238}U (4500 million years) we will not consider doses from daughter products. Fox and voles represent burrowing species which we will assume spend 10 and 50 % of their time underground respectively. Internal (D_{int}) and external (D_{ext}) dose rates for each radionuclide can then be estimated employing Eqs. 2.3 and 2.4 (see Sections 2.2.2 and 2.2.3, respectively).

The total dose rate from each radionuclide (D_{tot}) can then be estimated by summing the internal and external dose rate, in the case of ^{90}Sr the total dose rate is estimated by summing dose rates for ^{90}Sr and ^{90}Y. The overall total dose rate in the first scenario is obtained by summing the dose rates for ^{90}Sr and ^{137}Cs.

Estimated dose rates are presented in Table 7.3 for ^{137}Cs and ^{90}Sr, and Table 7.4 for ^{238}U. There is little contribution of D_{ext_in} for ^{137}Cs and especially ^{90}Sr because the deposit is assumed to be in the top 1cm of the soil whereas organisms are assumed to be at greater depths.

Table 7.3 Estimated weighted dose rates for representative species assuming a deposition of 78 kBq m^{-2} of both ^{137}Cs and ^{90}Sr. Estimates for ^{90}Sr include contributions from ^{90}Y. Calculations are presented using best estimate (BE) and maximum CR values (see Table 7.2).

Representative species		*Dose rate (Gy a^{-1})*					
		^{137}Cs				^{90}Sr	^{137}Cs+^{90}Sr
		Internal	*External (on soil)*	*External (in soil)*	*Total*	*Internal*	*Total*
Soil invertebrate		n/a	n/a	$1.2x10^{-3}$	$1.2x10^{-3}$	n/a	$1.2x10^{-3}$
Plant roots		n/a	n/a	$3.1x10^{-4}$	$3.1x10^{-4}$	n/a	$3.1x10^{-4}$
Vole	BE	$4.6x10^{-3}$	$5.6x10^{-4}$	$7.0x10^{-6}$	$5.2x10^{-3}$	$5.6x10^{-3}$	$1.1x10^{-2}$
	Max	$5.9x10^{-3}$	-	-	$6.5x10^{-3}$	$3.2x10^{-2}$	$3.8x10^{-2}$
Reindeer	BE	$2.2x10^{-2}$	$9.3x10^{-4}$	0	$2.3x10^{-2}$	$2.0x10^{-2}$	$4.3x10^{-2}$
	Max	$1.0x10^{-1}$	-	-	$1.0x10^{-1}$	$4.8x10^{-2}$	$1.5x10^{-1}$
Fox	BE	$1.2x10^{-3}$	$8.9x10^{-4}$	$3.6x10^{-8}$	$2.1x10^{-3}$	$4.1x10^{-3}$	$6.2x10^{-3}$
	Max	$3.2x10^{-3}$	-	-	$4.1x10^{-3}$	$1.1x10^{-2}$	$1.5x10^{-2}$
Lagopus spp.	BE	$1.2x10^{-3}$	$1.1x10^{-3}$	0	$2.2x10^{-3}$	$1.9x10^{-4}$	$2.4x10^{-3}$
	Max	$5.0x10^{-3}$	-	-	$6.1x10^{-3}$	$1.2x10^{-3}$	$7.3x10^{-3}$
Lagopus spp. egg	BE	$8.5x10^{-5}$	$3.5x10^{-3}$	0	$3.6x10^{-3}$	$3.3x10^{-4}$	$3.9x10^{-3}$
	Max	$8.5x10^{-4}$	-	-	$4.3x10^{-3}$	$3.3x10^{-3}$	$7.6x10^{-3}$

Table 7.4 Estimated weighted dose rates for representative species assuming 1 kBq ^{238}U kg^{-1} (dry weight) homogenously distributed in soil. Estimates are presented using best estimate (BE) and maximum CR values (see Table 7.2).

Representative species	*Dose rate (Gy a^{-1})*				
	Best estimate				***Maximum***
	Internal	*External (on soil)*	*External (in soil)*	*Total*	*Total*
Soil invertebrate	n/a	n/a	$4.8x10^{-7}$	$4.8x10^{-7}$	-
Plant roots	n/a	n/a	$6.8x10^{-6}$	$6.8x10^{-6}$	-
Vole	$5.6x10^{-4}$	$6.4x10^{-8}$	$7.6x10^{-7}$	$5.6x10^{-4}$	$6.0x10^{-4}$
Reindeer	$2.0x10^{-3}$	$3.4x10^{-8}$	0	$2.0x10^{-3}$	$2.0x10^{-2}$
Fox	$1.5x10^{-4}$	$3.6x10^{-8}$	$3.9x10^{-8}$	$1.5x10^{-4}$	$1.5x10^{-3}$
Lagopus spp.	$1.1x10^{-4}$	$5.3x10^{-8}$	0	$1.1x10^{-4}$	$1.5x10^{-4}$
Lagopus spp. egg	$4.3x10^{-4}$	$1.7x10^{-7}$	0	$4.3x10^{-4}$	$4.3x10^{-3}$

8 Criteria and standards for Arctic biota

The dose-effects relationships for low-LET radiation derived from the EPIC database, in coordination with recommendations and achievements from other international programmes/projects are a valuable input to the development of internationally agreed safety guidance for protection of wildlife from ionising radiation. It would be expected that a necessary part of guidance would include standards and criteria. According to risk management terminology, these are distinguished by the following definitions: standards being regulatory or legal limits, either dose limits or environmental concentrations, and criteria referring to levels of exposure above which adverse environmental effects may occur.

8.1 The derivation of Dose limits

As stated earlier, no international agreed regulations exist for protecting the natural flora and fauna from detrimental effects of ionising radiation. A main concern for environmental regulations is the establishment of radiation safety standards for biota. Such standards would apply to normal operating activities of industries dealing with technogenic/natural radionuclides, which are associated with a chronic exposure of flora and fauna at comparatively low dose rates (with accumulated doses well below those likely to lead to increased mortality) (IAEA, 1976).

8.2 International developments

There have been several review publications on radiobiological effects in wild nature (IAEA, 1976, 1992; Blaylock & Trabalka, 1978; NCRP, 1991; Polikarpov, 1977, 1998; Turner, 1975; Woodhead, 1984; UNSCEAR, 1996). In most cases, the intention of authors was to concentrate attention on the effects of chronic low-dose exposures, but these data were very limited. As a result, the existing reviews refer largely to studies of radiation effects from acute exposure at high doses; hence these data are not directly relevant to the environmental concerns. A major problem in the evaluation of the severity of environmental effects and subsequent derivation of standards for non-human organism's exposure has been the lack of available data on effects at low-level chronic radiation in international publications.

In the 1990s, the international reviews of radiation effects on flora and fauna have been published by IAEA (1992) and UNSCEAR (1996). Based on summaries of available radiobiological literature, including some data from Russian sources, these documents provide the following set of preliminary conclusions on the thresholds of observable radiation effects for terrestrial and aquatic biota:

IAEA report (1992, summary):

"Chronic dose rates of 1 mGy d^{-1} to even the more radiosensitive species in terrestrial ecosystems are unlikely to cause measurable detrimental effects in populations and that up to this level adequate protection would therefore be provided".

"*In the aquatic environment it would appear that limiting chronic dose rates to 10 mGy d^{-1} or less to the maximally exposed individuals in a population would provide adequate protection for the population"*;

UNSCEAR report (1996, para 264):

"For the most sensitive animal species, mammals, there is little indication that dose rates of 10 mGy d^{-1} to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (1-2.4 mGy d^{-1}), the same statement could be made with respect to reproductive effects.

For aquatic organisms, the general conclusion was that maximum dose rates of 0.4 mGy h^{-1} (≈10 mGy d^{-1}) to a small proportion of the individuals in aquatic populations and, therefore, lower average dose rates to the whole population would not have any detrimental effects at the population level."

Furthermore, it was stated that for "*the most sensitive plant species, the effects of chronic radiation were noted at dose-rates 1-3 mGy h^{-1}. It was suggested that chronic dose-rates less than 0.4 mGy h^{-1} (≈10 mGy d^{-1}) would have only slight effects in sensitive plants but would be unlikely to produce significant deleterious effects in the wider range of plants present in natural plant communities."*

The conclusions of the IAEA and UNSCEAR reports specified the ranges of chronic dose rates, which are of concern in the environmental protection of the flora and fauna. None of these dose rate levels were intended as recommendations for radiation protection criteria, although they clearly could have implications for the development of such criteria and standards.

Dose limits have been applied in other situations as exemplified by the approach advocated by the USDoE (2002). The limits used by the USDoE have been established earlier based on the findings of numerous reviews considering the effects of ionising radiation on flora and fauna (e.g. NCRP, 1991; IAEA, 1992) and relate to the protection of populations of wild organisms. A dose limit of 10 mGy d^{-1} is applied to aquatic animals and terrestrial plants and a dose limit of 1 mGy d^{-1} applied to terrestrial animals.

Although these basic recommendations, and in the latter case dose-limits, exist, their applicability directly within the context of EPIC is limited because:

(1) For reasons discussed in the introduction (Section 1.2), there are reasons to believe that Arctic climatic conditions influence the expression of radiation induced effects and, furthermore, that Arctic ecosystems are potentially more vulnerable to contaminants than organisms in other European climatic regions. The dose limits derived for temperate environments may, therefore, be unsuitable for direct application to the Arctic.

(2) The dose limits considered above relate to the protection of populations of wild flora and fauna. In contrast, the approach taken by EPIC focuses on environmentally-relevant endpoints at the individual organism level, hence all data collation and subsequent analyses is made at the individual level.

8.3 Developments in EPIC and FASSET

With respect to environmental protection, it is important to derive dose-effects relationships for a large range of exposures, providing a scale of severity of radiation effects on natural biota following the increase in irradiation levels. Such information will further facilitate the derivation of appropriate dose-standards and has therefore been a key theme for both the FASSET and EPIC projects.

A large database on radiation effects on biota has been compiled within the EC Project FASSET, based mainly on available English-language publications. In the FASSET database, again, the preponderance of radiation effects data is for acute dose exposures (Woodhead & Zinger, 2003). In general terms, it appeared that although there might be minor effects at lower dose rates in sensitive species, the dose rates for statistically significant effects in most studies was about 0.1 mGy h^{-1}; the responses were then observed to increase progressively with increasing dose rate and usually became very clear at dose-rates > 1 mGy h^{-1} when these were delivered over a large fraction of the life-span.

From the information compiled in EPIC, a preliminary scale which maps observed biological effects onto ranges of absorbed dose has been constructed (Table 8.1). Dose-effect relationships have been thus tabulated for the generic groups: terrestrial animals, terrestrial plants and aquatic animals. The table also includes the "background" dose-rate range observed under natural conditions.

Table 8.1 Scale mapping absorbed dose-rates onto effect

Absorbed dose rate (Gy d^{-1})	*Effect*
10^{-6} -10^{-5}	Natural radiation background for Arctic/northern organisms
10^{-4} to $5x10^{-4}$	Minor cytogenetic effects. Stimulation of the most sensitive species
$5x10^{-4}$ to $1x10^{-3}$	Threshold for minor effects on morbidity in sensitive vertebrate animals.
$2x10^{-3}$ to $5x10^{-3}$	Threshold for effects on reproductive organs of vertebrate animals, decrease of embryo's survival.
$5x10^{-3}$ to 10^{-2}	Threshold for life shortening of vertebrate animals. Threshold for effects in invertebrate animals. Threshold for effects on growth of coniferous plants.
10^{-2} to 10^{-1}	Life shortening of vertebrate animals; chronic radiation sickness. Considerable damage to coniferous trees.
10^{-1} to 1	Acute radiation sickness of vertebrate animals. Death of coniferous plants. Considerable damage to eggs and larva of invertebrate animals.
> 1	Acute radiation sickness of vertebrate animals; lethal dose received within several days. Increased mortality of eggs and larva of invertebrate animals. Death of coniferous plants, damage to deciduous plants.

A general conclusion can be made, that the threshold for deterministic radiation effects in wildlife lies somewhere in the range 0.5-1 mGy d^{-1} for chronic low-LET radiation. This is in broad agreement with the conclusions made in the UNSCEAR reports. Having said this, the extrapolation of biological effects observed at one level

of biological organisation to a higher level is no simple matter. Although minor effects on morbidity in sensitive vertebrate animals are observed at the dose range specified above, populations of highly productive vertebrate organisms (mice, some ubiquitous fish species) are viable at dose rates in the order 10 mGy d^{-1}.

The establishment of dose limits may therefore depend not only on the types of organism that require protection but on the level of protection, e.g. protection of viable populations versus protection of individuals from a particular radiosensitive species.

The generalised conclusions, within EPIC, regarding the threshold dose-rates at which various effects are observed are consistent with earlier studies. From the available information it is, therefore, not possible to justify any Arctic specific dose-standards at the present time. Assumptions of Arctic vulnerability might provide justification for applying an additional safety factor to any derived dose limits, e.g., that standards be set at say a factor of ten lower than those derived for other for ecosystems. Having said this, the data set upon which such a conclusion is drawn is limited in scope (see below) and the hypothesis relating to whether there is a unique expression of radiation-induced biological damage under Arctic conditions remains to be properly tested.

Furthermore, the problem of evaluating the appropriate weighting factors for high-LET radiation in the context of wildlife protection is still unsolved. It was evident from the analyses of available data (EPIC Deliverable Report 5, Sazykina *et al*., 2003) that heavy alpha-emitting radionuclides with very low specific activity and chemical toxicity can not be used for the purpose of w_r estimations, because the bulk of observed effects on biota are associated with chemical toxicity of these elements. The safety regulations for these radionuclides (e.g. ^{238}U, ^{232}Th) are more appropriate to establish for each radionuclide separately.

As discussed in Section 6.3, Background dose rates have been derived for Arctic and/or related ecosystems. This information is summarised in Table 8.2.

Table 8.2 Summary of natural background dose rates for marine reference organisms, derived from EPIC Deliverable Report 5 (Sazykina *et al*., 2003).

Ecosystem	*Organism*	*Dose-rate (μGy d^{-1})*
Marine	Phytoplankton[a]	0.5 - 2.1
	Zooplankton[a]	0.6 - 4.1
	Crustaceans[a]	2.7 - 14
	Molluscs[a]	2.7 - 13
	Macrophytes[a]	1.7 - 12
	(Benthic) Fish[a]	1.3 - 10
	Waterfowl[a]	0.5 – 1.6
Freshwater	Fish	1.4 – 2.2
Terrestrial	Generic vertebrate[b]	Circa 3.2

[a] Derived for the Kara Sea – it is assumed that phytoplankton, zooplankton and waterfowl receive all external irradiation from the water column whereas crustaceans, molluscs, macrophytes and benthic fish receive all external irradiation from sediment;
[b] Generic terrestrial vertebrate in a temperate environment (from Whicker & Shultz, 1982).

It should be noted that background dose-rates for Arctic terrestrial flora and fauna are particularly poorly defined and information for freshwater environments is limited to only a few reference organism types.

Used in conjunction, information for reference organisms, relating to doses at which various effects are observed and background dose rates might be used to inform management decisions. Such an approach would be in line with the "Derived consideration levels" discussed by Pentreath (2002).

8.4 Concentrations standards –

Another way to organise the implementation of standards is through the setting of concentration standards. Such methods have been applied both in the US and Russia.

8.4.1 Biota Concentration Guides (BCG) – US approach

A prominent example is the US DoE's graded approach for evaluating radiation doses to aquatic and terrestrial biota (USDoE, 2002). This assessment methodology is in essence a compliance tool whereby doses to aquatic flora and fauna can be evaluated against specified limits on radiation doses to these biota. Having defined the dose rate limits, as described above (Section 8.2), biota concentration guides (essentially limiting radionuclide concentrations in sediments and water) for specified radionuclides are derived by dividing this limit by external and internal dose rates per unit concentration in sediment or water. In other words, at the BCG concentration, dose rates to biota will attain the dose limit. An example of the BCG is shown in Equation 8.1:

$$BCG_{s,i,ra} = \frac{365 DL_{ra}}{C_{ra}\left[\left(LP_{s,i,ra} DCF_{\text{int},i}\right) + \left(DCF_{iext,i}\right)\right]} \quad (8.1)$$

where,
$BCG_{s,i,ra}$ = Biota concentration Guide, i.e. concentration of radionuclide "i" in sediment (Bq kg^{-1}), based on screening level assumptions that numerically equates to the Dose Rate DL_{ra} to riparian animal

DL_{ra} = Recommended dose limit for riparian animals (1 mGy d^{-1})
C_{ra} = Correction factor for area or riparian animal residence time

$LP_{s,i,ra}$ = Lumped parameter (dimensionless) – ratio of the activity concentration in riparian animal to sediment concentration of radionuclide "i"

The methodology uses a sum of fractions rule, whereby activity concentrations measured in sediment and water are divided by corresponding BCGs for all radionuclides considered. The sum of fractions should be < 1 for compliance to be demonstrated. The graded approach, advocated by the DoE, involves a data assembly phase wherein sources, receptor and routes of exposures are considered and environmental activity concentration data collated. Following this, a general screening phase can be employed using default parameters and maximum activity concentrations. Failing this, successively more detailed levels of analyses are employed including site-specific screening (site representative parameters and condition utilised), site specific analyses (using site appropriate kinetic allometric modelling tools) and finally a site specific biota dose assessment (employing an eco-risk framework).

8.4.2 Control concentrations (CC) - Russian approach.

There are no official criteria for radiation protection of flora and fauna in Russia. However, the issue has been under consideration since the 1970s, mainly in the context of the establishing the control concentrations of radionuclides in marine areas ensuring the safety of the human population, as well as marine fauna and flora.

In earlier work (Gusev, 1975; Shekhanova, 1983), attempts were made to establish control levels (working limits) of the radionuclide content in sea water, with consideration for hygienic and radioecological criteria of limiting the exposure of humans and marine biota. These problems were also discussed in several publications (Sazykina, 1996; Sazykina &Kryshev 1999a,b; Kryshev & Sazykina, 1998).

In recent years, a methodology was developed for radionuclide permissible levels in sea water, based on the current requirements for ensuring the radiation safety of the population and the environment (Sazykina & Kryshev, 1999a,b; 2002).

It was proposed that the maximum permissible concentrations (control levels) of radionuclides in seawater should be estimated in order to ensure radiation safety of both humans and marine biota, using both hygienic and radioecological criteria. Control levels of concentrations were calculated for each radionuclide separately; as several radionuclides are present in sea water, the permissible levels are calculated using standard rules for mixed contaminants.

From hygienic (human protection) criteria, the control concentrations of radionuclides in sea water were calculated under the following conditions: radiation dose to the population from consumption of marine foodstuffs should not exceed 10 % of the permissible dose limit (1 mSv a^{-1}); dose is assessed for a critical population group with considerable consumption of marine foodstuffs. These hygienic criteria satisfy Russian and international standards for ensuring the radiation safety of the human population (IAEA, 1996; NRB-99).

From radioecological criteria, the control concentrations of radionuclides in sea water ensuring the radiation safety of marine flora and fauna were calculated using the following guidelines:

- radiation dose to sea animals should not exceed 100 mGy a^{-1};
- radiation dose to sea plants should not exceed 1000 mGy a^{-1}.

These doses correspond to about 1 % of LD_{50} (at which 50 % of the organisms die after single exposure). Under conditions of chronic exposure, doses exceeding 10 mGy d^{-1} to aquatic fauna can be ecologically significant.

Dose assessments were made for critical groups of marine biota characterized by the highest exposure level at a given content of radionuclides in sea water.Using the radioecological criteria, the control concentrations were determined with the following relationship:

$$X_k = PC_{ik} / (F_{ik} B_{ik} + F_{dk} B_{dk}), \quad (8.2.)$$

where,

X_k is the control concentration of the radionuclide k in sea water; PC_{ik} is the ecological dose limit for the i^{th} group of marine organisms from exposure to the radionuclide k, Gy a^{-1};

F_{ik} is the concentration factor of the radionuclide k in the i^{th} group of marine organisms;

B_{ik} is the dose factor for the i^{th} group of marine organisms on internal exposure to the radionuclide k, Gy a^{-1}/Bq kg^{-1}; F_{dk} is the concentration factor of the radionuclide k in bottom sediments; B_{dk} is the dose factor for the i^{th} group of marine organisms on external exposure to the radionuclide k from bottom sediments, Gy a^{-1}/Bq kg^{-1}.

The control concentrations of radionuclides in sea water calculated from radioecological criteria are presented in Table 8.3. Fish and mollusc are the critical groups of marine organisms for most radionuclides.

Table 8.3 The control concentrations (CC) of radionuclides in sea water calculated from the radioecological criteria, Bq l^{-1} ((Sazykina & Kryshev, 1999a,b; 2002; relevant to the seas of the Russian North).

Radionuclide	*CC*	*Critical group*	*Radionuclide*	*CC*	*Critical group*
^{3}H	1700000	Mammals	^{99}Tc	1000	Mollusks
^{51}Cr	6000	Fish	^{106}Ru	30	Mollusks
^{54}Mn	8	Fish	^{129}I	1100	Algae
^{59}Fe	4	Fish	^{131}I	400	Algae
^{60}Co	2	Fish	^{134}Cs	13	Fish
^{59}Ni	850	Fish	^{137}Cs	30	Fish
^{63}Ni	1100	Fish	^{144}Ce	6	Fish
^{65}Zn	11	Fish	^{147}Pm	200	Fish
^{89}Sr	120	Fish	^{152}Eu	7	Fish
^{90}Sr	60	Fish	^{154}Eu	5	Fish
^{95}Zr	3	Fish	$^{239,240}Pu$	6	Mollusks
^{95}Nb	8	Fish	^{241}Am	1	Mollusks

The control concentrations (CC) for each radionuclide, calculated from hygienic and radioecological criteria, are compared, and the lower of the two values is selected; this value is considered as the maximal permissible level of radionuclide in seawater ensuring the protection of both humans and marine biota. The hygienic criteria was found to provide more rigid restrictions than radioecological ones for most radionuclides; the radionuclides ^{241}Am, ^{239}Pu, ^{240}Pu, ^{60}Co, and ^{65}Zn, which are characterized by high values of accumulation in individual marine foodstuffs, have the lowest CC; for tritium CC in sea water are higher than the specific activities established for fresh water (this is associated with the fact that tritium does not accumulate in marine foodstuffs and sea water is not used for drinking). At present, the existing concentrations of radionuclides (^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu and some others) in sea water of the Arctic Seas are 10^{3}-10^{4} times lower than CC.

8.4.3 Limitations with the concentration standards approach

Concentration standards combine information on dose effects and environmental transfer and uptake. For the same assumed dose effect relationship in an organism the derived concentration standard will be lower in ecosystems having high transfer and bioaccumulation. Thus if limits were based on **concentration standards** rather than dose standards, then there would be clear grounds for having Arctic specific criteria, since there is a reasonable amount of evidence that transfer and uptake parameters under Arctic environments are different, for some radionuclides, compared to those observed under temperate conditions.

From methodological point of view, the “permissible concentration” approach, which was developed in Russia for marine environment, could be extended for terrestrial and freshwater ecosystems. However, there are some practical difficulties in estimating

the reference radionuclide transfer parameters for terrestrial/freshwater ecosystems. In the seawaters of standard salinity, the chemical composition of seawater is maintained at a constant level, therefore, in equilibrium, the concentration factors for radionuclides accumulation in biota are the same within the whole marine area. In contrast, in freshwater ecosystems, each lake/river has unique composition of waters and sediments, which modify the site-specific radionuclide-transfer parameters. Average values of concentration factors and transfer parameters estimated for lake/river ecosystems of a large region have very high uncertainty. In the terrestrial ecosystems, soils of different types also demonstrate a large range of uncertainties in the values of radionuclide transfer parameters. Therefore, the databases of transfer parameters for terrestrial ecosystems cannot be averaged in the same manner as for marine environment; and it may be more appropriate to use site-specific data.

With these points in mind, a “concentration standard” approach has not been advocated within the framework of EPIC. It is felt that the uncertainty associated with such values would be too large to be sensibly applied. The process of establishing dose limits is still incomplete and although much progress has been made with respect to the derivation of appropriate transfer factors for Arctic reference organisms, further refinement is still clearly required.

9 Compatibility of EPIC exposure assessment framework with other environmental impact assessment methodologies

9.1 Comparison with other assessment frameworks

Other assessment systems have been considered at some length elsewhere (Larsson *et al*., 2002a) and there is no justifiable reason to repeat this exercise here. However, some general observations from Larsson *et al*. (2002a) are appropriate for consideration in this report. Assessment methodologies often include three major phases:

(i) Entry characterisation – describe sources so that factors relevant to the assessment including physico-chemical form, magnitude of discharge, temporal variation in input etc. are provided.

(ii) Exposure analyses/assessment – predict the exposure of the substance to the assessment endpoint. This might be a concentration in a specific organ or for radiation, absorbed dose-rate to whole body.

(iii) Effects analyses/assessment – analyse concentration or dose-effects relationships in order to identify concentrations/doses at which harmful effects are observable for selected endpoints.

The EPIC assessment is compatible with this approach but has not involved a detailed analysis of "entry characteristics". The assessment methodology is designed to be generically applicable and within the constraints of the project it is not possible to explore whether this general approach can accommodate all possible input and ensuing radiation exposure scenarios. It is recognised, for example, that the suite of radionuclides discharged for any given scenario might not be a subset of the limited set considered within EPIC. It is also recognised that the physico-chemical form may lead to quite different environmental behaviour of radionuclides compared to the generic case. Under such situations the assessor would be advised to conduct a site-specific analysis.

Several differences between assessment systems (20 pathway based 'systems were analysed of which 11 considered impacts/risks of non-radioactive hazardous substances) have been identified by Larsson *et al.,* (2002a). These differences and the way in which the EPIC system can be classified in accordance with the various approaches adopted are listed below:

(i) Aim of the assessment. These vary and include compliance with regulatory standard (e.g. USDoE, 2002), impact assessment for authorised releases (Copplestone *et al*., 2001), assessment of hazards associated with chemical releases (e.g. Environment Canada, 1997) and a tool to develop environmental standards (e.g. USEPA, 2000). The aim of the EPIC system includes aspects of many of these other aims. The system is initially being developed to allow realistic environmental impact assessment to be conducted in Arctic environment following releases of radioactivity.

However, it is envisaged that the EPIC methodology may be used to inform the derivation of recommended standard/limits for the Arctic. With such standards in place the methodology could be used in a compliance situation (although it is recognised that such an outcome would involve sanction by Arctic countries at a national level).

(ii) Degree of specificity. This arises at the problem formulation stage and often depends on the aim of the assessment. The difference is most pronounced when comparing screening-level assessments using generic, and often conservative data/model parameters with site-specific assessments using more "realistic" information. The EPIC system has been developed to lie somewhere between these extremes, using regional-specific, 'best estimate' data-sets/models as oppose to conservative estimates. The general methodology should, however, be applicable to both screening and site specific assessments.

(iii) Assessments vary with respect to the number of 'levels' employed in the system. An example of a multi-tiered approach is provided by USDoE compliance methodology (USDoE, 2002). EPIC is essentially a single-tiered approach essentially for reasons pertaining to its envisaged application (see point (i)). Multi-tiered approaches are clearly suitable for application in compliance situations to remove the requirement for detailed, labour-intensive analyses, unless absolutely necessary. The EPIC system has a degree of complexity built in, allowing realistic impact assessment for the Arctic to be conducted. However, the system could be modified to a compliance tool if such a need arises.

(iv) The point in the assessment at which risk characterisation is conducted, i.e. comparison between a standard/limit and measured/predicted quantity differs. As considered above (Section 1.4) risk characterisation is only addressed within the EPIC system, by evaluating dose-rates to reference organism in relation to documented dose-rate response relationships to inform management decisions. Standard/limits are not employed by the system although it is envisage that such limits may be recommended for the Arctic in the future based on part on EPIC project data sets.

(v) The choice of endpoint varies between systems. This encapsulates differences in the type of ecosystem to be assessed, the type of effect and species to be studied, the level of biological hierarchy to be studied and/or protected. The general endpoints for the EPIC system have been defined in Section 6.1. Systems vary with respect to guidance given on the selection of measurement endpoints (e.g. the concentration of a contaminant or measurable effect in a selected organism) and assessment endpoints (the effect that is inferred from the measurement endpoint which the assessment is designed to study/protect). Some frameworks include a predefined choice of endpoint others leave the choice to the assessor. The choice of measurement endpoint within EPIC is the activity concentration and derived dose rate for reference organisms. The use of critical organisms (used in site specific assessments) and reference organisms (generic studies) are used in some systems. The selection of reference organisms within EPIC has been predefined (Section 3.1) and the criteria employed in the selection are compatible with other systems. For EPIC the

choice of assessment endpoints covers the umbrella biological effects categories mortality, morbidity, reproductive success and cytogenetic damage – a choice that should cover most envisaged application requirements for the system. The level of biological hierarchy to be protected is often taken to be the population – probably based on the observation that humans are prepared to accept, in many cases, the limited culling of numerous species for human use. Some systems (e.g. Environmental Canada, 1997) also consider the protection for individuals under some circumstances. The EPIC approach is in line with this latter view for the reasons cited under Section 1.5.

(vi) Difference in the extrapolation between measurements and assessment endpoints. Many systems adopt an approach whereby a wide range of 'reference' organisms is selected in order to represent all species within an ecosystem. It is assumed that the test organisms, from which dose-response data were derived, do not need to be present in the environment. However, the range of reference organisms studied should have some relationship with these test animals allowing extrapolations to be made. In contrast other systems select organism in line with specific assessment goals. For example, sensitive organisms may be chosen based on their known sensitivity to a toxin and the effects estimated for these organisms are extrapolated to higher levels of biological hierarchy. The EPIC system takes elements of some of these varying approaches, a broad suite of reference organisms has been selected but the selection of each group was informed by a number of important generic considerations.

(vii) Effects data analyses. Based mainly on observations from non-radioactive substances, Larsson *et al*. (2002a) report that differences are evident in which effects are deemed relevant and the statistical significance and/or acceptability of tests. Various statistical methods are also applied to effects data in order to establish a 'safe' level below which no adverse effects are observed in the endpoint of concern. Since the EPIC system is not being primarily developed to derive standards, this type of effects data analysis falls beyond the remit of the project.

9.2 Compatibility with MARINA II methodology for assessing doses and radiation impact on marine biota

The recent MARINA II Update project, together with the assessment of radiation exposure to human population, considered a specific task of assessing the dose rates to, and estimating the possible radiobiological effects on, representative non-human organisms, inhabiting the marine waters of the North-East Atlantic within the OSPAR area (EC, 2002).

An assessment methodology was identified for the estimation of doses and radiation impact on marine biota, based on the current 'state-of-art' in the dosimetry of non-human organisms, and available information of the effects of chronic radiation exposure on aquatic organisms. The methodology includes the following components: identification of biological endpoints of concern; selection of region-

specific organisms for assessment; adaptation of dosimetric models for dose calculations; radiological assessment for marine biota (EC, 2002). This is in line with the EPIC approach.

9.2.1 Biological endpoints of concern

Four umbrella endpoints were adopted to be inclusive of all relevant effects of radiation at the level of individual organisms: morbidity, reproduction, cytogenetic effects, and mortality – compatible with those considered within EPIC. Following the conclusions of comprehensive reviews on radiation effects in non-human organisms (NCRP, 1991; IAEA, 1992; UNSCEAR, 1996), dose rates of chronic exposure within the range 1-10 mGy d^{-1} (10^{-3}- 10^{-2} Gy d^{-1}) have been considered as the levels at which minor radiation effects on the morbidity, fertility and fecundity of individual aquatic animals begin to become apparent first in laboratory studies, and, at higher exposure, in natural populations.

To evaluate the possible harm to biota, the dose rates to organisms inhabiting the industry-impacted marine areas were compared with the available information on the effects of chronic radiation exposure in aquatic organisms.

9.2.2 Selection of reference organisms

It was practically impossible to perform radioecological assessment for every species from the thousands inhabiting the waters of the North-East Atlantic. This problem was solved by selecting a limited set of representative marine organisms, including molluscs (mussel and winkle/limpet), large crustaceans (crab and lobster), and fish (cod and plaice). The contamination of these region-specific species is studied within radioecological monitoring/research programmes and databases on the concentrations of radionuclides are available for these organisms. In the radiological assessment, the use of region-specific organisms throughout the whole OSPAR region provided an advantageous possibility to compare on a unified basis the doses/effects to biota in different local sites of the North-Atlantic. These approaches are in line with those recommended within EPIC.

9.2.3 Dosimetry of marine organisms

In the MARINA II Update study, dose rates to representative marine organisms have been calculated using the existing dosimetric approaches; adaptations were made to take into account the sizes and habits of the region-specific organisms. Dose conversion factors were calculated for recommended representative organisms and different radionuclides. To account the differences in the relative biological efficiency (RBE) of α-, β-, and γ- emitters, as a conservative assumption, a radiation weighting factor (w_r) of 20 has been selected for α-emitting radionuclides, and factor of 1 for other radionuclides. The dosimetric approaches are similar to those developed within EPIC with the exception of the selection of radiation weighting factors: by way of example, a w_a of 10 has been selected for the alpha component of radiation and a w_β of 3 has been applied to ^3H.

9.3 Compatibility with developments made internationally, ICRP, IUR, IAEA

The International Union of Radioecology, the IUR, considers that there is already sufficient information to start introducing an overall framework for the systematic protection of the environment from ionising radiation, drawing upon specialist reviews and interpretations of the large amount of radiobiological and radioecological information that has been gathered over the last fifty years (IUR, 2002). The basic elements of the system advocated by the IUR have been discussed at some length elsewhere (Pentreath, 1999; Strand et al, 2000; Strand & Larsson, 2001) but are essentially the same as that being developed within EPIC and FASSET. However, the organisation has also highlighted the need to plug some gaps in our knowledge and to improve upon existing databases. The IUR point to the fact that an increased interest in environmental protection has highlighted a number of knowledge gaps in the scientific data on sources and effects of radiation in non-human species, making the following observations:

(i) Although the transfer of radionuclides is quite well known within some food-chains, there are very little data on the behaviour of radionuclides in non-temperate zones and on uptake to species that do not form part of the human food chain.

(ii) There is a need to develop both transfer models (flux, dynamic, ecosystem, etc.) and genotoxicological biomonitoring techniques that are capable of allowing impact assessments at a variety of species, population and ecosystem levels and that could also deal with other environmental stressors.

(iii) Mathematical models should be developed and applied to relate the effects of radiation on individuals (particularly with regard to early mortality, reproductive success, and cytogenetic damage) to potential impacts at the population level.

(iv) Knowledge of the doses and effects of background radiation is lacking, as are dose-effect relationships, including information on RBE for a variety of species, doses and dose rates. Interaction of radionuclides with other stressors, including possible synergistic effects, is only just starting to be investigated.

These observations are pertinent to the discussions relating to the EPIC framework and emphasise the fact that although basic tools may be available for assessing impacts of ionising radiation on the environment, large areas of data paucity and knowledge gaps are prevalent.

The International Commission on Radiological Protection, the ICRP, have revised their previous stance encapsulated by the paraphrase “if man is protected from ionising radiation, the environment is also adequately protected” (ICRP, 1977; ICRP, 1991) to a position wherein a Task Group on environmental protection has been established and plans are being made to incorporate environmental issues, based on the advice of the Task Group, into the revised basic recommendations of the Commission (which are concerned with all aspects of radiological protection). At the

present time (Autumn 2003), the ICRP have completed a report on the protection of non-human species from ionising radiation, this report having being placed in the public domain for consultation (ICRP, 2002). The elements of the ICRP approach are consistent with those proposed by the FASSET and EPIC projects having been based, to a large extent on the same ideas (see Pentreath, 1999). However, a number of ideas have been developed further in order to address how the system to protect man may be combined with the system to protect the environment under a common front (Strand & Holm, 2002). In the process of revising their basic recommendations of human radiological protection, the ICRP is exploring the possibility of moving away from dose-effects assessment based purely on human dose effects data and the hypothesis of a no threshold linear response relationship (with the implication that any small increment in radiation exposure carries with it a small incremental increase in risk) to a more embracing and understandable approach based on bands of concern with explicit reference to background dose rates (Pentreath, 2002). This would be consistent with the proposed dose assessment approach for flora and fauna, i.e. *Derived consideration levels*, where data could be presented as scales of dose-effects levels to facilitate different management options. Essentially, consideration levels for flora and fauna could be compiled from 2 sets of information namely (i) logarithmic bands of dose rates relative to natural dose rates and (ii) dose rates that are known to have an effect on selected biological endpoints including reproductive success, mortality, morbidity and scoreable cytogenetic parameters. Pentreath (2002) envisages that in adopting such an approach for any given situation involving environmental contamination by radionuclides, management decisions would be facilitated by information on two bands of concern. The first would relate to members of the public and be based on Reference Man and secondary data sets, the other would relate to the environment and be based on consideration levels based on primary and secondary reference organisms.

After its initial work on compiling information in the 70's and up to the early 90's (see for example IAEA, 1976, IAEA, 1992), the IAEA has also taken up renewed interest in environmental protection, including an evaluation of the ethical and legal issues. Two reports have been published (IAEA, 1999, 2002) and the agency has organized a number of specialist meetings that have been successful in establishing a consensus on both the need for a system of protection and some fundamental ethical principles of environmental protection. The IAEA is in the process of developing a safety standard that will provide the basis for the assessment of radioactive materials on the environment, or living components of it and for the technical components of environmental management decisions (Robinson, 2002). The assessment component of the IAEA work programme is heavily influenced by the system being developed under FASSET and EPIC and is likely to adopt many of the methodologies developed within these projects.

10 Conclusions and recommendations

10.1 General Conclusions

Within the frame of the EPIC project the following major steps were made in the direction of the development of a practical methodology for radiological assessment of the Arctic/northern wildlife:

(i) A set of region-representative species have been selected which are characteristic for the marine, freshwater and terrestrial areas of the European Arctic. The selected species satisfy all/most of the selection criteria, they form large populations, and their natural areas of geographical distribution cover the whole or the greater part of the marine areas of the European Arctic. The contamination of the selected species is studied within radioecological monitoring/research programmes, so the databases on the radionuclide concentrations are available for most of the selected organisms.

(ii) Site-specific radioecological information have been collated concerning the assessment of concentration factors (CFs) of radionuclides in Arctic biota.

(iii) Models and computer codes were developed in order to calculate internal and external doses to non-human organisms; dose-conversion factors have been calculated for a set of reference Arctic organisms and a number of radionuclides.

The EPIC database "Radiation effects on biota" has been compiled forming a large collection of radiation effects on northern biota covering a very wide range of radiation dose rates to wild flora and fauna: from below 10^{-5} Gy d^{-1} up to more than 1 Gy d^{-1}. A great variety of radiation effects are registered in the EPIC database. These encompass effects from stimulation at low doses up to death from acute radiation syndrome at high doses. Based on information, compiled in the EPIC database, the preliminary dose-effects relationships were derived for terrestrial and aquatic animals of northern climatic zone, also for terrestrial plants. The dose-effects relationships provide a preliminary scale of severity of radiation effects at increasing levels of chronic radiation exposure. Furthermore, information on background dose-rates were derived for selected reference organisms in terrestrial, freshwater and marine environments. Together, these data sets could inform decision making processes and provide input towards the development of Arctic dose standards.

10.2 Needs for further development of assessment methodology

Despite the availability of large data sets, it should be noted that large information gaps exist. With regard to transfer of radionuclides in the environment, it has not been possible to derive transfer information for all radionuclide-reference organism combinations. This is especially true in the cases of freshwater and terrestrial environments where data paucity is often great. Even basic information relating to activity concentrations of natural radionuclides in Arctic environments are limited in coverage and thus render the derivation of background dose rates highly uncertain. The existing information concerning the effects of chronic exposure on the Arctic

wildlife does not cover all groups of sensitive species; for instance, there is a lack of data on large and long-lived Arctic animals, such as seals, polar bears, foxes, which probably are the most radiosensitive animals in the Arctic ecosystems. There is also a deficiency of special experimental studies of those peculiarities in metabolism and biochemical composition of Arctic organisms, which may modify the response of Arctic organisms to ionising radiation compared with organisms from warmer climatic zones.

Effects of some natural alpha-emitting radionuclides (U, Th) on wildlife demonstrate the complex simultaneous action of chemical toxicity and high-LET radiation. In the consideration of these radionuclides a problem arises in developing a unified methodology for combined assessment for chemical toxicity and radiation on biota. The problem of evaluating the appropriate weighting factors for high-LET radiation in the context of wildlife protection is still unsolved. It became evident, however, that heavy alpha-emitting radionuclides with very low specific activity and high chemical toxicity can not be used for the purpose of w_r estimations, because the bulk of observed effects on biota is associated with chemical toxicity of these elements. The safety regulations for these radionuclides (e.g. ^{238}U, ^{232}Th) are more appropriate to establish for each radionuclide separately.

10.3 Recommendations for future research

There is a requirement to collate further information on natural radionuclides in Arctic environments through field studies. Furthermore there is a requirement to refine and test existing dynamic models simulating the behaviour and fate of radionuclides in Arctic ecosystems. Empirical data are also required in defining transfer factors for numerous radionuclides and reference organism types.

The EPIC database provides a large collection of radiation effects on wildlife under the conditions of chronic exposure. At present, the radiation impacts in the datasets are given mostly as they appeared in the source publications, i.e. activity concentrations in biota and environment, and/or author's dose estimates. A detailed dose assessment, using modern models for dose-to-biota calculations, is required to provide reliable estimations of dose rates for the EPIC datasets, and make dose reconstructions in cases there only "radionuclide concentration-effects" data were available from source publications.

There is a lack of experimental data on radiation effects in typical Arctic organisms, bespoke experimentation is required to determine if extreme Arctic conditions influence the response of biota to ionising radiation exposure.

Glossary

The following terms and definitions have been adopted or modified from: FASSET Deliverable 2, R&D Publication 128, ICRU report 65 (2001) and USDoE (2002).

Absorbed dose
Quantity of energy imparted by *ionising radiation* to unit mass of matter such as tissue. Unit *gray*, symbol Gy. 1 Gy = 1 joule per kilogram.

Actinide
A group of 14 elements with atomic number from 90 (thorium) to 103 (lawrencium) inclusive. All are radioactive.

Activity
Attribute specifying an amount of a *radionuclide*. Describes the rate at which transformations occur. Unit *Becquerel*, symbol Bq. 1 Bq = 1 transformation per second.

Aggregated transfer factor (T_{ag})
The aggregated transfer factor/coefficient, T_{ag}, is the mass activity density, A_m (Bq kg^{-1}) in a specified object per unit areal activity density, A_a (Bq m^{-2}) in the soil. A_a in this case refers to the depth-integrated activity per unit area in soil underlying the specified object.

Allometric
The allometric approach is based on the observation that many metabolic parameters, including basal metabolic rates, ingestion rates, biological half times etc., are related (as power functions) to the masses of organisms.

Alpha particle
Is a helium-4 nucleus, consisting of two protons and two neutrons, given off by the decay of many heavy elements, including uranium and plutonium.

Assessment endpoint
The biological effect inferred from the measurements or predictions and which the assessment framework is designed to study.

Assessment framework
Identification and demarcation of the assessment boundaries. In EPIC, the framework contains the process from problem formulation through to characterisation of the effects of radiation on individuals. The overall assessment system describes the tools, methods and information flow used to carry out the impact assessment.

Benthic
Pertaining to, or with the characteristics of, the benthos; also, the bottom region of a lake or sea.

Bioaccumulation
The process whereby an organism accumulates chemicals in living tissues to concentrations higher than those existing in the surrounding media (e.g., soil, water, food).

Bioaccumulation factor (BAF)
The ratio of the concentration of a chemical in the tissue of an organism to its concentrating in the surrounding media, in situation where both the organism and its food are exposed and the ratio does not change substantially over time.

Bioconcentration
The net accumulation of a chemical by an aquatic organism as a result of uptake directly from the ambient water, through gill membranes or other external body surfaces.

Bioconcentration factor (BCF)
The ratio of the concentration of a chemical in the tissue of an aquatic organism to its concentration in water, in situations where the organism is exposed through the water only and the ratio does not change substantially over time.

Biokinetic model
A mathematical model which incorporates metabolic rate equations and is dynamic (time-dependent).

Biological diversity (Biodiversity)
The number and abundance of species found within a common environment. This includes the variety of genes, species, ecosystems, and the ecological processes that connect everything in a common environment.

Biological half-life
The time required for a biological system (e.g. animal) to eliminate, by natural processes, half the amount of a substance that has been absorbed into that system.

Biomagnification
The increase in concentration of a chemical in the tissue of organisms along a series of predator-prey associations, primarily through the mechanism of dietary accumulation.

Biomagnification factor (BMF)
The ratio (unitless) of the concentration of a chemical in a predator organism at a particular trophic level to the concentration of the chemical in the tissue of its prey organism at the next lowest trophic level for a given ecosystem and chemical exposure.

Biosphere
The portion of Earth and its atmosphere that can support life.

Biota
The animal and plant life of a given region.

Bioturbation
Perturbation or disturbance of sediments of soils by one or more biological mechanisms.

Chronic
Refers to an extended continuous exposure to a stressor or the effects resulting from such an exposure.

Concentration factor (CF)
In this report, the term has been applied specifically for aquatic ecosystems and is defined as the ratio of the concentration of the radionuclide in the organism or tissue (normally fresh weight) to that in water (normally filtered), assuming the system is under equilibrium.

Concentration ratio (CR)
In this report, the term has been applied specifically for terrestrial ecosystems and is defined as the activity density of *reference organism* relative to that of soil (ICRU, 2001).

Cytogenetic
Observed effects in chromosomes that can be correlated with adverse hereditary or genetic effects.

Cytogenetic damage
Damage to chromosomes that can be detected on the microscopic level.

Decay
The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance.

Dose
Normally relates to the term *absorbed dose* as specified above.

Dose conversion factor (DCF)
Represents the instantaneous dose rate per unit activity concentration of the radionuclide in an organism or in the environment. Synonym: DCC, Dose Conversion Coefficient.

Dose rate
Dose (normally *absorbed dose*) received over a specified unit of time.

Dose-effect
The relationship between dose (or dose-rate) and the gradation of the effect in an exposed individual or population, that is a biological change measured on a graded scale of severity.

Dose-response
A correlation between a quantified exposure (dose) and the proportion of an exposed population that demonstrates a specific effect (response).

Dynamic model
A mathematical model which incorporates time as an independent variable.

Ecosystem
The interacting system of a biological community and its non-living surroundings.

Ecological risk assessment
The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Ecosystem
The interacting system of a biological community and its non-living surroundings.

Effect
A biological change caused by an exposure.

End-point

1. The final stage of a process, especially the point at which an effect is observed.
2. A radiological or other measure of protection or safety that is the calculated result of an analysis or assessment.

Equivalent dose
The quantity obtained by multiplying the *absorbed dose* by a weighting factor (*radiation weighting factor*) to allow for the different effectiveness of the various ionising radiations in causing harm to tissue. Unit sievert, symbol Sv.

Exposure
The co-occurrence or contact between the endpoint organism and the stressor (e.g., radiation or radionuclide)

Exposure assessment
The process of measuring or estimating the intensity, frequency, and duration of exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.

Fecundity
The number of viable offspring produced by an organism; mature seeds produced, eggs laid, or live offspring delivered, excluding fertilized embryos that have failed to develop.

Fertility
In sexually reproducing plants and animals it is the number of fertilized eggs produced in a given time.

Food chain
A linear series of species linked by specific *trophic* or feeding relationships, e.g. plant-herbivore-carnivore.

Hazard
A condition or physical situation with a potential for an undesirable consequence, such as harm to heath or environment.

KERMA
Kinetic Energy Released in Material. It is a non-stochastic quantity relevant only for fields of indirectly ionising radiations (photons or neutrons) or for any ionising radiation source distributed within the absorbing medium. It represents the initial kinetic energy of the primary ionising particles produced by the interaction of the incident radiation per unit mass of interacting medium. In the SI system KERMA is measured in units of joules per kilogram or grays.

Linear energy transfer (LET)
A measure of how, as a function of distance, energy is transferred from radiation to the exposed matter. Radiation with high LET is normally assumed to comprise of protons, neutrons and alpha particles (or other particles of similar or greater mass). Radiation with low LET is assumed to comprise of photons (including X-rays and gamma rays), electrons and positrons.

Measurement endpoint
Measured or predicted value that an assessment produces

Monte Carlo method/simulation
Of or relating to a problem-solving technique that uses random samples and other statistical methods for finding solutions to mathematical or physical problems.

Morbidity
A loss of functional capacities generally manifested as reduced 'fitness', which may render organisms less competitive and more susceptible to other stressors, thus reducing the life span.

Mortality
Death; the death rate; ratio of number of deaths to a given population.

Natural radionuclide
Radionuclides that occur naturally in significant quantities on Earth.

Occupancy factor
Refers to the fraction of the time that an organism expends in a specified habitat.

Octanol-water partition coefficient (K_{ow})
The K_{ow} is defined as the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase octanol-water system.

Phytoplankton
Passive or weakly motile suspended plant life; the plant subgroup of *plankton*.

Poikilotherm
An organism, such as a fish or reptile, having a body temperature that varies with the temperature of its surroundings; an ectotherm.

Pollution
The presence of matter or energy [e.g., smoke, gas, hazardous or noxious substances, light, heat, litter or a combination thereof] in sufficient quantities and of such characteristics and duration as to produce, or likely to produce, undesired environmental effects.

POPs
Persistent Organic Pollutants (POPs) are chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to biota and the environment.

Radiation weighting factor
Its value represent the *relative biological effectiveness* of the different radiation types, relative to X- or gamma-rays, in producing endpoints of ecological significance.

Radiological protection
The science and practice of limiting the harm to environment from radiations.

Radionuclide
An unstable nuclide that undergoes spontaneous transformation, emitting *ionising radiation*.

Reference organisms
A series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects.

Relative biological effectiveness (RBE)
For a given type of radiation, RBE is defined as:

$$\text{RBE} = \frac{\text{Dose of the reference radiation needed to produce the same effect}}{\text{Dose of the given radiation needed to produce a given biological effect}}$$

Response
The proportion or absolute size of an exposed population that demonstrates a specific effect. May also refer to the nature of the effect.

Risk
A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard. A technical estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence or magnitude of the event given that it has occurred.

Risk Assessment
A qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of pollutants. It includes problem formulation, exposure and dose-response assessment and risk characterisation

Risk Characterisation
The synthesis of information obtained during risk assessment for use in management decsions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the adverse health or ecological effects likely to occur in a population or environmental compartment, together with identification of uncertainties.

Semi-natural ecosystem
Extensively (as opposed to intensively) used land.

Transfer factor (TF)
Is defined as the ratio of the activity density (Bq/kg or Bq/l) of a radionuclide in the receptor compartment to that in the donor compartment. In this report the term transfer factor is used as a generic term that includes CRs, CFs and activity concentration relative to annual deposited activity.

Trophic level
Functional classification of organisms in an ecosystem according to feeding relationships from first level autotrophs through succeeding levels of herbivores and carnivores.

Zooplankton
Sub-group of plankton in aquatic ecosystems and which are animals.

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Appendix 1: Life history data sheets

1.1 Terrestrial representative species

1.1.1 Reindeer lichen (*Cladonia rangiferina*)

Classification

Kingdom: *Fungi*
Division: *Bryophyta, Pteridophyta*
Class: *Lycopsida*
Order: *Lecanorale*
Family: *Cladoniaceae*
Genus: *Cladonia*

Distribution and habitat

Cladonia spp. Has a circumpolar distribution adapted to a cool, moist climate with little or no shade. It occurs in submontane to alpine environments in the open, in 'open' canopy forest and in tundra on shallow humus layers or dry peat and on moist to very dry, sandy, nitrogen-poor soils with low pH values ranging between 4.5 and 5.5, thus avoiding calcareous soils. As they are able to take up moisture from the air, the underlying soil is not as important a source of moisture so they can colonize and become dominant on rocks, logs and soils too shallow or sterile to support higher plants, provided that humidity is sufficiently high for lichen growth and temperature is sufficiently low to inhibit competitors. *Cladonia rangiferina* can survive in a broad range of habitats and is thus more common than the other species of lichen in less favourable habitats such as wet bogs and shaded woods.

Growth patterns (including size, rooting depth, longevity, seeding time)

Cladonia spp. Are slow-growing (*C. rangiferina* had an average annual growth rate of approximately four mm per year), long-lived, densely branched ground lichens often forming clumps or mats which have a high surface to volume ratio. Wind is the most important dispersal agent. As they have no roots they absorb their nutrients from the atmosphere. They grow vegetatively by producing new growth annually at the top, passing through three growth stages: (i) growth-accumulation period, which lasts an average of 10 years but can vary from 5 to 25 years. (ii) growth-renewal period (which has the highest growth rate) where the base dies off at a rate equal to the growth, this stage often exceeds 100 years and (iii) degeneration period, where the base dies off at a greater rate than it grows from the top, this stage may also exceed 100 years. Factors that contribute to the variation in lichen growth include: plant age; disturbance by animals; substrate, drainage and exposure. After events such as fire, the first reindeer lichen to become established is *Cladonia Mitis* followed by *C. alpestris*, *C. rangiferina* or *C. arbuscula*.

Plant and animal associates

Cladonia spp. Are commonly associated with: whortleberry (*Vaccinium myrtillus*), rock cranberry (*V. vitris-idaea*), bog blueberry (*V. uliginosum*), lowbush blueberry (*V. angustifolium*), bog birch, sheep laurel (*Kalmia angustifolia*), common bearberry (*Arctostaphylos uva-ursi*), black crowberry (*Empetrum nigrum*), *Stereocaulon paschale*, and Schreber's moss (*Pleurozium schreberi*). They are important in the winter diet of reindeer (*Rangifer tarandus*) but as their growth rate is so slow they cannot tolerate re-grazing for 2 to 5 years if the grazing is moderate, or 10 to 15 years if the area is heavy grazed.

Sources of information and picture credits

http://www.fs.fed.us/database/feis/plants/lichen/claspp/all.html
http://biology.clc.uc.edu/graphics/taxonomy/fungi/lichens/reindeer%20moss/

1.1.2 Bigelow sedge (*Carex bigelowii*)

Classification

Kingdom: *Plantae*
Division: *Anthophyta*
Class: *Monocotyledoneae*
Order: *Cyperales*
Family: *Cyperaceae*
Genus: *Carex*

Distribution and habitat

Bigelow (stiff) sedge is a circumpolar species which can be found as far north as 71° N in a wide range of habitats usually in damp stony places within forest tundra and alpine meadows usually above 600 metres in an acid soil. Plants can occasionally become dominant in tundra regions, shrublands, or in sedge meadows but it is normally only found in limited numbers. The plant itself is easily confused with *Carex aquatilis*.

Growth patterns (including Size, rooting depth, longevity, seeding time)

Bigelow sedge grows to be between 5-25cm tall and is a long-lived perennial which reproduces mainly by short rhizomes that can re-generate quickly (in 2 months). Its fibrous die back to rootstocks each winter and its leaves senesce in Autumn with new ones being produced from June onwards. The upper part of the plant can live for up to 4 years, retaining the previous year's growth, but the rhizomes remain productive for more than 12 years. Flowers are produced when the plant reaches two years old from July to September (depending on location) and are pollinated by the wind, more flowers (and hence more seeds) are produced at disturbed sites. Seeds are formed upon stems 10-41cm high and can remain dormant in the soil seedbank for many years although younger seeds (1-20 years old) are more likely to germinate; the germination rate being greater on organic soil.

Plant and animal associates

Bigelow sedge is not an important forage plant although domestic sheep and reindeer (*Rangifer tarandus*) will graze it occasionally during spring and early summer (where they do their grazing encourages its growth). Species commonly associated with it include willows (*Salix spp*.), dwarf arctic birch (*Betula nana*), shrubs including the cowberry (*Vaccinium vitis-idaea*), grasses including some species of *Agrostis*, *Festuca* and *Carex* together with various other mosses and lichens.

Sources of information and picture credits

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http://www.fs.fed.us/database/feis/plants
http://www.sci.muni.cz/botany/gallery/aj2_a.htm

1.1.3 Cowberry (*Vaccinium vitis-idaea*)

Classification

Kingdom: *Plantae*
Division: *Magnoliophyta*
Class: *Magnoliopsida*
Order: *Ericales*
Family: *Ericaceae*
Genus: *Vaccinium*

Distribution and habitat

Vaccinium vitis-idaea grows under a wide range of climatic conditions. It is widely distributed in northern temperate forests and in many arctic and alpine dwarf shrubland communities such as heathland. It can grow in a variety of soil types with a pH range of 2.7-8.2 but yields are greater on peat soils with a pH between 4.0-4.9. It can survive in extremely harsh conditions such as mountain summits, sea cliffs and sand dunes and also, at its southern range, boggy ground. Fruit production varies widely according to location; plants growing in the shade rarely produce flowers or fruit, and in harsh arctic environments only plants in protected areas, flower.

Growth patterns (including Size, rooting depth, longevity, seeding time)

The cowberry is a low, creeping, evergreen shrub that commonly reaches 5-15cm in height growing in dense rhizomatous colonies forming mats where up to 80% of the total biomass of the mature plant is underground. The depth of the rhizomes is influenced by the local conditions but they are generally found in the organic horizon between 10-20cm deep. They have a network of fine, shallow, fibrous roots (which actively grow in early spring and autumn) to a depth of 5-28cm, and can produce a taproot. The stems are slender and trailing and can root at the nodes which are important in subarctic conditions. The thick leaves are an elongated oval shape and begin to grow in March and generally finish in mid-July surviving for up to 3 years. Few flowers are produced until the plant reaches 5-10 years old developing from buds formed the previous year. Two flowering periods (spring and summer) can occur at some low-elevation sites, each period lasting for 9 to 27 days. Temperatures of -1.5º C can kill half of all flowers and exposure to -3.5º C can destroy half of the buds and unripe fruit. The fruit (berry) is approximately 6-10mm in diameter which contains an average of 3-15 seeds each about 1mm in length which ripen 78-84 days after flowering. Seeds germinate 3 weeks after exposure to temperatures of 20-25º C (in light or dark conditions), fresh seed usually germinating best. Yields range from 17.4 kg ha^{-1} in Swedish peatlands, 500 kg ha^{-1} in some Finnish forests whereas in cultivated stands 8150 kg ha^{-1} may be achieved.

Plant and animal associates

Plant species commonly found with *Vaccinium vitis-idaea* include the dwarf birch (*Betula nana*), willow (*Salix spp.*), sedges (*Carex spp.*), lichen and mosses (*Cladonia* and *Sphagnum spp.*) and other shrubs such as the crowberry (*Empetrum nigrum*) and coudberry (*Rubus chamaemorus*). Flowers are generally pollinated by bees and syrphid flies whilst the seeds are dispersed by many birds and mammals. Reindeer (*Rangifer tarandus*), arctic hares (*Lepus arcticus*) and moose (*Alces alces*) browse the leaves and the berries are readily eaten by a variety of birds and are essential to birds migrating northward in the spring such as the herring gull (*Larus argentatus*), Canada goose (*Branta canadensis*), and some breeds of thrush (*Turdus spp.*). Rodents burrow under snow to reach them and the red fox (*Vulpes vulpes*) consumes large amounts (in late autumn) as does the polar bear (*Ursus maritimus*). In some countries berry picking is an important recreational activity and the fruit is widely processed and marketed locally in many areas of Europe, Scandinavia and the fomer Soviet Union as well as being exported into the USA where it is consumed mainly by people of Scandinavian descent. In Eurasia indigenous people use the leaves and fruit as food or medicine and “Arbutin” which is obtained from the leaves and stems is used by the pharmaceutical industry.

Sources of information and picture credits

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http://www.rook.org/earl/bwca/nature/shrubs/vacciniumvit.html
http://www.ibiblio.org/herbmed/pictures/p14/pages/vaccinium-vitis-idaea-2.htm

1.1.4 Common juniper (*Juniperus communis*)

Classification

Kingdom: *Plantae*
Division: *Coniferophyta*
Class*: Pinopsida*
Order: *Pinales*
Family: *Cupressaceae*
Genus: *Juniperus*

Distribution and habitat

Juniperus communis is the most widespread juniper species occurring in many areas including Europe, it is almost completely circumpolar with the exception of a gap near the Bering Sea. It can grow on a wide range of sites: dry, open, rocky, wooded (where it is an important understory species), hillsides (at altitudes between 1370-3450m) and sand dunes and reaches maximum abundance on harsh, stressed environments in which competition is lacking. As it is intolerant of shade it is usually found in open environments. At polar limits, common juniper grows as a dwarf shrub in forest tundra.

Growth patterns (including Size, rooting depth, longevity, seeding time)

The common juniper is a native, evergreen shrub which most often grows as a low and mat-forming reaching up to 1.5m high and 2-4m wide made up of branches which are 5-10mm diameter; although occasionally it will grow into a tall columnar tree. The needle like leaves grow in whorls of three and are between 5-19mm long. The seed cones are 5-9cm long and are usually mature during the second growing season to approximately 6-13mm in size; they contain 2-3 seeds each. They are dispersed from August to October. Ideal conditions for germination are a moist, aerated but compact soil and a period of warmth followed by approximately 7 months cold; but even with these conditions rates are usually poor as the older the plant becomes the less viable the seed. In general there are few viable seeds remaining in the soil seedbank. Birds mainly disperse the seed but strong winds can also carry them. It is also possible for the plant to spread by producing 'adventitious roots' which occur when branches become buried; this method is common in subarctic plants possibly as it may aid water and nutrient uptake. Plants begin to actively grow in the spring. Flowering (cone development) varies according to location, but usually occurs from April-June with the seeds maturing during the following year. In Arctic conditions this process may be slower with the seeds maturing in the 3rd year.

Plant and animal associates

In general animals rarely browse the foliage although in some areas reindeer (*Rangifer tarandus*) occasionally browse it (when lichen growth is poor) as do moose (*Alces alces*), hares (*Lepus spp.*) and other wild ungulates; sheep will eat the berries. Limited grazing pressure can encourage growth although it will not regenerate if it is damaged to woody growth. The cones are eaten by many species of birds and mammals and they are used commercially to flavour gin. Juniperus communis has deworming properties, notably against liver fluke.

Sources of information and picture credits

Polunin O. & Walters, M. 1985. A guide to the vegetation of Britain and Europe. New York: Oxford University Press.

http://www.fs.fed.us/database/feis/plants
http://www.nabu-borken.de/html/flora/wacholder/wacholderbluete.htm

1.1.5 Springtails (*Collembola spp.*)

Classification

Kingdom: *Animlaia*
Phylum: *Arthropoda*
Class: *Insecta*
Order: *Collembola*
Family: *Sminthuridae*
Genus: *Sminthurus*

General habits, habitat and home range

Collembola are the most various and widely distributed soil invertebrate, with over 3,500 known species. They live almost everywhere but are most abundant in warm damp places. They are chiefly soil and/or litter dwellers and often exist in densities of >100 000 per m^3 of soil, and can be easily seen if the top layer of leaf litter is carefully removed. Different collembola (and collembola at different stages of growth) are specialized for different microhabitats in litter, ranging from the warm and dry surface layer down to the cool, moist, deep litter layers where they can survive temperatures of less than -60 ºC.

Dietary habits and main prey species

Most collembola feed on the fungi and bacteria that decompose organic matter but many arboreal (living in trees) and epidaphic (living on the surface of the soil) species also feed on algae whereas a few are carnivorous, feeding on nematodes and other collembola. Some species can live for a long time without food, the longest being 18 months for a single specimen on its own in laboratory conditions.

Birth weight, gestation period and general life cycle

A female will lay about 90 to 150 eggs during her life, though this varies with species. They moult about once a week and have to have an empty gut before moulting because they shed part of the stomach lining with their external skin. Sperm is dropped in packets at random by males and retrieved by females, which retain the packets until they are needed for fertilisation or until it is lost during their molt. Eggs can also sometimes develop without fertilisation (a process known as parthenogenesis). And take about a month to hatch at 8ºC; but can take less time at warmer temperatures. Some species are multivoltine (having many generations in a year), particularly in the tropics, while many others are univoltine, however, in Arctic conditions some species may take up to 4 years per generation. Their average life expectancy is less than 1 year.

Sources of information and picture credits

Encyclopaedia Britannica 2002
Sarah Heyman and Jan Weaver, http://www.missouri.edu/%7Ebioscish/coll.html
http://www.earthlife.net/insects/collembo.html
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1.1.6 Mites

Classification

Kingdom: *Animalia*
Phylum: *Arthropoda*
Class: *Arachnida*
Subclass: *Acari*
Order: *Acariformes*
Suborder: *Oribatida*

General habits, habitat and home range

There are many different species of mites colonising almost everything and everywhere. Those that occur in soil and humus and occasionally on tree trunks and foliage are described in more detail below. In some soils mites can be very common, amounting to 7% of all the invertebrate biomass. For example, $1m^2$ of mixed temperate hardwood or boreal coniferous litter may harbour upwards from one million mites representing 200 species in at least 50 families. They help to regulate microbial processes directly by feeding on detritus and microbes, and indirectly by predation on other microfauna. Mites can transport themselves to new areas in three main ways: a) the most common, attaching themselves to a wide range of other animals (Phoresy). In some cases the mite will feed from its transport during the journey but in most cases the 'phoretic host' suffers no harm. b) using a thread in a similar manner to spiders but hanging from it until it is long enough for the wind to tear it and the mite away from the original support c) without a thread, some mites are so light that all they have to do to fly is to find an open space and let go of the earth.

Dietary habits

Mites are unable to digest their food internally so they inject digestive fluids into their food and suck the liquefied remains into their mouths.

Birth weight, gestation period and general life cycle

Most insect species are bisexual. The male arachnid usually deposits sperm on the ground as a ‘spermatophore’ or constructs a ‘sperm web’ which it then transfers to the female. The eggs that are produced then pass through some, or all of the following life stages (called stases): a) prelarva (which has no mouth or legs and does not feed or move from inside the eggshell) b) larva, which is hexapod c) three nymphal stages called 'protonymph' 'deuteronymph' and tritonymph all of which are octopods d) adult. This life cycle takes between one to six weeks (average 2-3) for completion.

Sources of information and picture credits

Encyclopaedia Britannica 2002

Top left: Scanning electron micrograph of microbe grazing oribatid mite, *Neotrichozetes* **s**p. (Acariformes), from South America (© Copyright 1996, Jason Hurdis)
Bottom left: SEM of a predatory mesostigmatic mite, *Dendrolaelaspis* **s**p. (Parasitiformes), from Australia (© Copyright 1996, D.E. Walter)

Right: Photograph of a predatory water mite, *Limnesia* sp. (Acariformes), from Canada (© Copyright 1996, C. Podemski).

http://www.earthlife.net/insects/six.html

1.1.7 Arctic or Collared Lemming (*Dicrostonyx torquatus*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Mammalia*
Order: *Rodentia*
Family: *Muridae*
Genus: *Dicrostonyx*

General habits, habitat and home range

Lemmings are small herbivorous burrowing mammals found in tundra regions of North Eastern Europe and Siberia. There are two main species, the Collared or Arctic, (which is described in more detail below) and the Brown. They are the smallest mammals of the high Arctic and are a key species within arctic ecosystems. For unknown reasons, lemming populations fluctuate drastically, peaking about every four years and then crashing almost to extinction. It is because of this behaviour that they are so important within the Arctic food chain. They live in colonies in a maze of tunnels and runways under leaf litter in summer and under insulating snow in winter and do not hibernate. There is little information on the home range of the collared lemming but the Nothern bog lemming *(Synaptomys borealis*) has a home range of less than 0.4 ha and their colonies can reach 36 animals per 0.4 ha). Most of their habitat is underlain by permafrost, often within a few centimetres of the surface, which means that the lemmings are unable to dig deep burrows for shelter, even in summer. To enable them to dig through wind-packed snow and ice collared lemmings develop bifid "digging" claws in the autumn, structures unique to the genus *Dicrostonyx*. Their burrows can reach up to 6 meters long and 20cm wide, and lead to a nest made of grass. The collared lemming lives in higher and drier areas in summer but in winter moves to lower ground where the snow is deeper and thus provides more shelter. They can occasionally be found swimming in the arctic waters. Brown lemmings prefer the lower and wetter areas all year round. Both species migrate periodically from their home area when their population begins to exceed their food supply. The collared lemming is short and stocky with a very heavy coat year round, its fur varies with the seasons: in summer the coat is light to dark grey with a buff to reddish brown tone whereas in winter it is white.

Dietary habits and main prey species

Collared lemmings feed on roots, grass, bark, leaves, shoots, (e.g. from *Salix* spp. (willow), berries (e.g. *Vaccinium spp.* (cranberry)) and mosses. They forage in the subnivean ("under snow") space that forms between soil and snow, and almost never appear on the surface. Brown lemmings prefer to eat sedges, arctic cotton grass (*Eriophorum scheuchzeri*) and certain mosses. In winter, the habitat segregation between the two species tends to break down as the collared lemmings move to lower ground. Both species are preyed upon by *Mustela erminea* (stoat), *Alopex lagopus* (arctic fox), *Gulo gulo* (wolverine), *Ursus maritimus* (polar bear), *Nyctea scandica* (snowy owl), *Asio flammeus* (short eared owl), *Falco rusticolus* (Gryfalcon), *Stercorarius pomarinus* (pomarine jaeger), *Larus* spp. (gulls) and *Accipitridae* spp. (hawks).

Birth weight, gestation period and general life cycle

The lemming breeding season is from early spring to autumn with a gestation period of between 20 and 22 days. They produce up to 12 young with a birth weight of approximately 3g, which are weaned at 15-20 days. A female typically has two to three litters per year. Both sexes are able to reproduce within weeks of their birth. A lemming is unlikely to survive more than one winter.

Sources of information and picture credits

Encyclopaedia Britannica 2002
http://www.borealforest.org/world/mammals/arctic_lemming.htm
http://animaldiversity.ummz.umich.edu/accounts/dicrostonyx/d._groenlandicus$narrative.html

1.1.8 Vole (*Microtus spp.*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Mammalia*
Order: *Rodentia*
Family: *Muridae*
Genus: *Microtus*

General habits, habitat and home range

Microtus spp. are small burrowing mainly herbivorous mammals found mainly found in habitats with grass where they dig underground burrows constructing food and nesting chambers within them. They do not hibernate and are active throughout the winter. They live in colonies of a few individuals up to a maximum of about 300 animals in burrows which are found just below the soil surface up to a depth of 0.56 meters. Home ranges between species vary; a bank vole has a home range of about 40 meters, a meadow vole uses approximately 20m^2 whereas the pine vole restricts its range to the area around its burrow.

Dietary habits and main prey species

Microtus spp. eat mainly grasses and seeds and occasionally insects. During the winter in snow covered areas, they make runways beneath the snow and feed on the snow-flattened grasses, they also burrow up through the snow to reach grass seed heads. They are the staple food of weasels (*Mustela nivalis*), marten (*Martes* spp.), foxes (*Vulpes* spp.), all owls, most hawks, inland breeding gulls, Skua (*Stercorarius* spp.) and occasionally grey herons (*Ardea cinerea*), domestic cats (*Felis catus*), northern pike (*Esox lucius*), and other voles.

Birth weight, gestation period and general life cycle

Populations fluctuate greatly from year to year. The lifespan of a vole is between 1-3 years, but is generally less than two years. Breeding starts during late winter and continues until August. The gestation period is about 21 days, and they can have up to six litters per year of 4-8 young. The young are weaned at 2 weeks and reach maturity at 3-6 weeks, when they themselves may start breeding.

Sources of information and Picture credits

Reach 1991 given in: Talmage, S.S., 1990. Comparative evaluation of several small mammal species as monitors of heavymetals, radionuclides and selected organic compounds in the environment. (MF).

http://www.state.ak.us/local/akpages/FISH.GAME/notebook/smgame/voles.htm
http://animaldiversity.ummz.umich.edu/accounts/microtus/m._pennsylvanicus$media.html#photos

1.1.9 Reindeer (*Rangifer tarandus*)

Classification

Kingdom: *Animalia*
Phylum: *Vertebrata*
Class: *Mammalia*
Order: *Artiodactyla*
Family: *Cervidae*
Genus: *Rangifer*

General habits, habitat and home range

Reindeer are large herbivorous mammals. After calving, they collect in large "postcalving aggregations" to avoid predators and escape mosquitoes and warble flies. These large groups stay together in the high mountains and along seacoasts where wind and cool temperatures protect them from summer heat and insects. After the insect numbers decline in August, they scatter. Large herds often migrate long distances (up to 640 km, traveling up to 30km a day) between their summer and winter ranges. The migration is probably triggered by changing weather conditions, such as the onset of cold weather or snowstorms. Smaller herds may not migrate at all.

Dietary habits and main prey species

Reindeer are ruminants and are classified as a "concentrate selector" to "intermediate forager" which means they select higher quality forage. They must keep moving to find adequate food. In summer (May-September), they eat the leaves of willows, sedges, flowering tundra plants, and mushrooms to regain weight lost post calving. They switch to lichens (*Cladonia* spp.), sedges and small shrubs (e.g. blueberry) in September. In the spring they search for emerging buds, leaves and flowers of sedges and dig for rhizomes. They eat approximately 2.5kg d^{-1} (DM) of lichen from September to May and a little grass (0.3 kg d^{-1}) whereas from June to August approximately 2.5 kg d^{-1} (DM) of their diet comes from grass together with a little lichen (0.7 kg d^{-1}). Their main predators are wolves (*Canis lupus*), wolverines (*Gulo gulo*) and lynx (*Lynx lynx*). Brown bears *(Ursos arctos*), foxes (*Alopex vulpes*) and golden eagles (*Aquila chrysaetos*) also kill large numbers of new-born calves.

Birth weight, gestation period and general life cycle

Usually one calf is born after gestation period of 7½ months weighing approximately 6kg. If the female is in very good condition she can breed at 16 months old, but 28 months old is more typical. Most adult cows are pregnant every year and give birth to one calf, twins are very rare. Their average life-span is 4½ years, although some individuals may live to be 13.

Sources of information

Encyclopedia Britannica 2002,
ECOMARC (see Beresford *et al.*, 2003).
http://www.state.ak.us/local/akpages/FISH.GAME/notebook/biggame/caribou.htm

1.1.10 Red fox (*Vulpes vulpes*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Mammalia*
Order: *Carnivora*
Family: *Canidae*
Genus: *Vulpes*

General habits, habitat and home range

The red fox is a carnivorous mainly solitary mammal, primarily active at dusk and at night. Its preferred habitat is mixed farmland and woodland. The size of their territories depends on their habitat ranging from 0.2km^2 in urban areas up to 40km^2 in upland areas. Each territory is usually occupied by a fox family group (containing several adults in areas where there is a plentiful supply of food) and they remain in the same home range for life. Individuals and family groups have main earthen dens and often other emergency burrows in the home range. The same den is often used over a number of generations. Pathways throughout the home range connect the main den with other resting sites, favoured hunting grounds and food storage areas.

Dietary habits and main prey species

Red foxes have a very varied diet, usually foraging alone. They are opportunist feeders, catching food surplus to their requirements. In lowland rural areas, small mammals (especially field voles (*Microtus agrestris*) and rabbits (*Oryctolagus cuniculus*) are the major source of food along with earthworms, beetles, fruit (particularly blackberries) and small birds. On salt marshes, they eat crabs and dead seabirds, whilst in upland regions carrion can be important, particularly during winter. Daily food consumption is between 0.5- 1 kg per day (fresh weight).

Birth weight, gestation period and general life cycle

Usually only one vixen in a family group produces cubs; once a year in the spring. The gestation period is generally around 52 days, but ranges between 49 and 56 days. Litter size varies from 1-13 pups, the average is 5 with a range in birth weight of 100-130g. A vixen stays in the earth with her cubs for the first two weeks of their lives. At about four weeks old, usually in late April or early May, the cubs begin to come into the open. Their average life expectancy is between 3 and 6 years.

Sources of information and picture credits

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http://www.gov.nf.ca/snp/Animals/redfox.htm
http://www.floodlight-findings.com/2redfox/redfox.html

1.1.11 Arctic fox (*Alopex lagopus*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Mammalia*
Order: *Carnivora*
Family: *Canidae*
Genus: *Alopex*

General habits, habitat and home range

The arctic fox is an omnivorous burrowing mammal which does not hibernate. It is found in coastal and inland arctic and alpine tundra, in the arctic regions of Eurasia, North America, Greenland and Iceland. The species can be found in almost all Arctic areas, as far north less than 60 km from the North Pole at 89°40'N and including the islands of Iceland, Spitzbergen, Novaya Zemlya, Pribilof, Commander and Wrangel. Two subpopulations are endangered one found on the Commander Islands in Russia (*Alopex lagopus semenovi*) and the other found in Norway, Sweden, Finland and the Kola Peninsula. Their dens (made in either the ground or in snow) extend from 1.8-3.7m underground and can have between 4–250 entrances with a system of tunnels covering about 30m^2 and are used for both shelter and rearing young. Their home range can be between 8.6-18.5 km^2 and they are capable of migrating more than 1000km in a season and will travel over sea ice. During midwinter they lead a mostly solitary existence except when congregating to feed on the carcasses of marine mammals and *Rangifer tarandus* (reindeer).

Dietary habits and main prey species

Arctic foxes create a store of food over the summer which then freezes in the permafrost. Their diet varies greatly from one part of their range to another as they feed on whatever animal or vegetable material is available. In continental areas their main prey in summer are lemmings, voles and the carcasses of reindeer with only 5 – 10% of the diet composed of birds, eggs, ground squirrels, and berries. In winter, ptarmigans are important component of their diet and they will often follow polar bears to feed on the remains of their kills. They eat fish and carrion at any time of year. For an average litter of 11 whelps just starting to eat solid food, about 30 lemmings or the equivalent are required per day increasing to over 100 just before the whelps leave the den. The adults and young can therefore consume about 3,500 to 4,000 lemmings during the denning period. When lemmings are abundant the foxes hunt over an area of 2.5–5.0km^2 but when food is scarce they will range much further. Adult arctic foxes have few enemies although golden eagles (*Aquila chrysaetos*) may be a threat to young whelps at the den and both brown bears (*Ursos arctos)* and grey wolves (*Canis lupus*) are capable of digging whelps or adults from within their den.

Birth weight, gestation period and general life cycle

Arctic foxes reach sexual maturity at 9 to 10 months old and usually breed once a year between April and June. Their gestation period is about 52 days. The mean litter size is about 11; each with a birth weight about 57g. The whelps begin to emerge from the den when they are about 3 weeks old and begin to hunt and move away from the den at about 3 months old. They begin eating meat at about one month old and are fully weaned at 1½ months. The family units gradually break up during September and October although the same pairs may remain together on the same territory for up to five years. Juvenile mortality is often very high and many die in their first year. Adult mortality is around 50% per year. The average life span for animals that reach adulthood is around three years.

Sources of information and picture credits

Encyclopaedia Britannica 2002
http://www.cws-scf.ec.gc.ca/hww-fap/afox/arfox.html
http://www.state.ak.us/local/akpages/FISH.GAME/notebook/furbear/arcfox.htm
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http://www.muellerworld.com

1.1.12 Willow ptarmigan (*Lagopus lagopus*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Aves*
Order: *Galliformes*
Family: *Tretraonidae*
Genus: *Lagopus*

General habits, habitat and home range

Ptarmigan live in alpine and arctic tundra throughout the northern hemisphere, often near pools and, further south, in mountains above the tree line. They breed in Iceland and northern Scotland, thoughout most of northern Fenno-Scandia and the Kola Peninsula and also on Bear Island, Svalbard and Franz Josef Land. All the populations are resident but interruptions may occur in Arctic regions and there is some altitudinal movement. The extent of their autumnal movements varies, but migrations of 160-240km one way are probably the longest undertaken by any ptarmigans (in Alaska). They are nomadic from November to March, moving erratically from one sheltered slope or patch of food to another, usually feeding and roosting in the snow close together. In April and early May flocks numbering several thousand move back to their breeding/summering grounds where they rapidly dissipate as each cock demands his own space.

Dietary habits and main prey species

Ptarmigan survive winter in the Arctic and mountain-tops by browsing shrubs and scratching up lichens and leaves. They feed on the young shoots of *Vaccinium myrtillus* (billberry), *Empertrum nigrum* (crowberry) and *Calluna* spp. (heather spp). When snow covers the ground, they eat willow (*Salix* spp.) buds and twigs, and a little birch (*Betula* spp.). This diet lasts until spring, giving way as snow melts to a blend of insects, over-wintered berries, new leaves, and flowers. In summer the birds eat a mixture of vegetable matter and occasionally take advantage of caterpillars or beetles. Gradually, as insects disappear and plants become dormant, the diet turns increasingly to berries, seeds, and buds. By mid-October most ptarmigan (except those in coastal areas) are back to their winter diet. Their most important predator is the *Falco rusticolus* (gyrfalcon) but *Vulpes* spp. (fox) and *Nyctea scandica* (snowy owl) also prey upon them.

Birth weight, gestation period and general life cycle

In early spring, the male ptarmigan become intolerant of other males and establish territories which they defend vigorously. The mating season begins in late May or soon after the snow melts. The hens usually lay between 6 and 10 eggs which are incubated for three weeks in a nest on the ground. The chicks hatch in 2-3 weeks and leave nest immediately. They can get off the ground 9-10 days after hatching and begin to fly well when they get their first full set of flight feathers at 8-10 weeks of age. They are notorious for their fluctuating populations.

Sources of information and picture credits

Encyclopaedia Britannica 2002
http://www.state.ak.us./local/akpages/FISH.GAME/notebook/bird/ptarmiga.htm
http://www.vindelalven.se/turist/eng/Dalripa.shtml Håkan Jonsson

1.1.13 Bird egg - Red Grouse (*Lagopus lagopus scoticus*)

General information

Red grouse nest in a hollow in the ground, generally in open moorland. The eggs are yellowish white with rich dark chocolate or red brown blotches. The hen usually lays about six eggs, but can lay up to 17 and will spend approximately 20 days incubating them. Crows (*Corvus corone corone*) and stoats (*Mustela erminea*) are the most common predators of the eggs.

Sources of information and picture credits

Witherby, H.F., Jourdain, Rev. F.V.R., Ticehurst, N.F. and Tucker, B.W. The handbook of British Birds. Volume V. London: H.F. Witherby Ltd.

http://www.environmental-entomology.co.uk/birdsam3.html
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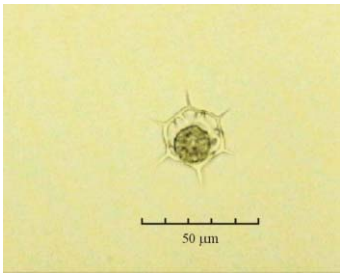
1.2 Marine representative species

1.2.1 Phytoplankton



Phytoplankton are the free drifting microscopic organisms that form the largest plant community in the oceans. Though normally existing in solitary form, they may form large chains or spherical shaped colonies, some large enough to see with the naked eye. These single celled organisms are the primary food source, directly or indirectly, of all sea organisms. Phytoplankton contain the pigment chlorophyll, which is used by plants for photosynthesis, in which sunlight is used as an energy source to fuse water molecules and carbon dioxide into carbohydrates—plant food. Because sunlight is most abundant at and near the sea surface, phytoplankton remain at or near the surface.

Diatoms and Dinoflagellates form the main groups of phytoplankton inhabiting the Arctic Ocean, where the bottom surface of the ice, the ice-water interface and the water column form distinct habitats, which are colonized by different taxonomic assemblages. It is stated that pennate diatoms are dominant in the bottom ice, centric diatoms at the ice-water interface and flagellates in the ice-covered water column. The biomass and production in the sea ice are generally dominated by large algal cells (> 5µm) while the under-ice water column is dominated by small algal cells (0.7-5µm).
Phytoplankton varies seasonally in amount, increasing in spring and Autumn with favourable light, temperature, and minerals.
Phytoplankton's reproduction occurs both sexually and asexually. While their asexual reproduction is based on binary fission, cell fusion forms the basis of sexual reproduction.

Sources of information and picture credits

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Encyclopædia Britannica 2003 Encyclopædia Britannica Online. 06 Feb, 2003 <http://search.eb.com/eb/article?eu=61384>.
http://www.marine.ie/scientific+services/monitoring/phytoplankton/
http://www.nodc.noaa.gov/OC5/BARPLANK/WWW/HTML/allphoto.html

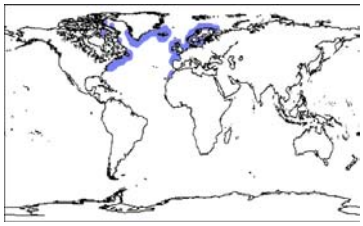
1.2.2 Bladder wrack (*Fucus Vesiculosus*)

Classification

Kingdom: *Protista*
Phylum: *Chromophycota*
Class: *Phaeophyceae*
Order: *Fucales*
Family: *Fucacea*
Genus: *Fucus*

Geographical distribution and habitat

The bladder wrack, *Fucus vesciculosus*, is a large brown algae, common on the middle shore. It is found in high densities and fronds grow up to 2 metres long, living for about three years. The species is found intertidally on rocky shores in a wide range of exposures. It provides substrate and shelter for herbivorous isopods and surface grazing snails.



It is found in the Baltic Sea, Norway, Britain, Ireland, Atlantic coast of France, Spain and Morocco, Iceland, Greenland and the eastern shores of United States and Canada.

The morphology of the plant varies in response to the environmental conditions leading to distinct varieties. Plants from exposed locations usually have no airbladders and are known as *Fucus vesiculosus* forma *linearis*. The loss of airbladders is thought to be because they increase a plant's drag, making them more vulnerable to being washed off by waves. Depth is not relevant as the plant is intertidal although it does occur at shallow depths in the Baltic.

No conducting tissue is found in *Fucus spp*.; it is unnecessary as the plant is small enough to be able to manufacture food locally.

Reproduction

These brown algae have a gametic life cycle. That is, the products of meiosis are gametes. Gamete production takes place in specialised crypt-like structures called *conceptacles* which are borne in fertile, swollen areas at the tips of the plants called *receptacles*. Some species are monoecious with both sexes occurring on one plant; others are dioecious with each sex being found on different plants. Some monoecious species may have both sexes in one conceptacle whilst others may have them in separate conceptacles.

The species is highly fecund often bearing more than 1000 receptacles on each plant, which may produce in excess of one million eggs. Development of the receptacles takes three months from initiation until when gametes are released. On British Shores receptacles are initiated around December and may be present on the plant till late summer. Gametes may be produced from mid winter until late summer with a peak of fertility in May and June.

Eggs and sperm are released into the seawater and fertilised externally. Zygotes settle to the seabed and begin development wherever they fall. The egg becomes attached to the rock within a few hours of settlement and may adhere firmly enough to resist removal by the next returning tide.

Size at maturity is 15-20 cm. *Fucus vesiculosus* is used in cosmetic preparations and in thalassotherapy.

Sources of information and picture credits

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http://www.seaweed.ie/descriptions/fucves.html
http://www.horta.uac.pt/species/Algae/Fucus_vesiculosus/Fucus_vesiculosus.htm

1.2.3 Northern shrimp (*Pandalus borealis*)

Classification

Kingdom: *Animalia*
Phylum: *Crustacea*
Class: *Malacostraca*
Order: *Decapoda*
Family: *Pandalidae*
Genus: *Pandalus*

Geographical distribution and habitat

Pandalus borealis, the northern shrimp, is a very important commercial product. It is one of the most common and numerous of invertebrate species in the Atlantic, from the North Sea to Spitsbergen, Iceland, along the shores of Newfoundland and Greenland, and in the Pacific Ocean, from the Japan Sea and British Columbia to the Bering Sea.*P. borealis* is most common over a soft mud bottom. Its bathymetric range is from 9 to 1380 m but fishable concentrations normally occur between 54 and 400 m. There is a direct relationship between abundance of this shrimp and high organic content in sediment. This shrimp exhibits migratory behaviour, inshore-offshore migrations, which are related to seasonal and inshore-offshore temperature differences. Both the distribution and migratory behaviour of northern shrimp change with age. Adult shrimps tolerate water temperatures from -1.68 to 11.13˚C, whereas larvae may live at 14˚C. Both larvae and adults have been found at salinities from 25.9 to 35.7 per cent.

Feeding behaviour

The diet of *P. borealis* is obtained from the plankton as well as from the benthos. The shrimp feed on euphausiacea, copepods, mysids, decapod larvae, harpacticids, isopods, tanaidaceans, cumaceans and benthic amphipods. The polychaetes are second in importance to the crustaceans in terms of the number of species consumed. The spectrum of food organisms is determined essentially by the prey available, the time of day, and the developmental stage of the shrimp. Following stomach investigations it has been reported that the shrimps have a nocturnal activity phase during which they mainly feed on plankton. On the other hand, there is also a diurnal activity phase during which benthic species are consumed, and the stomachs are filled to a maximum degree in the afternoon. The males feed on plankton in the pelagic zone more actively than do females. In its habitat, *P. borealis* is eaten by large fish such as dogfish, Greenland halibut, turbot, and hake.

Sex change, spawning and hatching

Pandalus borealis is a protandric hermaphrodite, which reproduce first as male and subsequently changes into female and spawn as such for the rest of its life. Temperature plays a significant role in determining the time (age) of sex change. Over its geographic range, the northern shrimp has different seasons of spawning and hatching, and water temperature appears to be the controlling factor. In southern Norway, where mean annual bottom temperature is about 7˚C, spawning take place in October and November and hatching of eggs in March and April, for an ovigerous period of between five and six months. Upper north in Norway (Ofoten and Mist Fjords), where mean annual bottom temperature is about 5˚ C, spawning occurs in September and October and hatching in April and May. In the far northern areas (Spitsbergen, Jan Mayan, western Greenland), having mean temperatures of 1˚C or less, the ovigerous period (including spawning and hatching periods) may begin as early as July or August and last 10 to 12 months. The life span of *P. borealis* range from 3 to over 8 years in various locations in the Atlantic and its length can reach up to 120 mm or larger. In high latitudes and at colder ambient temperatures the growth rate is slower, the life span and ovigerous period longer and age at sex changes later.

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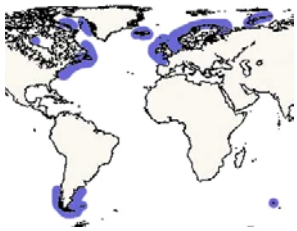
1.2.4 Blue mussel (*Mytilus edulis*)

Classification

Kingdom: *Animalia*
Phylum: *Mollusca*
Class: *Pelecypoda*
Order: *Mytiloida*
Family: *Mytilidae*
Genus: *Mytilus*

Geographical distribution and habitat

The blue mussel, *Mytilus edulis,* is a semi-sessile epibenthic bivalve that is anchored to a secure substrate, or attached to other mussels, with byssus threads secreted from glands in the animal's foot. As a gregarious organism it (at high densities) forms dense beds of one or more (up to 5 or 6) layers. It is found intertidally and subtidally, in estuarine and fully saline habitats.



M. edulis is widely distributed in the northern hemisphere; it occurs in European waters extending from the arctic waters of the White Sea and northern Norway southwards to as far south as the Atlantic coast of southern France. In the W. Atlantic it extends from the Canadian Maritimes south to North Carolina. It occurs on the coasts of Chile, Argentina, the Falkland Islands and the Kerguelen Isles. *Mytilus edulis* has been reported from Iceland.

Dietary habits and predators

The blue mussel, both as a planktotrophic larva and as an adult, is an active suspension feeder, deriving its nutrition by filtering organic particles from the water column. Phytoplankton cells are the dominant food source for all life stages. Attached bacteria are a major source of protein in detritus, and there is evidence that adult blue mussels can digest bacteria. Both larvae and adults use cilia to remove food particles from suspension. The mussel is capable of removing particles down to 2-3 µm with 80-100% efficiency and shows a great range of adaptations to changing conditions, including the ability of adjusting its filtration rate to maintain a complex balance between the amount of material filtered, the amount rejected as pseudofeces, and the amount ingested.

Predation pressure on the blue mussel is highest during the 3 weeks when it is a planktonic larva, for it is then subject to grazing from a wide variety of species, ranging from jellyfish to larval and adult fishes. The vulnerability of mussels decreases as they grow and attain relatively large and thick shell (4-5 cm). They may then be preyed upon by predators such as large starfish, large crustaceans, and some birds.

Life history

Mussels generally produce gametes and are ready to spawn by the time they are one year old; however, when adverse environmental conditions (e.g., prolonged periods of exposure to air) cause a slow rate of growth, sexual maturity is sometimes not attained until the second year. Gametogenesis, spawning, and nutrient storage are linked in an integral process termed the reproductive cycle. This cycle in any blue mussel population is the result of a complex balance between exogenous factors such as food availability, temperature, salinity, and duration of exposure to air and endogenous factors such as nutrient reserves, hormonal cycle, and genotype. Thus, it is impossible to predict the timing of the reproductive cycle for any particular population except for environments in which variations in physical factors are not large. In general, mussels from the warmer more southerly waters of the northern hemisphere spawn earlier than those further north.

Fertilization is external. Fecundity and reproductive effort increase with age and size, young mussels diverting energy to rapid growth rather than reproduction. An individual female (ca 7mm) can produce 7-8 million eggs, while larger individuals may produce as many as 40 million eggs.

Larval development

The stages of larval development and their durations are summarized in Table below, simplified version. It must be emphasized that the larval stage may last anywhere from 15 to 35 days and that the duration is dependent on prevailing environmental conditions.

Life stages and characteristics of the blue mussel (Bayne 1976b)

Stage	*Size (length)*	*Age and characteristics*
Fertilized egg	68-70 µm	0-5 h Non motile
Trochophore	70-110 µm	5-24 h Ciliated and motile.
Veliger		Up to 35 days; Feeds and swims with ciliated velum.
Plantigrade	0.26-1.5 mm	Up to 6 months; temporarily attached to filamentous substrates.
Juvenile		Up to 2 years; sexually immature.
Adult	Up to 100 mm	Up to 20 years; sexually mature.

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Image: Keith Hiscock (published on the Marlin Web site)

1.2.5 Worm - Blow lug (*Arenicola marina*)

Classification

Kingdom: *Animalia*
Phylum: *Annelida*
Class: *Polychaeta*
Order: *Capitellida*
Family: *Arenicolidae*
Genus: *Arenicola*

Geographical distribution and habitat

Lugworms are burrow-dwelling annelid worms, and can reach densities as high as 100-150 per square metre in certain areas. They live in U or J-shaped burrows (20-40cm deep) with characteristic depressions at the head end (the 'blow hole') and a cast of defaecated sediment at the tail end. These worms can make up to 30% of the biomass of an average sandy beach, making them a very important part of the food web of these beaches. They bioturbate the sand and are food for a wide variety of other animals such as flatfish and wading birds, which may 'nip' off the tail as it deposits casts.Population density is correlated with mean particle size and organic content of the sediment. Arenicola marina is generally absent from sediments with a mean particle size of <80µm and abundance declines in sediments >200µm (fine sand) because they can not ingest large particles. Its absence from more fluid muddy sediments is probably because they do not produce large amounts of mucus with which to stabilise their burrows. Populations are greatest in sands of mean particle size of 100µm. Between 100-200µm the biomass of *Arenicola marina* increases with increasing organic content. However, juveniles prefer medium particle sizes (ca. 250 µm) over fine or coarse sand. Lugworms have a wide distribution and are found in shores of Western Europe, Spitzbergen, north Siberia, and Iceland. In the western Atlantic it has been recorded from Greenland, along the northern coast form the Bay of Fundy to Long Island. Its southern limit is about 40° N.

Feeding behaviour

It has been observed that the lugworms show a pronounced preference for small particles. This is ascribed to a difference in chance of adhesion of small and large particles to the papillae of the proboscis. *Arenicola marina* ingests small particles (<2mm) which stick to the proboscis papillae while larger particles are rejected. It feeds on micro-organisms (bacteria), meiofauna and benthic diatoms in the sediment and is also capable of absorbing dissolved organic matter (DOM) such as fatty acids through the body wall. Feeding, defaecation and burrow irrigation is cyclic. Each cycle takes about 42 minutes in large worms but 15 min in smaller worms, depending on individual. Each cycle consists of defaecation (worm mainly in the tail-shaft), followed by rapid irrigation and a longer period of feeding, after which the worm defaecates again and the cycle repeats.

Reproduction

Lugworms have separate sexes with external fertilization and an annual episodic breeding frequency; their spawning is highly synchronized and usually occurs on only one or two days a year over a two week period in October to November. The exact timing of spawning varies between locations and some populations demonstrate protracted spawning. *Arenicola marina* is sexually mature at 1-2 years. While the number of eggs can varies between 100,000-1,000,000 the average number of oocytes is reported to be 316,000 oocytes per female, with an average wet weight of 4 g.

Spawning occurs at low tide, and as the tide comes in, the viscous sperm puddles are washed, diluted and enter the burrows of the females. The sperm puddles contain inactive sperm, the addition of seawater triggers them to become active and begin swimming. Fertilization occurs in the female burrow and after four to five days the larva hatches, 0.24 mm long. The larvae undergo early development here, later moving to the surface to be transported by the tide to settle on firmer areas. They then develop in mucous tubes attached to the substratum. Once developed, the worms are carried

by the tide to more sandy/mud sediments where they can burrow.

Adults reach between 120 -200mm in length and vary in colour from pink to dark pink, red, green, dark brown or black. The suggested life span is 5-10 years. *Arenicola marina* is used routinely as a standard bioassay organism for assessing the toxicity of marine sediments.

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Image: Dr. Matt Bentley (published on the MarLIN Web site)
http://www.marinebio.com

1.2.6 European lobster (*Homarus Gammarus*)

Classification

Kingdom: *Animalia*
Phylum: *Arthropoda*
Class: *Malacostraca*
Order: *Pleocyemata*
Family: *Nephropidae*
Genus: *Homarus*

Geographical distribution and habitat

The European lobster is found in the eastern Atlantic from northern Norway (Lofotoen Islands) to south-eastern Sweden and Denmark, where it is apparently blocked from inhabiting the Baltic Sea by lowered salinity and temperature extremes. Its distribution extends southward along the mainland European coast and around the Great Britain and the Azores, to a southern limit of about 30˚ north latitude on the Atlantic coast of Morocco. This species also occurs, though less abundantly, in the north-western regions of the Black Sea and in the coastal and island areas of the Mediterranean Sea and its subseas. The European lobster generally selects or excavates shelter on rocky or stony bottoms where the substrate is sand or gravel. Juveniles and adults dig out hollows or tunnels under the boulders or stones with one or more openings, using the hollows as hiding places. It is found from very shallow water to the depth of 150 meters, but is more common at depth of 10-60 meters. Marking and recapturing experiments off Ireland, Scotland, and Norway suggest that the European lobster does not undertake extensive migrations alongshore or inshore-offshore. Maximum distances travelled were 8-12 km, with an average of approximately 2 km.

Dietary habits and predators

Reported observations indicate that the European lobster hides during the day within its shelter and forages for food at night. Like the American lobster, a larger percentage (60-70%) of the population leaves their shelter during the summer and fall than during the winter. Lobsters normally do not feed in the winter, but remain in their shelters when the water temperature falls below 5˚ C. Investigations of the feeding behaviour and diet of the European lobster off the west coast of Sweden indicated that the major food items consumed were crabs, gastropods, polychaetes, with mussels and starfish comprising a minor portion of the diet. During the molting season lobsters ate a lot of calcareous material. Berried females had the same feeding behaviour and diet as other lobsters. Small lobsters preferred polychaetes, small crabs, and gastropods. The major predators on the juvenile lobster are sculpin, cunner, tautog, black sea bass, and sea raven.

Life history

New lobster life begins as thousands (5000-20000) of fertilized eggs, about 1 mm in diameter, are pushed out of the female's oviducts. The embryos travel along the underside of their mother's abdomen until they reach the pleopods, where they attach and remain for the next nine to eleven months. The incubation period of the eggs is highly variable and temperature dependent. Fully developed embryos hatch as pre-larvae. On their way toward the surface waters, they molt into the first larval stage. Lobsters have three distinct planktonic larval stages with a total duration of 3-6 weeks. Metamorphosis from the larval to a postlarval stage occurs at the fourth molt. These postlarvae lobsters move downward to the sea bottom and start a benthic life.Adulthood is reached after five to eight years, depending largely on the water temperature. The lobsters mate when the female changes her shell. The spawning period for European lobster begins early in July and extends into September. The European lobster can exceed 5kg in weight and 1m in length. They are solitary creatures with a potential lifespan of 30 years.

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1.2.7 Arctic cod (*Boreogadus saida*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Actinopterygii*
Order: *Gadiformes*
Family: *Gadidea*
Genus: *Boreogadus*

Geographical distribution and habitat

Arctic cod or polar cod form (present) an essential component of the arctic food chain in the diet of marine mammals and sea birds. They have a circumpolar distribution and are found further north than any other fish species (84° 42' N)!

These are pelagic fish which thrive in water temperatures below 5° C and range from nearshore regions along the coast to well out at sea, and from the surface, often in the drift ice and along the edge of the pack ice, to as deep as 900 m.

Migration patterns are unknown, except for prespawning migration to nearshore waters in the autumn. The Barents Sea stock also undertakes winter mass migrations into the White Sea for spawning.

Dietary habits and main prey species

Arctic cod is major link in the transfer of energy from the zooplankton to the top level carnivores. Both the larvae and the adult fish feed on planktonic organisms. they are the main consumers of plankton in the upper water column (unlike their relatives the Atlantic cod, which feed on the bottom). As they grow, they graduate from a diet of copepod eggs and larvae to adult copepods and amphipods and finally, after reaching a length of 12 cm, they feed on arrow worms, adult copepods, amphipods and may even become cannibalistic. The dietary importance and proportions of the major groups pf prey are based on prey availability. For example, the food of some of the specimens examined in the White Sea consisted exclusively of young shrimp.

These fish are the primary food source for sea birds such as murres, guillemots, and kittiwakes; fish, including arctic char and plaice; harp and ringed seals; and narwhal and beluga whales.

Reproduction

Arctic cod spawns once in its lifetime. The spawning season extends from late November to early February in the Beaufort Sea, from end of December to February in Russian waters, and from January to February (sometimes April) in the White Sea. At spawning time, females produce 9 000 to 21 000 eggs that are only 1.5 mm in diameter, on average 11900 eggs per female.

Although spawning occurs in the coastal areas of the Beaufort Sea and under the shore ice of the White and Barents Seas, the relative importance of nearshore sites compared with regions farther offshore for spawning remains unknown.

Much is unknown about the larval and juvenile life of arctic cod. They have a rather slow growth; attain a length of 3 cm at the first year of their life, 14-16 cm at the second year, 19-20 cm at the third year and when they are sexually mature, usually at the age of 4, they are 21-23 cm long. In the Beaufort Sea, most mature males are 2 to 3 years old, whereas most mature females are 3 years old. These ages at first maturity are similar to those reported for the northwest Atlantic and Russian stock. In

Cheshskaya Bay (White Sea), sexual maturity occurs in the 4th to 5th year of life. A predominance of females among older fish is reported in most populations of arctic cod (74% females in populations of 3 to 6 years old fish).

Arctic cod have a short life span of only 6-7 years with a common length of 25 cm. the maximum length is 40 cm. Scientists can determine the age of an arctic cod by counting annual rings of growth on tiny bones in the ear, like counting the rings of a tree.

Sources of information and picture credits

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1.2.8 Atlantic cod (*Gadus morhua*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Teleostei*
Order: *Gadiformes*
Family: *Gadidea*
Genus: *Gadus*

Geographical distribution, habitat and general habits

Atlantic cod is a marine demersal fish that inhabits cool-temperate to subarctic waters from the shoreline to well down the continental shelf, to depths over 600 m, but mostly found within the continental shelf areas from 150-200 m. It lives in almost every salinity from nearly fresh to full oceanic water. Like the herring cod also form races with different spawning habits, rates of growth and preferred areas. The most important stocks are oceanic, migratory fish which undertake extensive spawning and feeding migrations. They are distributed over the North Atlantic Ocean, ranging from the middle United States to Baffin Island on the west, to Northern Europe, the North Sea, the Baltic Sea and as far east and north as the Kara Sea. Within this total population there are several recognized cod stocks that do not appear to intermingle. These are found around Newfoundland, The Faeroes, in the North Sea, the Baltic Sea, along the Norwegian Coast and adjacent Barents Sea, and between Iceland and Greenland. In addition to these large, migratory stocks, there are also local, stationary races which always remain close to inshore.

The eggs and larvae of cod from different races all appear to drift to their respective nursery areas but once the larvae sink to the bottom where feeding continues, energy must be expended in maintaining position against the current. Adults may migrate distances of up to 200 miles or more to their breeding grounds. During the long spawning and feeding migrations of the adults there is evidence that the shoals travel with suitable currents often in depths of 300 – 400m. Juvenile cod, or codling, do not make such extensive migrations, although to the south of their range they approach the coast and move southwards with wintertime cooling of the sea, and make an offshore and northward migration in spring.

Dietary habits and main prey species

The Atlantic cod is a voracious and omnivorous species. Its diet may vary considerably for different areas and from year to year based on availability of prey species. Larvae and postlarvea feed on plankton, juveniles mainly on invertebrates (copepods, amphipods, crustaceans, and crabs), and older fish on invertebrates and fish (redfish, capelin, herring, cod). Small crustaceans are of outstanding importance (90%) in the food of juveniles (up to 25 cm length). They are progressively replaced by decapods of medium and large size. Fish become more important than crustaceans in the diet of older individuals. Other systematic groups play a smaller role as forage organisms: polychaetes (less than 10%); echinoderms and other benthic organisms (minor quantities); and occasionally seaweeds (Irish moss – Chondrus crispus) and others. While the proportion of benthic organisms shows hardly any change throughout the year, fish consumption varies seasonally. Deep-water cod show preference for herring throughout the summer and autumn (peak June-July), but in winter and during the spawning period, they sustain themselves on mixed food in coastal areas. Cannibalism is prevalent within this species, with larger cod eating smaller cod. Feeding occurs at dawn and dusk, but small fish (of less than 20 cm) feed continuously. Cod is preyed on by seals and minke whales.

Life history

Cod usually spawn from February to June in cold water, 4-6˚C, near the bottom or further up in the water column. Females spawn over a period of several days and the number of eggs laid varies, according to the size of the female, between 500,000 and 7 million. Fertilized eggs which are about 1.4

mm in diameter are distributed in the upper 100m of the ocean and hatch, at a length of about 4 mm, in 2-4 weeks, depending on water temperature. Up to six months following hatching the young cod are found in midwater feeding on zooplankton, particularly copepods. Descent from the water column to bottom habitats occurs at sizes of 2.5-6 cm (Fahay 1983; Lough et al. 1989). During this stage they feed on benthic organisms such as certain crustaceans and may possibly migrate to shallow inshore waters during the summer and return to deeper waters in the winter much in the same way as do young herring. They increase to 8cm in the first six months, and to between 14-18cm by the end of their first year. As the cod grow they change their diet to small pelagic fish and some crustaceans. At this stage they may then join mature fish of the same race and start a migration circuit. These fish may complete an entire circuit before spawning. Depending on the race of cod, spawning may occur at an age of 5-15 years. Having spawned once, they continue to respawn annually for many years.

Progeny from adults spawning off the southwest shores of Iceland can drift to different locations and complete different migration circuits before spawning. However, there is evidence that some fish can complete one circuit and then make another different circuit during a second migration.

Cod that spawn along the Norwegian coast migrate north in April and spend the summer in the north and east parts of the Barents Sea. In the fall these fish move south and west to winter off the coast of Norway and eventually spawn near the coast on early spring. The young of these fish drift to the nursery areas which are in the northern part of the Barents Sea.

Cod are relatively long living and can reach a maximum of about 20 years of age. The growth rate is rather high, the females growing slightly faster than the males. Three-year-old fish average 56 cm (males) and 59 cm (females); 5-year olds, 81 cm (males) and 85 cm (females). The largest fish are found in colder water.

Sources of information and picture credits

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1.2.9 Plaice (*Pleuronectes platessa*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Actinopterygii*
Order: *Pleuronectiformes*
Family: *Pleuronectidae*
Genus: *Pleuronectes*

Geographical distribution and habitat

The plaice is one of the most economically important flatfish in Europe. It inhabits most of the shallow coastal waters of Northern Europe. It is found as far north as Iceland and The Faeroes and south along the coasts of France, Spain and Portugal with specimens being recorded in the Mediterranean Sea. They are found in the Irish Sea in the west and extend east to the North Sea, Baltic Sea and as far as the White Sea off the northwest coast of Russia. There appear to be distinct stocks of plaice near the Murman coast, Iceland, The Faeroes and in the Baltic Sea, each with its own migration pattern.

The plaice lives on sandy and muddy bottoms from the shoreline and to a depth of about 200 metres. Most adults are found at depths of 10-50 metres, while the young are almost exclusively found in shallower water. In the autumn, when the young are 7-12 cm, they wander into deeper water to pass the winter. These observations have been expressed as a law wherein size increases with distance from shore (and depth), while numbers decline.

Dietary habits and main prey species

As larvae they feed on the microscopic larvae of worms and gastropods and as young they feed mainly on small worms and crustaceans, but with increasing age they start to take larger food animals; by autumn they are eating larger bristle-worms, sand hoppers and thinshelled bivalves, which also form the principal diet of the adults; they are then about 7-12 cm long and move slowly into deeper water for the winter. During the winter the plaice´s food consumption is reduced and it is not until spring that the young fish move back again to their feeding grounds in shallow water.

Reproduction and general life cycle

As with most fish, the breeding cycle of plaice is temperature dependent. Spawning takes place at temperatures of about 6°C, in the western Baltic from November to June in depths of 69-90 metres, in the North Sea from January until June in depths of 20-40 metres. The main spawning grounds for North Sea plaice are south of Dogger Bank. Off Iceland the plaice spawns in March-April, in the Barents Sea from March to May, partly in depths of 160-200 m at a temperature of only 2-2.5°C, and partly also in shallower water.
The female, depending on her size, lays between 50000 and 520000 eggs. The eggs have a diameter of 1.6 mm and are shed and fertilized above the sea bed in areas of sufficient salinity for them to float. The eggs hatch in 2-4 weeks, according to the temperature, the colder the later. The newly hatched larvae are 6 mm long and look like normal round fish living in a pelagic state. 1-2 months later, when they are about 10 mm long, they start their transformation to a bottom living fish. The left eye wanders up over the head and the young start swimming on their left side. When they reach 12-14 mm in length

they abandon their pelagic lifestyle and move to shallower coastal waters. It can take 2-3 years before they move to deeper water. In the North Sea the males reach sexual maturity in their 3rd- 4th year at a length of 18-26 cm, the females in the 6th year at a length of about 35 cm, but in the Barents Sea the males in their 6th-9th year (30-40 cm) and the females in their 7th-13th year (34-47 cm). Age at maturity depends on water temperature. The colder the water, the later the fish matures.
Plaice can grow very large, up to 1m in length, average length 25-40 cm. The largest plaice caught weighed 7kg. They are also very long lived and can survive to 50 years of age. Females grow faster and live longer than males.

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1.2.10 Herring gull (*Larus argentatus*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Aves*
Order: *Charadriiformes*
Family: Laridae
Genus: *Larus*

General habits and geographical distribution

Herring gulls have a wide geographical distribution through the northern hemisphere, with three main centers: north-west Europe, Arctic Russia, and the northern part of North America. In the Arctic, these birds inhabit islands and coastal area of the Arctic Ocean. The race L.a.argentatus breeds from Denmark, through Scandinavia to the White Sea and Kola Peninsula. Birds breeding elsewhere in Europe belong to the race L.a.argenteus. In Europe, populations of herring gulls increased during the recent decades. Herring gull breeds in a wide variety of habitats including rocky outcrops, small islands, beaches, steep cliffs, buildings, etc.

Dietary habits

Herring gulls are mixed-feeding birds. They eat fish, shrimps, prawns, crabs, small mammals and birds, eggs, grain, carrion and edible rubbish.

General life cycle

The Herring gull is largely a coastal breeder, although in Finland and north-western Russia it has an extensive inland breeding distribution. Nestling of herring gulls occur from April to July. Female gull produces 2 – 4 eggs (3 eggs on average). The eggs are laid on alternate days so that the young hatch at 2 day intervals. The eggs are incubated by both parents for 28-30 days. The chicks, which are covered in grey down with dark blotches, are fed by both parents on regurgitated food. To obtain a meal they peck at the red spot on the parent's bill.

Fledging takes place at the age of 35- 42 days and for the first year of their life their feathers are speckled brown. They do not develop the full adult plumage for several years.

The Herring gull becomes sexually mature at the age of 4 – 5 years. Its length and weight varies between 53 – 66 cm and 690 – 1495 g, respectively. They are relatively long living and can reach a maximum of about 31 years of age.

Herring gull is one of the most numerous of the larger gulls breeding in Europe. In the Arctic, numbers of herring gulls breeding on the coasts of the Barents and White Seas are estimated to be about 100,000-200,000. The world population is probably almost 2 million pairs.

Sources of information and picture credits

http://wildspace.ec.gc.ca/life.cfm?ID=HERG&Page=More&Lang=e
http://www.yptenc.org.uk/docs/factsheets/animal_facts/herring_gull.html

1.2.11 Harp Seal (*Phoca groenlandica*)

Classification

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Mammalia*
Order: *Carnivorora*
Family: *Phocidae*
Genus: *Phoca*

General habits, habitat and home range

Harp seals are the third most abundant seal in the world and probably the most commercially important ones. They inhabit the North Atlantic and Arctic Oceans from northern Russia, to Newfoundland and the Gulf of St. Lawrence, Canada. Harp seals are separated into three populations based on where they breed; the White Sea north of the Russia, the "West Ice" near Jan Mayen Island southeast of Spitsbergen, Norway, and off Newfoundland. The last population is divided into two herds, one breeding on the southward drifting Arctic pack ice off Southern Labrador (called the "Front" sub-population) and the other breeding on ice in the Gulf of St. Lawrence near the Magdalen Islands (called the "Gulf" sub-population). In years of negligible ice in the Southern Gulf, some seals that would normally have whelped (given birth) there reproduced instead on the Labrador ice floes. In spite of the evidence of mixing between the sub-populations, there is a consistent difference of about 5 days in the dates of whelping between the two areas. From recent marking studies and blood protein analyses, it now seems likely that these sub-populations do interbreed. The difference in birth dates of pups between the two areas appears to be the result of environmental differences. The survival of a harp seal pup during its first two weeks depends upon the availability of stable habitat. At the Front, heavy Arctic ice provides this stability until late March or early April. In the Gulf, the ice usually begins to disappear by mid-March and for the pup to survive, it must be born earlier than at the Front.

Harp seals are highly gregarious marine mammals, hauling themselves out of the water on to the ice in dense herds to bear their young, to mate and to moult. They also migrate and feed in loose herds of up to several hundred individuals. Harp seals are closely associated with pack ice. During spring, they migrate north following the receding pack ice. Herds that breed in the Gulf of St. Lawrence migrate north to Hudson Bay, Davis Strait, and Baffin Bay. The breeding population that congregates in the White Sea off the coast of Russia, and the population that pups mainly between Jan Mayan and Svalbard, move to ice patches north of the breeding areas which include the northern Barents and Kara Seas north of Svalbard, Franz Josef Land, and Severnaya Zemlya. Animals that reach the maximum extent of the range may migrate as far as 5000 km. The southward migration begins just ahead of the formation of new Arctic ice and involves all adults and most juveniles. Some immature seals spend much of the winter in the Arctic, as tagged seals have been recorded at West Greenland in all months. All three populations exhibit similar patterns of annual migration, although the timing of specific events such as pupping, varies slightly from place to place.

Dietary habits and main prey species

Harp seals consume a wide range of prey species and their diet appears to vary with age, season, location and year. They feed primarily on small marine fish and secondarily on crustacean macroplankton. Pups feed on crustaceans, mainly krill and amphipods of the genus themisto. The diet of older harp seals also comprises krill and themisto, but in addition, is characterized by substantial amounts of fish such as Arctic cod, Atlantic cod, capelin, and herring [AMAP, P. 133]. Young seals feed in the surface waters while adult harps dive deeper for cod and herring. They are reported to be capable of diving to depths of 100 to 150 fathoms (1 fathom = 1.83 m) and remain submerged for up to 15 minutes. One seal consumes about 450 kg of fish annually, cod being their most important food. Intense feeding occurs during summer and winter while less feeding occurs during spring and fall migration, whelping and moulting.

The few predators that take harp seals are polar bears, killer whales, sharks and humans. Other causes of mortality are decreases in food by large scale capelin fisheries, discarded netting, and oil pollution.

Natural history (Birth weight, gestation period and general life cycle)

In late September when new Arctic ice is forming, the seals start their journey southward. During January and February seals disperse widely and feed intensively. Huge amounts of energy in the form of blubber are accumulated during this time. This is particularly important for pregnant females, for they need this energy to support the enormous demands of their rapidly growing offspring during lactation.

Pregnant females give birth several days after they have hauled out onto the winter pack ice in late February or early March. Newborn pups are about 85 cm long, weigh about 11 kg and are yellowish in colour. In about 3 days the fur turns to a fluffy white from which the pups derive the name "whitecoats". Young harp seals rank among the fastest growing and most precocious of young mammals. They are nursed for about 12 days and then abandoned by their mothers. During this period pups nurse for periods of about 10 minutes six or seven times a day and they more than triple their weight on milk which contains up to 45% fat (compared to 4% for cow's milk). When weaned, pups weigh an average of 35 kg. More than half of this weight is fat in the form of blubber.

After the pups are abandoned by their mothers, they begin to lose weight and to moult their white coats. After about 18 days this coat is completely shed and is replaced with a short silvery one. Harp seal pups fast for four to five weeks following weaning during which they lose about 10 kg of body weight. Most likely the fast is necessary to provide the pup with time to develop the behavioural and physical abilities that are necessary for efficient foraging by these young mammals.
As soon as females have finished nursing but before they leave the "whelping patch", they are courted by males which have been waiting nearby in large herds. Mating appears to be promiscuous and may occur either in the water or on the ice. Males reach maturity at 7 or 8 years of age. The females come into breeding condition annually about two weeks after their pups are born, when nursing has ended. The gestation period is approximately 11.5 months. However, there is a period of about 3 months during which the development of the embryo is suspended. This delay in the growth of the embryo serves to ensure that pups are born at the same time each year. Usually only a single pup is born each year, but twins have been recorded. Females generally mature at between 4 and 6 years of age. Males are only slightly larger than females; the average length (from the nose to the tip of the tail) of adult males is 169 cm, and of adult females 162 cm. Weight ranges from 85 to 180 kg depending on time of year. Harp seals live up to 40 years of age.

Each year, beginning in early April, harp seals moult. Adult males and immatures, called "bedlamers", moult first, followed by adult females, which start to moult about the third week of April. During the approximately 4 weeks of moulting, harp seals rarely feed and as a result lose more than 20 % of their body weight mainly in the form of fat. After they have moulted, adults and immatures migrate to their summer feeding grounds in the Arctic, thus completing their annual cycle.

Sources of information and picture credits

AMAP (1998). Assessment report: Arctic Pollution Issues

http://www.nwtwildlife.rwed.gov.nt.ca/NWTwildlife/seals/harpseal.htm
http://www.ncr.dfo.ca/zone/underwater_sous-marin/hseal/harpseal.htm
http://www.stemnet.nf.ca/CITE/harp_seals.htm

APPENDIX 2: Weighted DCFs for reference organisms

2.1 Pelagic planktotrophic fish

Table A2.1.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Pelagic	Polar cod (*Boreogadus saida*)	15 × 3 × 1.5	ellipsoid

Table A2.1.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
Sr-90	9.77E-07	1.29E-11
Y-90	3.98E-06	7.39E-10
Tc-99	5.10E-07	3.86E-13
I-129	3.38E-07	1.06E-10
I-131	9.95E-07	1.88E-09
Cs-137	1.29E-06	2.80E-09
Cs-134	1.03E-06	7.65E-09
Pu-239	2.64E-04	2.56E-13
Am-241	2.81E-04	1.11E-10

Table A2.1.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	2.78E-17
K-40	2.47E-06	9.54E-10
U-238	2.15E-04	2.58E-12
Th-234	3.81E-06	7.58E-10
U-234	2.44E-04	3.51E-12
Th-230	2.40E-04	3.62E-12
Ra-226	2.46E-04	2.99E-11
Rn-222	9.91E-04	9.23E-09
Pb-210	2.04E-07	1.20E-11
Bi-210	1.85E-06	1.17E-10
Po-210	2.73E-04	4.14E-14
Th-232	2.03E-04	2.70E-12
Ra-228	2.27E-06	4.84E-09
Th-228	2.78E-04	1.18E-11
Ra-224	1.37E-03	8.10E-09

2.2 Pelagic carnivorous fish

Table A2.2.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Pelagic	Cod (*Gadus morhua*)	50 ×10 × 6	ellipsoid

Table A2.2.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
Sr-90	9.90E-07	4.18E-13
Y-90	4.55E-06	1.70E-10
Tc-99	5.10E-07	1.08E-17
I-129	3.71E-07	7.36E-11
I-131	1.20E-06	1.68E-09
Cs-137	1.61E-06	2.50E-09
Cs-134	1.78E-06	6.90E-09
Pu-239	2.64E-04	6.92E-13
Am-241	2.81E-04	9.70E-11

Table A2.2.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	0.00E+00
K-40	2.69E-06	7.38E-10
U-238	2.15E-04	9.04E-13
Th-234	4.32E-06	2.49E-10
U-234	2.44E-04	1.44E-12
Th-230	2.40E-04	2.15E-12
Ra-226	2.46E-04	2.73E-11
Rn-222	9.93E-04	7.85E-09
Pb-210	2.08E-07	8.50E-12
Bi-210	1.95E-06	1.99E-11
Po-210	2.73E-04	3.77E-14
Th-232	2.03E-04	1.33E-12
Ra-228	2.92E-06	4.19E-09
Th-228	2.78E-04	9.52E-12
Ra-224	1.38E-03	7.13E-09

2.3 Benthic crustacean

Table A2.3.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Benthic	Crab (*Cancer pagurus*)	10 × 10 × 5 (total size), 5×5×3 (body size without coat)	ellipsoid

Table A2.3.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
Sr-90	9.78E-07	4.36E-12	6.54E-09
Y-90	4.19E-06	2.56E-10	3.84E-07
Tc-99	5.09E-07	1.39E-13	2.08E-10
I-129	3.43E-07	8.42E-11	3.29E-08
I-131	1.02E-06	1.76E-09	5.14E-07
Cs-137	1.34E-06	2.62E-09	7.54E-07
Cs-134	1.13E-06	7.18E-09	2.02E-06
Pu-239	2.64E-04	8.52E-13	6.47E-11
Am-241	2.81E-04	1.02E-10	2.72E-08

Table A2.3.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	1.26E-17	1.89E-14
K-40	2.53E-06	7.93E-10	4.74E-07
U-238	2.15E-04	1.17E-12	5.14E-10
Th-234	3.99E-06	3.30E-10	3.79E-07
U-234	2.44E-04	1.78E-12	7.16E-10
Th-230	2.40E-04	2.42E-12	8.16E-10
Ra-226	2.46E-04	2.84E-11	1.09E-08
Rn-222	9.91E-04	8.23E-09	4.45E-06
Pb-210	2.05E-07	9.36E-12	2.45E-09
Bi-210	1.88E-06	3.98E-11	5.97E-08
Po-210	2.73E-04	3.92E-14	1.99E-11
Th-232	2.03E-04	1.56E-12	5.98E-10
Ra-228	2.40E-06	4.39E-09	2.32E-06
Th-228	2.78E-04	1.01E-11	3.27E-09
Ra-224	1.37E-03	7.43E-09	3.86E-06

2.4 Benthic fish

Table A2.4.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Benthic	Plaice (*Pleuronectes platessa*)	25 × 20 × 3	ellipsoid

Table A2.4.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
Sr-90	9.88E-07	4.66E-12	6.99E-09
Y-90	4.43E-06	5.94E-10	8.91E-07
Tc-99	5.10E-07	6.14E-15	9.21E-12
I-129	3.60E-07	1.69E-10	3.29E-08
I-131	1.13E-06	3.50E-09	5.29E-07
Cs-137	1.51E-06	5.18E-09	7.85E-07
Cs-134	1.54E-06	1.43E-08	2.06E-06
Pu-239	2.64E-04	1.90E-12	6.47E-11
Am-241	2.81E-04	2.04E-10	2.72E-08

Table A2.4.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	1.16E-23	0.00E+00
K-40	2.64E-06	1.59E-09	3.77E-07
U-238	2.15E-04	2.70E-12	5.14E-10
Th-234	4.20E-06	7.30E-10	4.26E-08
U-234	2.44E-04	3.98E-12	7.16E-10
Th-230	2.40E-04	5.08E-12	8.16E-10
Ra-226	2.46E-04	5.64E-11	1.09E-08
Rn-222	9.92E-04	1.65E-08	3.98E-06
Pb-210	2.07E-07	1.89E-11	2.45E-09
Bi-210	1.92E-06	8.18E-11	0.00E+00
Po-210	2.73E-04	7.80E-14	1.99E-11
Th-232	2.03E-04	3.36E-12	5.98E-10
Ra-228	2.73E-06	8.78E-09	2.15E-06
Th-228	2.78E-04	2.04E-11	3.27E-09
Ra-224	1.37E-03	1.48E-08	3.60E-06

2.5 Bivalve mollusc

Table A2.5.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Benthic	Common mussels (*Mutilus edulis*), Scallops (*Pecten maximus*)	5 × 3 × 2.5 (total size); 3.2 × 2 × 1.5 (body)	ellipsoid

Table A2.5.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
Sr-90	9.75E-07	1.48E-11	2.23E-08
Y-90	4.07E-06	6.50E-10	9.76E-07
Tc-99	5.09E-07	1.49E-12	2.23E-09
I-129	3.39E-07	1.06E-10	3.29E-08
I-131	9.97E-07	1.88E-09	5.47E-07
Cs-137	1.30E-06	2.79E-09	8.04E-07
Cs-134	1.05E-06	7.64E-09	2.07E-06
Pu-239	2.64E-04	1.54E-12	6.47E-11
Am-241	2.81E-04	1.11E-10	2.72E-08

Table A2.5.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External** (from bottom sediment), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	2.54E-14	3.81E-11
K-40	2.50E-06	9.37E-10	6.36E-07
U-238	2.15E-04	2.38E-12	5.14E-10
Th-234	3.88E-06	6.81E-10	8.95E-07
U-234	2.44E-04	3.28E-12	7.16E-10
Th-230	2.40E-04	3.46E-12	8.16E-10
Ra-226	2.46E-04	3.00E-11	1.09E-08
Rn-222	9.91E-04	9.12E-09	5.14E-06
Pb-210	2.05E-07	1.17E-11	2.45E-09
Bi-210	1.86E-06	1.08E-10	1.62E-07
Po-210	2.73E-04	4.14E-14	1.99E-11
Th-232	2.03E-04	2.54E-12	5.98E-10
Ra-228	2.31E-06	4.80E-09	2.58E-06
Th-228	2.78E-04	1.16E-11	3.27E-09
Ra-224	1.37E-03	8.04E-09	4.26E-06

2.6 Sea bird

Table A2.6.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Islands	Gull (*Larus spp.*)	15×11×8 (body); 21×16×11 (including feather)	ellipsoid

Table A2.6.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from semi-infinite source in water), Gy a^{-1} Bq^{-1} m^3	**External** (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.88E-07	5.82E-13	0.00E+00
Y-90	4.54E-06	5.98E-11	0.00E+00
Tc-99	5.10E-07	1.56E-15	0.00E+00
I-129	3.73E-07	2.93E-11	4.14E-07
I-131	1.19E-06	7.95E-10	9.53E-06
Cs-137	1.59E-06	1.17E-09	1.36E-05
Cs-134	1.77E-06	3.27E-09	3.72E-05
Pu-239	2.64E-04	2.62E-13	1.86E-09
Am-241	2.81E-04	4.50E-11	6.08E-07

Table A2.6.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, (on the water/air interface, from semi-infinite source in water), Gy a^{-1} Bq^{-1} m^3	**External,** (on the soil/air interface, from semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	2.77E-23	0.00E+00
K-40	2.68E-06	3.49E-10	3.16E-07
U-238	2.15E-04	3.19E-13	5.88E-11
Th-234	4.31E-06	1.00E-10	3.55E-08
U-234	2.44E-04	5.50E-13	1.51E-10
Th-230	2.40E-04	9.40E-13	3.59E-10
Ra-226	2.46E-04	1.30E-11	9.51E-09
Rn-222	9.92E-04	3.71E-09	3.35E-06
Pb-210	2.08E-07	3.77E-12	1.11E-09
Bi-210	1.94E-06	8.55E-12	0.00E+00
Po-210	2.73E-04	1.79E-14	1.68E-11
Th-232	2.03E-04	5.50E-13	1.77E-10
Ra-228	2.91E-06	1.99E-09	1.81E-06
Th-228	2.78E-04	4.43E-12	2.45E-09
Ra-224	1.38E-03	3.40E-09	3.04E-06

2.7 Pelagic crustacean

Table A2.7.1: Description

Habitat	Representative species	Reference dimension (cm) of adult	Shape
Pelagic	Northern shrimp (*Pandalus borealis*)	7 × 1.5 × 1.5	ellipsoid

Table A2.7.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
Sr-90	9.67E-07	2.31E-11
Y-90	3.72E-06	1.00E-09
Tc-99	5.08E-07	2.13E-12
I-129	3.34E-07	1.11E-10
I-131	9.57E-07	1.92E-09
Cs-137	1.24E-06	2.85E-09
Cs-134	9.23E-07	7.76E-09
Pu-239	2.64E-04	1.92E-12
Am-241	2.81E-04	1.13E-10

Table A2.7.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External** (from water column), Gy a^{-1} Bq^{-1} m^3
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	1.95E-14
K-40	2.39E-06	1.04E-09
U-238	2.15E-04	3.12E-12
Th-234	3.58E-06	9.88E-10
U-234	2.44E-04	4.17E-12
Th-230	2.40E-04	4.10E-12
Ra-226	2.46E-04	3.02E-11
Rn-222	9.91E-04	9.60E-09
Pb-210	2.03E-07	1.30E-11
Bi-210	1.80E-06	1.69E-10
Po-210	2.73E-04	4.19E-14
Th-232	2.03E-04	3.16E-12
Ra-228	2.11E-06	5.01E-09
Th-228	2.78E-04	1.24E-11
Ra-224	1.37E-03	8.34E-09

2.8 Carnivorous mammal

Table A2.8.1: Description

Habitat	Representative species of carnivorous mammal	Reference dimension (cm) of adult	Shape
Islands	Harp Seal *(Phoca groenlandica)*	170×45×40	ellipsoid

Table A2.8.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External,** on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.90E-07	6.84E-19	0.00E+00
Y-90	4.71E-06	1.29E-11	0.00E+00
Tc-99	5.10E-07	0.00E+00	0.00E+00
I-129	4.25E-07	1.92E-11	1.51E-07
I-131	1.96E-06	9.24E-10	6.86E-06
Cs-137	2.70E-06	1.40E-09	9.84E-06
Cs-134	4.77E-06	3.90E-09	2.69E-05
Pu-239	2.64E-04	2.06E-13	1.10E-09
Am-241	2.81E-04	4.70E-11	4.18E-07

Table A2.8.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External** (from water column), Gy a^{-1} Bq^{-1} m^3	**External**, on the soil/air interface (from semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	0.00E+00	0.00E+00
K-40	3.00E-06	4.29E-10	2.09E-07
U-238	2.15E-04	1.75E-13	2.17E-11
Th-234	4.48E-06	6.88E-11	2.39E-08
U-234	2.44E-04	4.02E-13	8.20E-11
Th-230	2.40E-04	9.38E-13	2.32E-10
Ra-226	2.46E-04	1.52E-11	6.88E-09
Rn-222	9.96E-04	4.58E-09	2.26E-06
Pb-210	2.13E-07	3.22E-12	5.84E-10
Bi-210	1.96E-06	2.04E-13	0.00E+00
Po-210	2.73E-04	2.16E-14	1.13E-11
Th-232	2.03E-04	4.84E-13	1.08E-10
Ra-228	4.71E-06	2.40E-09	1.22E-06
Th-228	2.78E-04	5.06E-12	1.72E-09
Ra-224	1.38E-03	4.41E-09	2.05E-06

2.9 Soil invertebrate (*Collembola spp.*)

Table A2.9.1: Description

Depth in soil/depth burrow, cm	Proposed reference organism	Reference dimension (cm) of adult	Shape
Mainly in litter layer	*Collembola* spp.	0.5×0.1×0.1	ellipsoid

Table A2.9.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External**, on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	6.36E-07	0.00E+00
Y-90	6.08E-07	0.00E+00
Tc-99	4.47E-07	0.00E+00
I-129	3.12E-07	6.40E-07
I-131	4.15E-07	1.04E-05
Cs-137	5.95E-07	1.51E-05
Cs-134	2.06E-07	4.14E-05
Pu-239	2.61E-04	5.06E-09
Am-241	2.78E-04	5.55E-07

Table A2.9.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00
C-14	2.41E-07	0.00E+00
K-40	7.00E-07	3.76E-07
U-238	2.14E-04	4.76E-10
Th-234	8.18E-07	4.24E-08
U-234	2.42E-04	6.70E-10
Th-230	2.37E-04	7.76E-10
Ra-226	2.43E-04	1.09E-08
Rn-222	9.68E-04	3.97E-06
Pb-210	1.93E-07	2.30E-09
Bi-210	6.02E-07	0.00E+00
Po-210	2.70E-04	1.98E-11
Th-232	2.02E-04	5.59E-10
Ra-228	4.35E-07	2.15E-06
Th-228	2.74E-04	3.22E-09
Ra-224	1.34E-03	3.60E-06

2.10 Soil invertebrate (Mites)

Table A2.10.1: Description

Depth in soil/depth burrow, (cm)	Proposed reference organism	Reference dimension (cm) of adult	Shape
100	Mites (the suborder *Oribatida* (oribatid or beetle, mites) of the order Acariformes	0.3×0.04	Flattened sphere

Table A2.10.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2	**External,** in soil at the depth 100 cm (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	3.74E-07	0.00E+00	0.00E+00
Y-90	2.46E-07	0.00E+00	0.00E+00
Tc-99	3.54E-07	0.00E+00	0.00E+00
I-129	2.92E-07	6.42E-07	0.00E+00
I-131	2.08E-07	1.04E-05	9.22E-10
Cs-137	4.22E-07	1.51E-05	4.19E-09
Cs-134	8.95E-08	4.14E-05	1.60E-08
Pu-239	2.55E-04	5.17E-09	3.95E-14
Am-241	2.70E-04	5.56E-07	0.00E+00

Table A2.10.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg	**External,** in soil at the depth 100 cm, (from the infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	7.50E-14
C-14	2.25E-07	0.00E+00	2.51E-08
K-40	3.13E-07	3.77E-07	3.12E-06
U-238	2.10E-04	4.99E-10	5.07E-06
Th-234	4.69E-07	4.26E-08	4.09E-06
U-234	2.37E-04	6.98E-10	7.48E-06
Th-230	2.33E-04	8.00E-10	7.08E-06
Ra-226	2.38E-04	1.09E-08	7.63E-06
Rn-222	9.31E-04	3.97E-06	6.86E-05
Pb-210	1.90E-07	2.39E-09	2.58E-08
Bi-210	2.77E-07	0.00E+00	1.69E-06
Po-210	2.63E-04	1.99E-11	1.03E-05
Th-232	1.99E-04	5.82E-10	4.23E-06
Ra-228	2.27E-07	2.15E-06	6.88E-06
Th-228	2.67E-04	3.25E-09	1.09E-05
Ra-224	1.29E-03	3.60E-06	8.91E-05

2.11 Small herbivorous mammal (Lemming)

Table A2.11.1: Description

Depth in soil/depth burrow, (cm)	Proposed reference organism	Reference dimension (cm) of adult	Shape
100	Collared Lemming (*Lemus dicrostonyx*)	[1]14×5.5×6.3 [2]8.8×3.4×3.9	Ellipsoid

[1]Actual volume; [2]Size of effective homogeneous ellipsoid (for dose calculation)

Table A2.11.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2	**External,** in soil at the depth 100 cm (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.81E-07	0.00E+00	0.00E+00
Y-90	4.28E-06	0.00E+00	0.00E+00
Tc-99	5.10E-07	0.00E+00	0.00E+00
I-129	3.47E-07	5.35E-07	0.00E+00
I-131	1.04E-06	9.82E-06	9.38E-10
Cs-137	1.37E-06	1.42E-05	4.29E-09
Cs-134	1.21E-06	3.89E-05	1.64E-08
Pu-239	2.64E-04	2.34E-09	4.00E-14
Am-241	2.81E-04	5.82E-07	0.00E+00

Table A2.11.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg	**External,** in soil at the depth 100 cm (from the infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	0.00E+00	4.56E-15
K-40	2.56E-06	3.45E-07	7.93E-07
U-238	2.15E-04	1.03E-10	1.20E-09
Th-234	4.07E-06	3.86E-08	3.34E-07
U-234	2.44E-04	2.10E-10	1.81E-09
Th-230	2.40E-04	4.18E-10	2.44E-09
Ra-226	2.46E-04	1.02E-08	2.85E-08
Rn-222	9.92E-04	3.66E-06	8.27E-06
Pb-210	2.06E-07	1.32E-09	9.47E-09
Bi-210	1.89E-06	0.00E+00	4.08E-08
Po-210	2.73E-04	1.83E-11	3.93E-11
Th-232	2.03E-04	2.21E-10	1.58E-09
Ra-228	2.48E-06	1.97E-06	4.40E-06
Th-228	2.78E-04	2.66E-09	1.01E-08
Ra-224	1.37E-03	3.31E-06	7.45E-06

2.12 Small herbivorous mammal (Vole)

Table A2.12.1: Description

Depth in soil/depth burrow, (cm)	Proposed reference organism	Reference dimension (cm) of adult	Shape
50	Vole (*Microtus* spp)	[1]10.3×4×4.9 [2]6.6×2.6×3.3	Ellipsoid

[1]Actual volume; [2]Size of effective homogeneous ellipsoid (for dose calculation)

Table A2.12.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2	**External,** in soil at the depth 100 cm (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.78E-07	0.00E+00	0.00E+00
Y-90	4.17E-06	0.00E+00	0.00E+00
Tc-99	5.09E-07	0.00E+00	0.00E+00
I-129	3.42E-07	5.62E-07	0.00E+00
I-131	1.01E-06	9.90E-06	6.63E-08
Cs-137	1.33E-06	1.44E-05	1.79E-07
Cs-134	1.11E-06	3.94E-05	5.42E-07
Pu-239	2.64E-04	2.59E-09	3.78E-12
Am-241	2.81E-04	5.71E-07	1.09E-13

Table A2.12.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg	**External,** in soil at the depth 100 cm (from the infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	0.00E+00	1.81E-13
K-40	2.52E-06	3.52E-07	8.38E-07
U-238	2.15E-04	1.27E-10	1.52E-09
Th-234	3.97E-06	3.95E-08	4.17E-07
U-234	2.44E-04	2.41E-10	2.21E-09
Th-230	2.40E-04	4.43E-10	2.72E-09
Ra-226	2.46E-04	1.03E-08	2.91E-08
Rn-222	9.91E-04	3.74E-06	8.53E-06
Pb-210	2.05E-07	1.40E-09	1.01E-08
Bi-210	1.87E-06	0.00E+00	5.61E-08
Po-210	2.73E-04	1.86E-11	4.02E-11
Th-232	2.03E-04	2.42E-10	1.83E-09
Ra-228	2.38E-06	2.01E-06	4.54E-06
Th-228	2.78E-04	2.73E-09	1.06E-08
Ra-224	1.37E-03	3.38E-06	7.64E-06

2.13 Large herbivorous mammal

Table A2.13.1: Description

Proposed reference organism	Reference dimension (cm) of adult	Shape
Reindeer (*Rangifer tarandus*)	200×19×32	ellipsoid

Table A2.13.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External,** on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.90E-07	0.00E+00
Y-90	4.70E-06	0.00E+00
Tc-99	5.10E-07	0.00E+00
I-129	4.13E-07	2.49E-07
I-131	1.65E-06	8.37E-06
Cs-137	2.25E-06	1.19E-05
Cs-134	3.54E-06	3.25E-05
Pu-239	2.64E-04	1.44E-09
Am-241	2.81E-04	5.33E-07

Table A2.13.3: DCFs (Natural radionuclides)

Nuclides	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	0.00E+00
K-40	2.89E-06	2.59E-07
U-238	2.15E-04	3.39E-11
Th-234	4.47E-06	2.94E-08
U-234	2.44E-04	1.08E-10
Th-230	2.40E-04	2.88E-10
Ra-226	2.46E-04	8.15E-09
Rn-222	9.94E-04	2.78E-06
Pb-210	2.11E-07	8.08E-10
Bi-210	1.96E-06	0.00E+00
Po-210	2.73E-04	1.39E-11
Th-232	2.03E-04	1.37E-10
Ra-228	4.00E-06	1.50E-06
Th-228	2.78E-04	2.07E-09
Ra-224	1.38E-03	2.52E-06

2.14 Herbivorous bird

Table A2.14.1: Description

Proposed reference organism	Reference dimension (cm) of adult	Shape
Willow ptarmigan or willow grouse *(Lagopus lagopus*)	[1]25×17×13 [2]14×9.4×7.2	ellipsoid

[1]Actual volume; [2]Size of effective homogeneous ellipsoid (for dose calculation)

Table A2.14.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External**, on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.87E-07	0.00E+00
Y-90	4.53E-06	0.00E+00
Tc-99	5.10E-07	0.00E+00
I-129	3.69E-07	3.84E-07
I-131	1.17E-06	9.44E-06
Cs-137	1.56E-06	1.34E-05
Cs-134	1.67E-06	3.68E-05
Pu-239	2.64E-04	1.79E-09
Am-241	2.81E-04	6.07E-07

Table A2.14.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	0.00E+00
K-40	2.67E-06	3.08E-07
U-238	2.15E-04	5.31E-11
Th-234	4.29E-06	3.47E-08
U-234	2.44E-04	1.42E-10
Th-230	2.40E-04	3.47E-10
Ra-226	2.46E-04	9.33E-09
Rn-222	9.92E-04	3.27E-06
Pb-210	2.08E-07	1.06E-09
Bi-210	1.93E-06	0.00E+00
Po-210	2.73E-04	1.64E-11
Th-232	2.03E-04	1.70E-10
Ra-228	2.85E-06	1.77E-06
Th-228	2.78E-04	2.40E-09
Ra-224	1.37E-03	2.97E-06

2.15 Egg from ground nesting bird

Table A2.15.1: Description

Proposed reference organism	Reference dimension (cm) of adult	Shape
Red Grouse (*Lagopus lagopus scoticus*) egg	4.6×3.2×3.2	ellipsoid

Table A2.15.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External**, on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.78E-07	0.00E+00
Y-90	4.18E-06	0.00E+00
Tc-99	5.09E-07	0.00E+00
I-129	3.42E-07	5.89E-07
I-131	1.01E-06	1.00E-05
Cs-137	1.33E-06	1.47E-05
Cs-134	1.11E-06	4.00E-05
Pu-239	2.64E-04	3.01E-09
Am-241	2.81E-04	5.59E-07

Table A2.15.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00
C-14	2.50E-07	0.00E+00
K-40	2.53E-06	3.61E-07
U-238	2.15E-04	1.70E-10
Th-234	3.98E-06	4.05E-08
U-234	2.44E-04	2.95E-10
Th-230	2.40E-04	4.84E-10
Ra-226	2.46E-04	1.05E-08
Rn-222	9.91E-04	3.82E-06
Pb-210	2.05E-07	1.50E-09
Bi-210	1.88E-06	0.00E+00
Po-210	2.73E-04	1.91E-11
Th-232	2.03E-04	2.78E-10
Ra-228	2.39E-06	2.06E-06
Th-228	2.78E-04	2.82E-09
Ra-224	1.37E-03	3.46E-06

2.16 Carnivorous mammal (burrowing)

Table A2.16.1: Description

Depth in soil/depth burrow (cm)	Proposed reference organism	Reference dimension (cm) of adult	Shape
100	Arctic fox *(Alopex lagopus)*	54×11×18	Ellipsoid

Table A2.16.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, on the soil/air interface (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2	**External**, in soil at the depth 100 cm (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	9.90E-07	0.00E+00	0.00E+00
Y-90	4.64E-06	0.00E+00	0.00E+00
Tc-99	5.10E-07	0.00E+00	0.00E+00
I-129	3.95E-07	2.97E-07	0.00E+00
I-131	1.39E-06	8.92E-06	1.02E-09
Cs-137	1.88E-06	1.27E-05	4.64E-09
Cs-134	2.55E-06	3.46E-05	1.77E-08
Pu-239	2.64E-04	1.58E-09	4.37E-14
Am-241	2.81E-04	5.73E-07	0.00E+00

Table A2.16.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External**, on the soil/air interface (from the semi-infinite source in soil), Gy a^{-1} Bq^{-1} kg	**External,** in soil at the depth 100 cm (from the infinite source in soil), Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00	0.00E+00
C-14	2.50E-07	0.00E+00	0.00E+00
K-40	2.77E-06	2.80E-07	6.03E-07
U-238	2.15E-04	4.02E-11	3.91E-10
Th-234	4.40E-06	3.17E-08	1.34E-07
U-234	2.44E-04	1.20E-10	7.53E-10
Th-230	2.40E-04	3.13E-10	1.50E-09
Ra-226	2.46E-04	8.68E-09	2.24E-08
Rn-222	9.93E-04	2.99E-06	6.48E-06
Pb-210	2.10E-07	9.08E-10	5.77E-09
Bi-210	1.96E-06	0.00E+00	5.25E-09
Po-210	2.73E-04	1.50E-11	3.11E-11
Th-232	2.03E-04	1.50E-10	8.27E-10
Ra-228	3.39E-06	1.62E-06	3.44E-06
Th-228	2.78E-04	2.21E-09	7.53E-09
Ra-224	1.38E-03	2.72E-06	6.02E-06

2.17 Plant roots

Table A2.17.1: Description

Depth in soil/depth burrow (cm)	Proposed reference organism	Reference dimension (cm) of adult	Shape
0 - 30	Plant roots (Fine leaved grass) (*Vaccinium myrtillus*)	29×0.0035×0.0035	ellipsoid

Table A2.17.2: DCFs (Artificial radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg (w.w.)	**External,** mean value at the depth 0-30 cm (from source on the depth 0.5 g cm^{-2} in soil), Gy a^{-1} kBq^{-1} m^2
Sr-90	1.95E-07	0.00E+00
Y-90	8.83E-08	0.00E+00
Tc-99	2.36E-07	0.00E+00
I-129	2.80E-07	1.86E-07
I-131	9.31E-08	2.56E-06
Cs-137	3.45E-07	3.97E-06
Cs-134	3.42E-08	1.10E-05
Pu-239	2.64E-04	1.09E-08
Am-241	2.81E-04	1.06E-07

Table A2.17.3: DCFs (Natural radionuclides)

Nuclide	**Internal,** Gy a^{-1} Bq^{-1} kg	**External,** from the infinite source in soil, Gy a^{-1} Bq^{-1} kg
H-3	8.61E-08	0.00E+00
C-14	2.13E-07	3.71E-08
K-40	1.23E-07	3.30E-06
U-238	2.15E-04	6.80E-09
Th-234	2.90E-07	4.27E-06
U-234	2.44E-04	8.67E-09
Th-230	2.40E-04	7.67E-09
Ra-226	2.46E-04	3.09E-08
Rn-222	9.79E-04	1.33E-05
Pb-210	1.92E-07	2.39E-08
Bi-210	1.12E-07	1.85E-06
Po-210	2.73E-04	4.29E-11
Th-232	2.03E-04	6.66E-09
Ra-228	1.37E-07	6.97E-06
Th-228	2.78E-04	1.65E-08
Ra-224	1.34E-03	1.45E-05

APPENDIX 3: Transfer factors for terrestrial reference organisms

Concentration ratios (CRs) describing the transfer of radionuclides from air (^{3}H and ^{14}C only) and soil to reference organism groups and representative species. Best estimate (generally mean of observed data) and range are given. For original source data refer to Beresford *et al*., (2003). Descriptions of allometric and ^{3}H and ^{14}C modelling can be found in Beresford *et al.,* (in press) and Galeriu *et al.,* (2003).

Representative Species	Bq kg^{-1} organism : Bq m^{-3} air		Bq kg^{-1} organism : Bq kg^{-1} soil (dry weight) Best estimate (range)									
	^{3}H[a]	^{14}C[a]	Cs	^{90}Sr	^{99}Tc	^{210}Po	^{226}Ra	Pu	I	Th	U	^{241}Am
Lichen	-	-	7.54 0.13-22.8	6.46 0.22 -42.6	-	0.28 0.01-0.88	0.83 0.48-1.39	-	-	0.27 0.16-0.62	0.20 -	-
All Gymnosperms	-	-	0.95 0.04-5.54	1.33 0.11-3.79	-	-	2.13 (0.01-72.6)$x10^{-1}$	-	-	0.22 0.17-0.28	0.29 (0.02-116)$x10^{-2}$	-
Juniperus spp.	-	-	0.51 0.28-1.20	-	-	-	4.26 1.25-7.26	-	-	-	0.30 0.05-0.55	-
Larix /*Picea* spp.	-	-	0.20 0.04-0.51	-	-	$3.25x10^{-3}$ -	$5.25x10^{-3}$ -	-	-	-	$1.75x10^{-4}$ (-)	-
Vaccinium spp	-	-	2.86 0.70-176	0.58 0.03-6.04	-	1.23 0.19-3.17	3.56 (0.06-76.4)$x10^{-3}$	-	-	0.16 0.02-0.24	0.32 (0.02-75.0)$x10^{-2}$	-
Salix spp.	-	-	0.51 (0.07-18.1) $x10^{-1}$	3.35 0.18-10.8	-	$8.50x10^{-3}$ -	$1.25x10^{-3}$ -	-	-	-	$1.00x10^{-4}$ -	-
All Monocotyledons	150 -	890 -	0.98 0.06-18.4	0.35 0.09-1.47	76[b] 10-760	0.44 0.32-0.56	$5.66x10^{-3}$ -	$3.40x10^{-4b}$ (0.01-65)$x10^{-2}$	$3.40x10^{-3b}$ (0.34-34.0)$x10^{-3}$	$1.10x10^{-2b}$ (0.11-11.0)$x10^{-2}$	$2.30x10^{-2b}$ (0.23-23.0)$x10^{-2}$	$1.20x10^{-3b}$ (0.01-17.0)$x10^{-2}$

[a] Estimated using a specific activity model (Galeriu *et al*. 2003).

[b] CR value for grass from IAEA (1994).

Representative Species	Bq kg^{-1} organism : Bq m^{-3} air		Bq kg^{-1} organism : Bq kg^{-1} soil (dry weight) Best estimate (range)									
	^{3}H[a]	^{14}C[a]	Cs	^{90}Sr	^{99}Tc	^{210}Po	^{226}Ra	Pu	I	Th	U	^{241}Am
Herbivorous mammals - all species	-	-	7.01 0.01-76.1	2.89 (0.03-79.6)x10^{-2}	-	4.17 0.40 -14.3	4.77x10^{-2} (0.21-19.5) x10^{-2}	1.01x10^{-3} (-)	-	0.64 (0.21-46.6) x10^{-2}	1.80x10^{-3} (0.12-2.84) x10^{-3}	2.26x10^{-3} -
Herbivorous Mammals - excluding reindeer	-	-	1.03 0.01-76.1	1.09 (0.05-61.8)x10^{-2}	-	-	4.13x10^{-2} (0.21-19.5) x10^{-2}	-	-	7.74x10^{-3} (0.21-1.33) x10^{-2}	-	-
Reindeer	150 -	1340 -	9.91 0.07-45.1	3.48 0.03-8.42	-	4.17 0.40 -14.3	6.07x10^{-2} (0.31-15.9) x10^{-2}	-	-	0.37 0.23-0.47	9.36x10^{-3c}	-
Lemmings & Voles	150 -	1340 -	3.49 1.69-4.43	1.87	2.96[c] -	-	6.91x10^{-2} 0.01-0.20	-	3.63x10^{-1c} -	7.74x10^{-3} (0.21-1.33) x10^{-2}	2.60x10^{-3} (2.40-2.80) x10^{-3}	-
Carnivorous mammals - *all species*	-	1340 -	2.76 0.10-12.9	0.72 0.12-1.86	-	1.68 1.51-1.85	3.53x10^{-2} (0.43-9.56) x10^{-2}	-	-	5.52x10^{-3} (0.1-1.0) x10^{-2}	7.09x10^{-4} (-)	-
Fox	150 -	1340 -	0.65 0.10-1.68	12.5[c]	0.60[c]	-	4.00x10^{-3} (-)	1.72x10^{-4}	1.66[c]	-	-	1.72x10^{-4c}
Herbivorous bird - *all species*	-	-	0.89 0.02-9.05	Data for *Lagopus* spp. only	-	-	3.38x10^{-2} (0.21-19.5) x10^{-2}	-	-	3.89x10^{-4} (3.08-5.44) x10^{-4}	4.98x10^{-4} (4.05-6.76) x10^{-4}	-
Lagopus spp.	150 -	1140 -	0.76 0.02-3.22	3.52x10^{-2} (0.18-22.2) x10^{-2}	-	-	2.53x10^{-2} (0.91-5.07) x10^{-2}	-	-	3.52x10^{-4} -	4.05x10^{-4} -	-
Herbivorous bird -egg	150 -	890 -	6.4x10^{-2d} -	-	-	-	-	-	-	-	2.0x10^{-3d} -	-

[a] Estimated using a specific activity model (Galeriu *et al*. 2003).

[c] Allometrically derived by Beresford *et al.* (in press).

[d] Estimated from dietary transfer to domestic hen eggs and CR values describing transfer to herbivorous bird whole-body (see Section 7.2.1)

APPENDIX 4: Concentration factors for marine reference organisms

In the process of constructing look-up tables, presenting transfer and uptake data for marine reference organisms, it was deemed appropriate to present data on equilibrium concentration factors. Although the application of such quotients may have a number of limitations as discussed in the main report (Section 4.1.5), the scope, detail and robustness of information required to parameterise, for example, fully dynamic-biokinetic models was not sufficient to allow any alternative approach to be taken at the present time (however desirable).

The recommended data have been derived specifically for Arctic marine environments, whenever possible, although in many cases the values for temperate world-ocean have been employed for lack of regional data. The latter information is extracted from IAEA (in press), in recognition that many of those conducting an assessment may choose to refer to an internationally-sanctioned data-base. Where differences between the data collated in the review conducted within EPIC and the IAEA recommended values were not great, the IAEA values were normally used. In a number of instances, empirical data pertaining to whole body CFs were not available. In such cases, a combination of empirical concentration factors and biokinetic models were used as described elsewhere (Beresford *et al*., 2003; Brown *et al*., 2003). The data included in the subsequent look-up tables, therefore, are intended to provide a substantial supplement to the more generic values provided in IAEA (IAEA, in press).

Unless otherwise stated the values provided in the tables relate to the whole body CF for the organism. The IAEA note (IAEA, in press) that where reliable information exists for element/organism combinations, in almost every case, the maximum and minimum values observed in the population fall within one order of magnitude of the recommended values. The Agency therefore advises that, except where noted, it can be assumed that CFs vary by one order of magnitude around the recommended value. In view of the compatibility of the EPIC marine transfer tables with the IAEA values, a similar approach is approved here.

Table A4.1 **H** concentration factors for marine systems (not presented)

There is evidence that the steady-state concentration of tritium in biological tissues approaches, but does not exceed the concentrations in ambient water (Whicker & Schultz, 1982). For this reason the default CF for tritium is normally taken as unity for all marine biota types. This is indeed the approach adopted by the IAEA (IAEA, in press)

However, there is also some evidence that organically-bound tritium (OBT) may account for cases in which the Tritium/Hydrogen ratio in biota slightly exceeds the ratio in ambient water (Whicker & Schultz, 1982). The fact that higher than expected activity concentrations in marine biota have been observed in environments in which a significant proportion of environmental tritium is present in an organically-bound form, e.g. Cardiff Bay area in the UK, exemplifies the limitations in applying a default unit CF.

For lack of more detailed information on the biological uptake of OBT in marine organisms, a default concentration factor of 1 is taken for H in all cases. These concentration factors may be suitably applicable where ^{3}H is present as tritiated water or water-exchangeable ^{3}H.

Table A4.2 **C** concentration factors* (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	C-1
Phytoplankton	9 000	C-2
Macroalgae	10 000	C-3
Pelagic crustacean	20 000	C-4
(Bivalve) mollusc	20 000	C-5
Polychaete worm	20 000	C-6
Benthic crustacean	20 000	C-7
Pelagic planktotrophic fish	20 000	C-8
Pelagic carnivorous fish	20 000	C-9
Benthic fish	20 000	C-10
Sea bird	50 000	C-11
Mammal	50 000	C-12

n/a = Not applicable.

*The IAEA (IAEA, in press) provide specific comments in relation to the derivation of carbon CFs in the accompanying notes to their tabulated recommended values. It is noted that for most elements, CFs are derived by dividing the body concentration of the element (or radioisotope) by the total concentration of the element (or radioisotope) in filtered sweater. If this was carried out for C, the denominator would include dissolved, CO_2, $(CO_3)^{2-}$ HCO_3^- dissolved organic carbon etc. For the purpose of consistency, all values relate to the organic carbon content of seawater.

C-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented by the activity concentration in the surrounding medium.
C-2: Value from IAEA (in press).
C-3: Value from IAEA (in press).
C-4: Value from IAEA (in press).
C-5: Value from IAEA (in press).
C-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (ingestion of benthic particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
C-7: Value from IAEA (in press).
C-8: The value for generic fish derived from IAEA (in press) has been taken to represent pelagic planktotrophic fish.
C-9: The value for generic fish derived from IAEA (in press) has been taken to represent pelagic carnivorous fish.
C-10: The value for generic fish derived from IAEA (in press) has been taken to represent benthic fish.
C-11: This is a rough estimate based on the derivation of information from humans. The carbon content of the body of man is 16 kg (ICRP, 1975). Dividing by the mass of reference man (70 kg), this yields a C concentration of 228.5 g/kg. This value is 2.39 x the C concentration used for fish. Multiplying this value by the CF reported for fish in IAEA (in press) yields a CF of 5×10^4. The application of human data to seabirds is open to question.
C-12: This is a rough estimate based on the derivation of information from humans (see C-12). In view of physiological similarities between mammals the derived CF value might be more appropriately applied to seals than to seabirds.

Table A4.3 **Sr** concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Sr-1
Phytoplankton	1	Sr-2
Macroalgae	180	Sr-3
Pelagic crustacean	15	Sr-4
(Bivalve) mollusc	10	Sr-5
Polychaete worm	10	Sr-6
Benthic crustacean	15	Sr-7
Pelagic planktotrophic fish	5	Sr-8
Pelagic carnivorous fish	15	Sr-9
Benthic fish	8	Sr-10
Sea bird	940	Sr-11
Mammal	10	Sr-12

n/a = Not applicable

Sr-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Sr-2: Value from IAEA (in press).
Sr-3: This value corresponds to ^{90}Sr brown macroalgae sampled from the Kara and Barents Sea areas (Fisher *et al*., 1999).
Sr-4: Value from the EPIC database for Arctic crustaceans (Beresford *et al.,* 2003).
Sr-5: Value from IAEA (in press).
Sr-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Sr-7: Value from the EPIC database for Arctic crustaceans (Beresford *et al.,* 2003).
Sr-8: Value from the EPIC database for Polar Cod (Beresford *et al.,* 2003).
Sr-9: Value from the EPIC database for Cod (Beresford *et al.,* 2003).
Sr-10: Value from the EPIC database for Plaice (Beresford *et al.,* 2003).
Sr-11: Based on the output of a biokinetic model as reported in Brown *et al*., (2003).
Sr-12: Value from the EPIC database for Greenland Seal (Beresford *et al.,* 2003).

Table A4.4 **Tc** concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Tc-1
Phytoplankton	4	Tc-2
Macrolalgae	26 000	Tc-3
Pelagic crustacean	100	Tc-4
(Bivalve) mollusc	300	Tc-5
Polychaete worm	300	Tc-6
Benthic crustacean	1400	Tc-7
Pelagic planktotrophic fish	80	Tc-8
Pelagic carnivorous fish	80	Tc-8
Benthic fish	80	Tc-8
Sea bird	870	Tc-9
Mammal	20	Tc-10

n/a = Not applicable

Tc-1: No CF data for bacteria have been derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Tc-2: Based on IAEA (in press)
Tc-3: Based on a mean value for brown seaweeds for 4 European marine areas (Hurtgen *et al*., 1988; Masson *et al*., 1995; Brown *et al*., 1999).
Tc-4: Value from the EPIC database for shrimp (Beresford *et al.,* 2003).
Tc-5: Value from the EPIC database for mussels (Beresford *et al.,* 2003).
Tc-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Tc-7: Value from the EPIC database for crab (Beresford *et al.,* 2003).
Tc-8: Based on IAEA (in press) derived from data from the English Channel (IPSN, 1999) – for generic fish.
Tc-9: Based on the output of a biokinetic model as reported in Brown *et al*. (2003).
Tc-10: Based on the average of 2 biokinetic model as reported in Brown *et al*. (2003).

Table A4.5 **I** concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	I-1
Phytoplankton	800	I-2
Macroalgae	400	I-3
(Pelagic) crustacean	3	I-4
(Bivalve) mollusc	10	I-5
Polychaete worm	10	I-6
Benthic crustacean	3	I-7
Pelagic planktrophic fish	9	I-8
Pelagic carnivorous	9	I-8
Benthic fish	9	I-8
Wading bird	880	I-9
Mammal	8	I-10

n/a = Not applicable

I-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
I-2: Value from IAEA (in press). The recommended value was derived using stable element data.
I-3: Data for brown seaweed reported in Holm *et al.* (1994). It should be noted that Holm *et al*. (1994) reported large variations in ^{131}I concentrations between red (mean = 48 800), green (CF = 921) and brown seaweed (CF = 418). This may account for the discrepancy observed with the IAEA recommended value which presumably pertains to all 3 seaweed groups.
I-4: Value from IAEA (in press) for crustaceans (presumably benthic in most cases). The IAEA notes that there are few recent I CF data for crustaceans and little to support or refute the concentration of 1 mg/kg (d.w.) used in the derivation of the recommended value.
I-5: Value from IAEA (in press) derived using stable element data.
I-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (ingestion of benthic particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
I-7: Value from IAEA (in press). The IAEA notes that there are few recent I CF data for crustaceans and little to support or refute the concentration of 1 mg/kg (d.w.) used in the derivation of the recommended value.
I-8: Value from IAEA (in press) for generic fish.
I-9: Based on the output from a biokinetic model as reported in Brown *et al*. (2003).
I-10: Based on the output from a biokinetic model as reported in Brown *et al*. (2003).

Table A4.6 **Cs** concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Cs-1
Phytoplankton	20	Cs-2
Macroalgae	75	Cs-3
Pelagic crustacean	35	Cs-4
(Bivalve) mollusc	50	Cs-5
Polychaete worm	50	Cs-6
Benthic crustacean	150	Cs-7
Pelagic planktotrophic fish	100	Cs- 8
Pelagic carnivorous fish	80	Cs-9
Benthic fish	100	Cs-10
Sea bird	580	Cs-11
Mammal	70	Cs-12

n/a = Not applicable

Cs-1: No CF data for bacteria have been derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Cs-2: Based on IAEA (1985) and IAEA (in press). These values in turn are based on 2 references Styron *et al*. (1976) and Heldal *et al*. (2001).
Cs-3: This value is based on mean of values cited in 2 publications (Holm *et al*, 1994) and Fisher *et al.* (1999) for brown macroalgae. Brown macroalgae has been selected as the reference type in this case owing to the fact that it exhibits the highest uptake. Brown seaweeds are more common in northern marine environments and are often sampled in monitoring work although they are normally not consumed by humans.
Cs-4: Value from the EPIC database for shrimp (Beresford *et al.,* 2003).
Cs-5: Value from the EPIC database for mussel (Beresford *et al.,* 2003).
Cs-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Cs-7: Value from the EPIC database for crab (Beresford *et al.,* 2003).
Cs-8: Value from the EPIC database for Polar Cod (Beresford *et al.,* 2003).
Cs-9: Value from the EPIC database for Cod (Beresford *et al.,* 2003).
Cs-10: Value from the EPIC database for Plaice (Beresford *et al.,* 2003).
Cs-11: Value from the EPIC database for Gull (Beresford *et al.,* 2003).
Cs-12: Value from the EPIC database for Greenland Seal (Beresford *et al.,* 2003).

Table A4.7 Po concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Po-1
Phytoplankton	70 000	Po-2
Macroalgae	1000	Po-3
Pelagic crustacean	45 000	Po-4
(Bivalve) mollusc	60 000	Po-5
Polychaete worm	16 000	Po-6
Benthic crustacean	37 000	Po-7
Pelagic planktotrophic fish	3 330	Po-8
Pelagic carnivorous fish	600	Po-9
Benthic fish	5 330	Po-10
Sea bird	39 000	Po-11
Mammal	21 000	Po-12

n/a = Not applicable.

Po-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Po-2: Value from IAEA (in press).
Po-3: Value from IAEA (in press). No new information has been collated on the uptake of Po by macroalgae following IAEA-TECDOC-211 (IAEA, 1978). However, it should be noted that information for European marine environments has been published by McDonald *et al*. (1992) and that the mean value derived from this study coincide exactly with the figure recommended by the IAEA.
Po-4: Value from the EPIC database for shrimp (Beresford *et al.,* 2003).
Po-5: Value from the EPIC database for mussel (Beresford *et al.,* 2003).
Po-6: These data are for whole annelids sampled in the Baltic Sea (Skwarzec & Falkowski, 1988).
Po-7:
Po-8: Value from the EPIC database for Polar Cod (Beresford *et al.,* 2003).
Po-9: Value from the EPIC database for Cod (Beresford *et al.,* 2003).
Po-10: Value from the EPIC database for Plaice (Beresford *et al.,* 2003).
Po-11: Based on the output from a biokinetic model as reported in Brown *et al*. (2003). A single compartmental model for retention of Po in man has been used.
Po-12: Value from the EPIC database for Greenland Seal (Beresford *et al.,* 2003).

Table A4.8 Ra concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Ra-1
Phytoplankton	2000	Ra-2
Macroalgae	100	Ra-3
Pelagic crustacean	100	Ra-4
(Bivalve) mollusc	100	Ra-5
Polychaete worm	100	Ra-6
Benthic crustacean	100	Ra-7
Pelagic planktotrophic fish	100	Ra-8
Pelagic carnivorous fish	100	Ra-8
Benthic fish	100	Ra-8
Sea bird	520	Ra-9
Mammal	25	Ra-10

n/a = Not applicable.

Ra-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Ra-2: Value from IAEA (in press).
Ra-3: The IAEA report (in press) that no new information has been collated on the uptake of Ra to macroalgae following IAEA-TECDOC-211 (IAEA, 1978).
Ra-4: Value from IAEA (in press).
Ra-5: The IAEA state (in press) that this value was derived from information which did not include CFs for lamellibranch or gastropod molluscs. The application of this CF value to bivalve molluscs must therefore be viewed with caution.
Ra-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Ra-7: Value from IAEA (in press). The IAEA report (in press) that no new information has been collated on the uptake of Ra to crustaceans following IAEA-TECDOC-211 (IAEA, 1978).
Ra-8: This is the value for generic fish derived from IAEA (in press).
Ra-9: Based on the output of a biokinetic model as reported in Brown *et al.* (2003). The appropriateness of using elimination rates derived from retention factors for man (ICRP-30, parts 1-4) is of some concern.
Ra-10: Based on the output of a biokinetic model as reported in Brown *et al.* (2003).

Table A4.9 Th concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Th-1
Phytoplankton	40 000	Th-2
Macroalgae	200	Th-3
Pelagic crustacean	1000	Th-4
(Bivalve) Mollusc	1000	Th-5
Polychaete worm	1000	Th-6
Benthic crustacean	1000	Th-7
Pelagic planktotrophic fish	600	Th-8
Pelagic carnivorous fish	600	Th-8
Benthic fish	600	Th-8
Sea bird	65	Th-9
Mammal	6*	Th-10

n/a = Not applicable
* Concentration ratio.

Th-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Th-2: Value from IAEA (in press)
Th-3: Value from IAEA (in press)
Th-4: Value from IAEA (in press) for crustaceans (mainly benthic). It should be noted that additional data pertaining to Th CFs for crustaceans were not found to supplement a value first derived in the 1970s (IAEA, 1978).
Th-5: Value from IAEA (in press). The derivation of this value is somewhat unclear as the technical report provides only the information that "no CF data for lamellibranch or gastropods molluscs were located".
Th-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Th-7: Value from IAEA (in press). It should be noted that additional data pertaining to Th CFs for crustaceans were not found to supplement a value first derived in the 1970s (IAEA, 1978).
Th-8: Value from IAEA (in press) for generic fish.
Th-9: Based on the output of a biokinetic model as reported in Brown *et al*. (2003).
Th-10: Based on the average of 2 biokinetic model outputs as reported in Brown *et al*. (2003). In the case of both models (model using allometrically derived excretion rate and multi-compartmental excretion model), the concentration ratio at 10 y, as oppose to the (equilibrium) CF, was used in the derivation of this value.

Table A4.10 U concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	U-1
Phytoplankton	20	U-2
Macroalgae	50	U-3
Pelagic crustacean	10	U-4
Mollusc	30	U-5
Polychaete worm	30	U-6
Benthic crustacean	10	U-7
Pelagic planktotrophic fish	1	U-8
Pelagic carnivorous fish	1	U-8
Benthic fish	1	U-8
Sea bird	3	U-9
Mammal	0.05*	U-10

n/a = Not applicable
* Concentration ratio.

U-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
U-2: Value from IAEA (in press).
U-3: This is a mean value derived for 3 European marine areas taken from McDonald *et al.* (1992).
U-4: Value from IAEA (in press) for crustaceans (mainly benthic). It should be noted that additional data pertaining to U CFs for crustaceans were not found to supplement a value first derived in the 1970s (IAEA, 1978).
U-5: Value from IAEA (in press). Value is for Lamellibranch or bivalve molluscs
U-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
U-7: Value from IAEA (in press). It should be noted that additional data pertaining to U CFs for crustaceans were not found to supplement a value first derived in the 1970s (IAEA, 1978).
U-8: Value from IAEA (in press) for generic fish.
U-9: Based on the output of a biokinetic model as reported in Brown *et al*. (2003).
U-10: Based on the average of 2 biokinetic model outputs as reported in Brown *et al*. (2003). In the case of the multi-compartmental excretion model, the concentration ratio at 10 y, as oppose to the (equilibrium) CF, was used in the derivation of this value.

Table A4.11 Pu concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Confidence	Comments
Bacteria	n/a	n/a	Pu-1
Phytoplankton	20 000	Medium	Pu-2
Macroalgae	4 650	High	Pu-3
Pelagic crustacean	300		Pu-4
Mollusc	150	Medium	Pu-5
Polychaete worm	150	Low	Pu-6
Benthic Crustacean	300	Medium	Pu-7
Pelagic planktotrophic fish	<200	Medium	Pu-8
Pelagic carnivorous fish	140	Medium	Pu-9
Benthic fish	<200	Medium	Pu-10
Sea bird	540	Low	Pu-11
Mammal	400	Medium	Pu-12

n/a = Not applicable

Pu-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Pu-2: Value from IAEA (in press).
Pu-3: Value pertains to brown macroalgae and is based on 4 references (Fisher et al., 1999; Germain *et al*., 2000; Holm *et al*., 1991 and Holm *et al.* 1994) covering 3 European marine waters.
Pu-4: Value from the EPIC database for generic crustaceans (Beresford *et al.,* 2003).
Pu-5: Value from the EPIC database for mussels (Beresford *et al.,* 2003).
Pu-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Pu-7: Value from the EPIC database for generic crustaceans (Beresford *et al.,* 2003).
Pu-8: Value from the EPIC database for Polar Cod (Beresford *et al.,* 2003).
Pu-9: Value from the EPIC database for Cod (Beresford *et al.,* 2003).
Pu-10: Value from the EPIC database for Plaice (Beresford *et al.,* 2003).
Pu-11: Based on the output of a biokinetic model as reported in Brown *et al.* (2003). It should be noted that this value is only obtained after an equilibration period of approximately 10 years. Shorter contaminant contact times will lead to concomitantly lower concentration ratios.
Pu-12: Value from the EPIC database for "Sea mammals" (Beresford *et al.,* 2003).

Table A4.12 Am concentration factors (l/kg) for marine systems

Reference organism	Bq/kg fresh per Bq/l	Comments
Bacteria	n/a	Am-1
Phytoplankton	20 000	Am-2
Macroalgae	8 000	Am-3
Pelagic crustacean	400	Am-4
Bivalve mollusc	20 000	Am-5
Polychaete worm	700	Am-6
Benthic crustacean	500	Am-7
Pelagic planktotrophic fish	100	Am-8
Pelagic carnivorous fish	100	Am-8
Benthic fish	100	Am-8
Sea bird	310	Am-9
Mammal	5*	Am-10

n/a = Not applicable
* Concentration ratio.

Am-1: No data for bacteria derived. It has been argued, and demonstrably shown (Pröhl *et al*., 2003) that absorbed doses for bacteria will be essentially determined by the external source represented.
Am-2: Value from IAEA (in press).
Am-3: Value from IAEA (in press). IAEA have derived a value for brown seaweed based on 4 references mainly dealing with European coastal environments.
Am-4: Value from IAEA (in press) for crustacean (mainly benthic). The CF value for Am was assumed to be the same as for Cf – a radionuclide for which experimental data were available.
Am-5: Value from the EPIC database for mussel (Beresford *et al.,* 2003). It should be noted that this values is considerably higher than the IAEA (in press) recommended value of 1000 and should be treated with some caution.
Am-6: This is an estimate. In view of similarities with mollusc in terms of habitat and feeding habits (benthic organism ingesting suspended particulate matter), this organism may represent a suitable proxy for the derivation of CFs. Empirical data are required.
Am-7: Value from the EPIC database for lobster (Beresford *et al.,* 2003
Am-8: Value from IAEA (in press) for generic fish.
Am-9: Based on the output of a biokinetic model as reported in Brown *et al.* (2003). It should be noted that this value is only obtained after an equilibration period of approximately 10 years. Shorter contaminant contact times will lead to concomitantly lower concentration ratios.
Am-10: This is a Concentration ratio based on the output of 2 biokinetic models as reported in Brown *et al.* (2003). This value was derived for a simulation period of 10 years at which time the system had not reached equilibrium. A period of several hundred years is required for the system to truly equilibrate.