Review of approaches for the estimation of radionuclide transfer to reference Arctic biota

A deliverable report for EPIC

Project ICA2-CT-2000-10032

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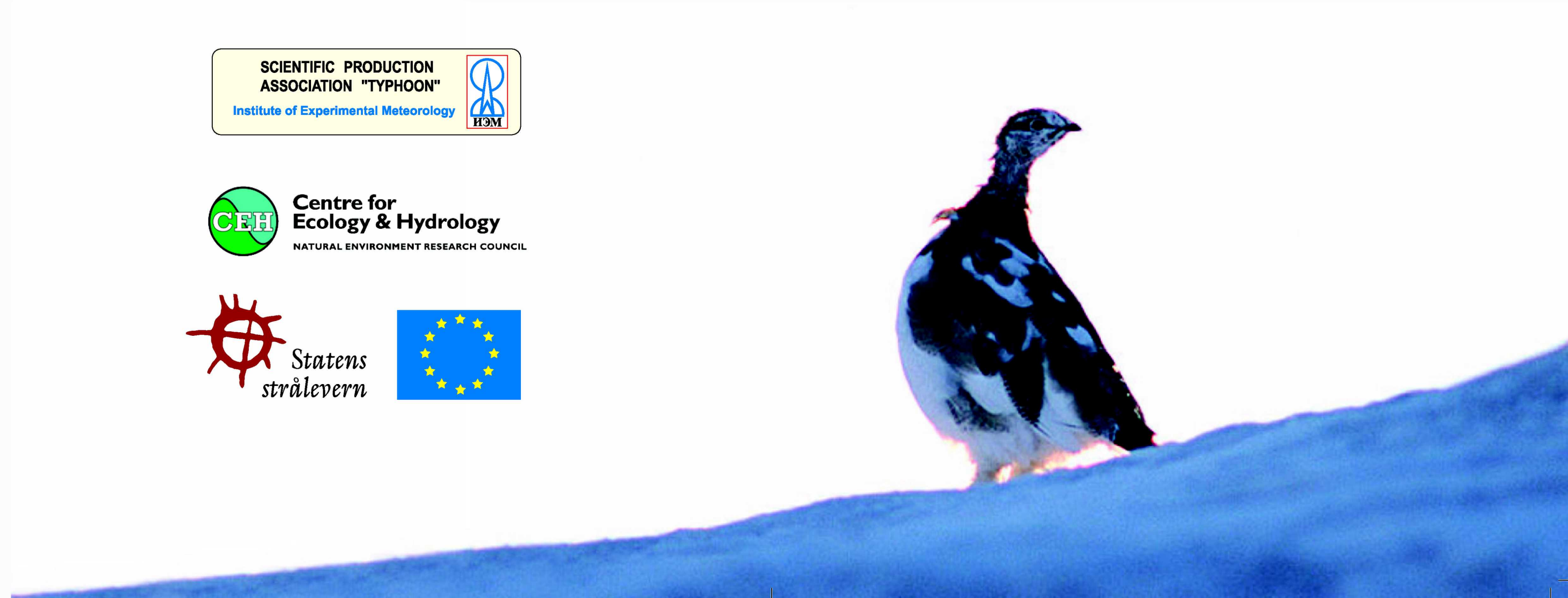

CENTRE FOR ECOLOGY AND HYDROLOGY
NATURAL ENVIRONMENT RESEARCH COUNCIL

Environmental Protection from Ionising Contaminants (EPIC)

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Transfer and Uptake Models for Reference Arctic Organisms

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Environmental **P**rotection from **I**onising **C**ontaminants (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

There are a number of national and international initiatives to develop approaches for (demonstrating) the protection of the environment from ionising radiation. The EPIC project aims to develop a methodology for the protection of natural populations of organisms in the Arctic environment from radiation. There is increasing concern over potential radioactive contamination of the European Arctic due to the wide range of nuclear sources. Environmental characteristics of the Arctic mean that it may be more vulnerable to contaminants than organisms in other European climatic regions.

In this report, the available data and models for estimating the transfer of radionuclides to Arctic reference organisms (as defined in the first EPIC deliverable) are reviewed. These will be used in future work to enable internal doses to be estimated. Arctic freshwater, marine and terrestrial ecosystems are considered in turn.

Arctic Freshwater Ecosystems

A review of the available literature has shown that there are few Arctic-specific concentrations ratios for freshwater biota. However, a proven dynamic model is available for describing the behaviour of selected radionuclides in abiotic and biotic components of freshwater ecosystems. For some radionuclides (Cs, Sr, P, Mn, Zn, I and Co) rates of uptake by fish are modelled using temperature dependent 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 we have only considered modelling approaches for Arctic lakes these could be adapted to Arctic rivers in combination with an appropriate a river transport model.

Marine

Concentration factors values for many marine biota are available within international reviews. Whilst these tend to be for edible tissues it is possible that in some cases they could be transformed into whole body burdens using published distributions of radionuclides within organisms. However, they are not specific to the Arctic where transfer may be influenced by environmental factors such as low temperature, seasonal variation in light intensity and ice cover.

Arctic–specific data have been collated for Cs, Pu, Sr and Tc from the open literature and are recommended to be used as supplementary information, although, in general, the collated Arctic concentration factors are similar to those for temperate environments.

Dynamic models have been used for the prediction of radionuclide activity concentrations in Arctic marine species has been demonstrated. Allometric relationships have been used in several cases where empirical data were unavailable for model parameterisation. The preliminary model appears to give reasonable predictions for ^{137}Cs and ^{239}Pu and demonstrates the fact that high trophic level organism may take very long time periods to become equilibrated with ambient water concentrations. Such an approach could also be used to provide missing data for Arctic freshwater ecosystems.

Marine contaminant transport models, some of which have been applied to the Arctic and include parameters of ice flow and formation, are reviewed.

Terrestrial

Data describing the transfer of radionuclides from soil–reference biota have been collated. The most abundant data were for radiocaesium and radiostrontium although many data for natural radionuclides were available from studies from the Arctic. No data were available for describing the transfer of some radionuclides to Arctic biota.

Allometric-kinetic models were also used to try to provide estimates of transfer for radionuclide-biota combinations for which data were lacking using, where possible, soil–plant transfer parameters derived during the review. Predicted values were in good agreement with observed data for some radionuclides (e.g. Cs, U) although less so for others. However, for some radionuclides where comparison appeared poor there was relatively little observed data with which to compare and the developed models were very simplistic not considering all transfer pathways.

There are no bespoke models to enable the dynamic prediction of radionuclide transfer to Arctic biota. One available human foodchain model includes limited parameterisation for Cs and Sr transfer in Arctic ecosystems. This has been relatively easily adapted to estimate ^{137}Cs and ^{90}Sr transfer to some Arctic biota and could be readily adapted to other radionuclide – reference organism combinations. However, there are many factors of Arctic ecosystems which may influence radionuclide behaviour including short growing seasons, prolonged freezing of soil, and effects of low temperatures on biological rates. However, whilst the influence of some of these has been documented, they are not included within existing predictive models. If exposure to ionising radiation within Arctic terrestrial ecosystems is to be robustly predicted such factors must be fully understood and properly incorporated into models.

Contents

1. INTRODUCTION

There are a number of national (e.g. Jones *et al.* 2003; Copplestone *et al.* 2001; Amiro 1997) and international (e.g. Strand & Larsson 2001; IAEA 2002; IUR 2002; ICRP 2003) initiatives to develop approaches for (demonstrating) the protection of the environment from ionising radiation.

The EPIC project aims to develop a methodology for the protection of natural populations of organisms in the Arctic environment from radiation. There is increasing concern over potential radioactive contamination of the European Arctic (AMAP 1998; Bøhmer *et al.* 2001) due to the wide range of nuclear sources including: power plants; nuclear powered vessels of the Russian military and civilian fleets; discharges from nuclear reprocessing plants; sites of weapons tests and peaceful nuclear explosions (Strand *et al.* 1997). Low temperatures, extreme seasonal variations in incoming solar radiation and lack of nutrients are some of the 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 this report, we review the available data and models for estimating the transfer of radionuclides to Arctic biota to enable internal doses to be evaluated; a review of suitable dosimetric models for use in the project can be found in Golikov & Brown (2003).

1.1. European Arctic

The area considered in EPIC is the European Arctic here defined as northern Scandinavia, northwest Russia (west of the Urals), the islands of Franz Joseph Land, Novaya Zemyla and Svalbard, and the Barents, Kara, White and Greenland Seas including the northern part of the Norwegian Sean (Figure 1.1). The Arctic can be divided into three regions - the High, Low and Sub- Arctic - based upon climatic characteristics of terrestrial ecosystems although we have extended this to include marine areas (see Beresford *et al.* 2001). A summary of the marine, freshwater and terrestrial ecosystems of the European Arctic together with lists of the species found in these ecosystems can be found in Beresford *et al.* (2001).

1.2. Reference Arctic Organisms

A problem in the development of an environmental protection framework is the diversity and number of flora and fauna species. In response to this, the use of *reference organisms* has been suggested to represent flora and fauna for which doses and potential effects are to be predicted (Pentreath & Woodhead 2001). In an earlier report we described an approach for the selection of reference organisms for European Arctic ecosystems on the basis of radiosensitivity, likely internal and/or external exposure, ecological niche, distribution and amenability for research and monitoring (Beresford *et al.* 2001); the proposed reference organism list was later refined (Brown 2003). The selected reference organisms for freshwater, marine and terrestrial ecosystems are presented in Table 1.1 together with suggested representative (typical and ubiquitous) species of each organism. These organisms are a potential list for use in assessment of the impact of ionising radiation in the Arctic. They may not all be applicable to any given evaluation but are sufficiently broad ranging to enable assessments to be conducted throughout different Arctic ecosystems. Within this report we will not consider the transfer of radionuclides to some of the reference organism groups as their small size means that we can assume their activity concentration to be unity with the surrounding media in any dose assessment. Reference organisms within Table 1.1 not considered in this report are soil micro-organisms, soil invertebrates, benthic bacteria, phytoplankton and small zooplankton (e.g. Rotifera).

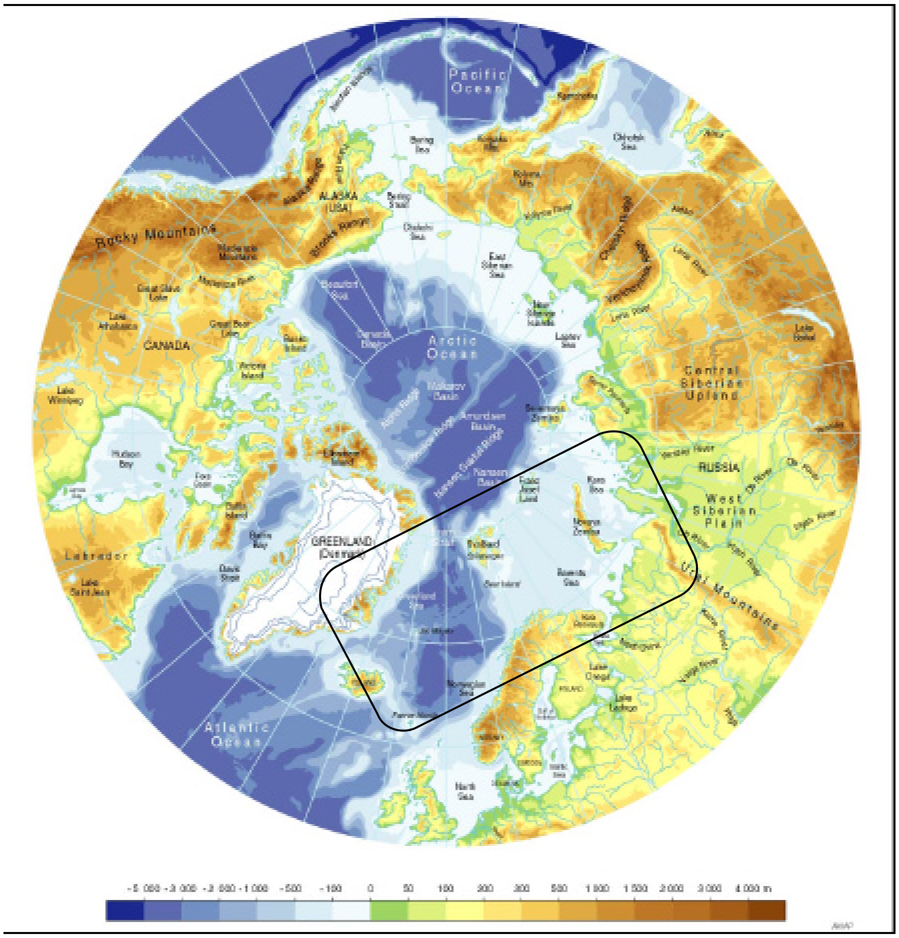

Figure 1.1. Topography and bathymetry of the Arctic (taken from AMAP 1998); the box delimits the approximate area of the European Arctic as defined within EPIC.

Table 1.1. Reference European Arctic organisms and representative species for freshwater, marine and terrestrial ecosystems as proposed by the EPIC project.

Freshwater

Reference organism	Representative species
Benthic bacteria	Not applicable
Aquatic plants	‘Freshwater monocotyledons’ (e.g. *Carex* spp.)
Phytoplankton	Not applicable
Zooplankton	Rotifera
Insect larvae	*Chironomid* spp.
Pelagic planktotrophic fish	*Coregonus peled* (northern whitefish), *Coregonus laveretus* (cisco) & *Coregonus albula* (shallow-water cisco)
Pelagic carnivorous fish	*Esox lucius* (pike)
Benthic fish	*Coregonus lavaretus* (cisco) & *Salvelinus alpinus* (Arctic char)
Carnivorous mammal	*Mustela lutrecla* (mink)
Fish egg	Not applicable

Marine

Reference organism	Representative species
Benthic bacteria	Not applicable
Macroalgae	*Fucus* spp.
Phytoplankton	Not applicable
Zooplankton	*Pandalus borealis*
Polychaetes	*Lumbrineris* spp.
Pelagic planktotrophic fish	*Boreogadus saida* (polar cod)[1] *Mallotus villosus*[2] *Clupea harengus* (herring)[3]
Pelagic carnivorous fish	*Gadus morhua* (cod)
Benthic fish	*Pleuronectes* spp. (e.g. *Pleuronectes platessa*, plaice)
Carnivorous mammal	'Seals' (*Erignathus barbatus* & *Phoca hispida*)
Benthos eating bird	*Somateria mollissima*
Fish egg	Not applicable

[1] High & Low Arctic
[2] Low & Sub Arctic
[3] Sub Arctic

Terrestrial

Reference organism	Representative species
Soil micro-organism	Not applicable
Lichens & Bryophyte	*Cladonia* spp.
Gymnosperm	*Juniperus* spp., *Larix dahurica*, *Picea obovata*
Monocotyledon	*Carex* spp., *Luzula* spp., *Festuca* spp.
Dicotyledon	*Vaccinium* spp.
Soil invertebrate	Collembola & mites
Herbivorous mammal	'Lemmings and voles' (*Dicrostonyx* spp., *Myopus* spp., *Lemmus* spp., *Microtus* spp., *Clethrionomys* spp. & *Eothenomys* spp.)[3] Reindeer (*Rangifer tarandus*)[4]
Carnivorous mammal	'Foxes' (*Vulpes vulpes* & *Alopex lagopus*)
Herbivorous bird and egg	*Lagopus* spp.

[3] Burrowing species common throughout Low- and Sub- Arctic
[4] Occurs in all three Arctic regions

1.3. Radionuclides considered

In Beresford *et al.* (2001), we selected a number of anthropogenic and natural radionuclides appropriate to assessments in the European Arctic representing a range of environmental mobilities and biological uptake rates. These were radioisotopes of caesium, strontium, iodine, technetium, plutonium, americium, carbon, hydrogen, uranium, radium, thorium and polonium. Whilst derivation of transfer parameters for these radionuclides will form the basis of this deliverable, a number of additional radioisotopes which are routinely considered in aquatic assessments within the EPIC area (P, Mn, Co and Zn) will be also be addressed with respect to aquatic ecosystems.

2. FRESHWATER ECOSYSTEMS

Within this section we will consider the transfer of radionuclides, and its modelling, to reference freshwater organisms. The modelling approaches described could be adapted to Arctic rivers. However, the dynamic modelling of radionuclide behaviour in Arctic rivers requires a river transport model, which is outside the scope of this project.

2.1. Concentration Factor Values for Arctic Lake Organisms

Radionuclide uptake to freshwater organisms is usually quantified using equilibrium concentrations factors (CF) which is as the ratio of the radionuclide activity concentration in the organism (Bq kg^{-1} normally fresh weight (FW)) to that of lake water (Bq kg^{-1}). For practical purposes the activity concentrations in lake water are often defined as activity per unit volume (Bq L^{-1}) but this makes little difference to the value of the CF.

There are relatively few estimations of CF values for reference species within Arctic lakes. Watkins *et al.* (1997) were unable to find any Arctic specific freshwater CF values in their review of radionuclide uptake in natural and semi-natural ecosystems. Table 2.1 summarises ^{137}Cs and ^{90}Sr uptake by reference fish species from seven Russian Arctic lakes contaminated by global fallout.

Table 2.1. CF values (mean±standard deviation (SD)) for ^{137}Cs (in muscle) and ^{90}Sr (in bone) for freshwater fish from lakes in Arctic Russia (reproduced from Beresford *et al.* 2001).

Fish species	Trophic level	Caesium-137	Strontium-90
Shallow-water cisco	Planktophage	1350±286	1030±822
Cisco	Benthophage	1510±630	1730±1540
Perch	Predatory	7310±4687	1240±1202
Pike	Predatory	3860±2405	1030±728

2.2. Dynamic Modelling of Radionuclides in Arctic Lake Ecosystems

2.2.1. Behaviour of Radionuclides in Abiotic Components

A model for the behaviour of radionuclides in abiotic components of lakes has previously been presented (Goskomgidromet 1988; BIOMOVS 1996; Kryshev 2002a), and this model will be used here. The model has been successfully tested against data for several radionuclides, including ^{137}Cs and ^{90}Sr, in different freshwater ecosystems (BIOMOVS 1996; Kryshev 2002a). The model describes 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. Equations describing these processes are as follows:

$$\frac{dC_w}{dt} = -l_w C_w + l_{ws} C_s + d \cdot z_0 S_0 e^{-mt} \tag{2.1}$$

$$\frac{dC_s}{dt} = l_{sw} C_w - l_s C_s \tag{2.2}$$

where: C_w is radionuclide activity concentration in water (Bq m^{-3});
C_s is radionuclide activity concentration in bottom sediments (Bq m^{-3});

t is time (y);
l_w and l_s are rate constants for the loss of radionuclide from water and sediments, respectively (y^{-1});
l_{ws} and l_{sw} are the parameters of radionuclide exchange between water and sediments and sediments and water, respectively (y^{-1});
d is the rate coefficient of radionuclide intake from the contaminated catchment area (y^{-1});
z_0 is radionuclide concentration in the catchment area (Bq m^{-2});
S_0 is the area of catchment (m^2); and
μ is the coefficient of the loss of the radionuclide from the catchment via lake outflow (y^{-1}).

Parameters of radionuclide elimination and exchange between water and sediments are determined using the following formulas:

$$l = l_p + \frac{ba_{dw}}{H} + \frac{Ua_{pw}}{H} + \frac{Q_f a_{dw}}{V} \qquad (2.3)$$

$$l_s = l_p + \frac{ba_{ds}}{h} + \frac{U_r a_{ps}}{h} + \frac{S_r a_{ps}}{h} \qquad (2.4)$$

$$l_{ws} = \frac{ba_{ds}}{H} + \frac{U_r a_{ps}}{H} \qquad (2.5)$$

$$l_{sw} = \frac{ba_{dw}}{h} + \frac{Ua_{pw}}{h} \qquad (2.6)$$

where: l_p is radioactive decay constant (y^{-1});
V is volume of lake (m^3);
H is average depth of lake (m);
h is depth of the effective layer of bottom sediments (m);
Q_f is water flowage rate ($m^3 y^{-1}$);
U is rate of radionuclide transfer from water to bottom sediments (m y^{-1});
U_r is the rate of radionuclide transfer from sediments to water (m y^{-1});
S_r is average sedimentation rate (m y^{-1});
b is rate of diffusion of radionuclide between water and sediments (m y^{-1});
a_{dw} and a_{ds} are the proportions of radionuclide in dissolved form in water and sediments, respectively;
a_{pw} and a_{ps} are the proportions of radionuclide on particulate matter in water and sediments, respectively.

The initial conditions ($t = 0$) for an acute contamination event are:

$$C_w = (A_0/V) + C_{w0}, \text{ and}$$

$$C_s = C_{s0}.$$

where: A_0 is the total radionuclide activity entering the lake (Bq);
C_{w0} and C_{s0} are the activity concentrations in water and sediment prior to the contamination event (Bq m^{-3}).

The analytical solutions of Equations (2.1)-(2.6) allow radionuclide activity concentrations in water and bottom sediments of a contaminated lake to be dynamically predicted

2.2.2. Radionuclide Transfer to Reference Organisms

The ECOMOD model as previously described in Sazykina (2000), Kryshev & Ryabov (2000) and Kryshev (2002a,b) was developed for freshwater ecosystems and has been used to predict radionuclide concentrations in freshwater biota. Previous applications of the model to contaminated water bodies demonstrated good agreement between measured radionuclide concentrations and model predictions (Sazykina 2000; Kryshev & Ryabov 2000; Kryshev 2002a,b). The dynamics of the activity concentration of a radionuclide in freshwater organisms are estimated from:

$$\frac{dy}{dt} = -(l_r + e_A \cdot \frac{W}{M} + \frac{1}{M}\frac{dM}{dt}) \cdot y + \frac{Q_1^A}{Q_0^A} \cdot (\frac{1}{M}\frac{dM}{dt} + e_A \cdot \frac{W}{M}) \cdot X(t) \qquad (2.7)$$

where: y is the activity of radionuclide in a given tissue (Bq kg^{-1} fresh weight (FW));

t is time (y);

$X(t)$ is the radionuclide activity concentration in food (Bq kg^{-1} FW) or in water (Bq L^{-1}) when bioassimilation occurs directly from water at time t;

W is the general metabolic rate of an organism (kg y^{-1});

M is the mass of an aquatic organism (kg);

Q_1^A is the concentration of stable element in a given tissue (mg kg^{-1});

Q_0^A is the concentration of stable element in food or water (mg kg^{-1});

e_A is the dimensionless proportionality coefficient between the rate of biological loss of a radionuclide from a deposit tissue and the general metabolic rate of the organism;

l_r is the radioactive decay constant (y^{-1}).

Equation (2.7) enables the calculation of radionuclide dynamics in specific tissues of freshwater organisms. The rate coefficient, e_A, is for the tissue with the slowest turnover of the given radionuclide; such an approach seems reasonable for predictions over time intervals greater than several days (Kryshev & Ryabov 2000; Kryshev 2002a,b). Radionuclide activity concentrations in freshwater invertebrates and plants are estimated using radionuclide specific CF values. Such a simplification is reasonable because equilibrium between radionuclide activity concentrations in the organism and water is established fairly quickly due to their small size (Kryshev & Sazykina 1994). The model can estimate activity concentrations of bioassimilated nuclides (Cs, Sr, P, Mn, Zn, I, Co) in reference organisms on the basis of concentrations of their stable analogous elements in water and aquatic organisms. For radionuclides which do not have a stable element (i.e. Ra, Po, Pu, Tc, Th, U), the knowledge of the equilibrium radionuclide CF is necessary. ECOMOD can predict the dynamics of radionuclide activity concentrations in aquatic organisms and equilibrium levels. Activity concentrations are calculated for critical tissues within the organisms accumulating the highest proportion of body burden (muscles for Cs; bones for Sr and Mn; whole body for Co and Zn); activities in non-accumulating tissues are estimated, using known proportions between the chemical compositions of different tissues.

To predict radionuclide activity concentrations in prey and predatory fish species of freshwater trophic foodchains, Equation (2.7) is transformed to the following:

$$\frac{dy_{prey}}{dt} = -(l_r + (e_A \frac{W}{M})_{prey} + (\frac{dM}{Mdt})_{prey}) y_{prey} + (\frac{Q_1^A}{Q_0^A})_{prey} \cdot ((e_A \frac{W}{M})_{prey} + (\frac{dM}{Mdt})_{prey}) CF_{food} \cdot C_w(t) \qquad (2.8)$$

$$\frac{dy_{pred}}{dt} = -(l_r + (e_A \frac{W}{M})_{pred} + (\frac{dM}{Mdt})_{pred})y_{pred} + (\frac{Q_1^A}{Q_0^A})_{pred} \cdot ((e_A \frac{W}{M})_{pred} + (\frac{dM}{Mdt})_{pred})y_{prey}(t) \tag{2.9}$$

where: the subscripts $_{prey}$ and $_{pred}$ relate to parameters for prey and predatory fish species, respectively;
CF_{food} is the average CF value for (invertebrate and/or plant) organisms which are consumed by prey fish; and
$C_w(t)$ is the radionuclide activity concentration in water at time t.

A logistic growth equation was used to estimate the mass-age dependence for fish in Arctic lakes:

$$M = \frac{M_{\max}}{1 + a \cdot \exp(-b \cdot t)} \tag{2.10}$$

where: M is the fish weight (g);
t is the fish age (y);
M_{max} (g), a and b (y^{-1}) are constant parameters.

Empirically derived parameters for Equation (2.10), derived from observed fish growth curves for Arctic Russian lakes (Winberg 1975; Hydrobiological 1966), are: for cisco M_{max} = 1200 g, a = 27.8 y^{-1}, b = 0.504 y^{-1}; and for pike M_{max} = 15000 g, a = 281.6 y^{-1}, b = 0.478 y^{-1}.

The metabolic rate, W (g FW d^{-1}), is proportional to a power function of fish weight (Winberg 1956; Ivlev 1962; Kryshev 2002a):

$$W = 0.0359 \cdot a_1 M^{a_2} \cdot \exp(0.093 \cdot TEMP) \tag{2.11}$$

where: $TEMP$ is water temperature (°C);
a_1 and a_2 are empirical parameters.

Values for a_1 and a_2 for freshwater and marine fish have been derived by Winberg (1956). Because the metabolic rate of fish is dependent upon water temperature, in Arctic ecosystems fish metabolic rates are low and the biological turnover of radionuclides in fish may be slower than in lakes of temperate ecosystems.

The ratio Q_1^A/Q_0^A in Equations (2.8 and 2.9) was assumed to be 1.0 for cisco for both radiocaesium and radiostrontium whilst for pike it was assumed to be 1.2 for radiocaesium and 0.6 for radiostrontium. Caesium-137 CF values in the food of shallow-water cisco and cisco were assumed to be 1300 and 1500, respectively, whilst the ^{90}Sr CF values in the food of shallow-water cisco and cisco were assumed to be 1000 and 1700, respectively. Under these assumptions, calculated equilibrium CF values agree with the observed equilibrium CF values in the reference fish species (see Table 2.1).

2.2.3. Demonstration of Dynamic Models Applied to Acute Freshwater Discharges

To demonstrate the prediction of radionuclide activity concentrations in selected reference Arctic lake fish species (Table 1.1), an acute contamination event resulting in initial ^{137}Cs and ^{90}Sr activity concentrations in lake water at time zero of 1 Bq L^{-1} was assumed. Predictions were made for a hypothetical lake with a surface area of 3.1 km^2; an average depth of 5 m; water outflow rate of 1 y^{-1}; depth of the effective layer of sediments of 0.05 m; and the proportion of ^{90}Sr and ^{137}Cs in dissolved form were assumed to be 0.9 and 0.8, respectively. It was assumed that radionuclides were released directly to the lake water and immediate uniform mixing in water occurred and the surrounding catchment was uncontaminated. Parameters describing the metabolism of the reference Arctic organisms were estimated using available literature data assuming an average lake water temperature of 7 °C (Winberg 1956, 1975). Cisco and pike were assumed to exclusively consume molluscs and cisco, respectively.

Predicted ^{137}Cs and ^{90}Sr activity concentrations in water, sediments and reference fish species are shown in Figures 2.1 and 2.2. Maximum ^{137}Cs activity concentrations in benthic fish (cisco) were reached 4-6 months after contamination whilst those in predatory fish (pike) were reached 1-2 years after contamination. The dynamics of ^{90}Sr activity concentrations of prey and predatory fish are considerably different from those predicted for ^{137}Cs. Over the first three years, ^{90}Sr activity concentrations are predicted to be higher in cisco than in pike, with pike becoming more highly contaminated between 3-13 years after contamination. Thereafter, cisco are predicted to become more contaminated than pike.

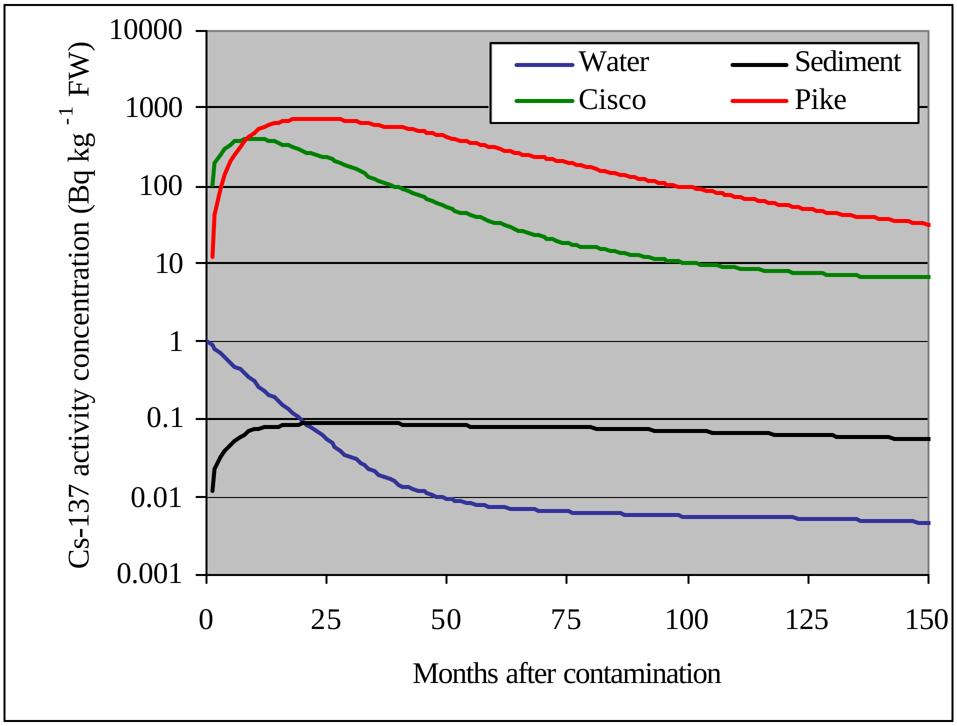

Figure 2.1. Predicted ^{137}Cs activity concentrations in different components of an Arctic lake ecosystem following an acute release resulting in a uniform 1 Bq L^{-1} of ^{137}Cs in water; predicted fish ^{137}Cs activity concentrations are for muscle.

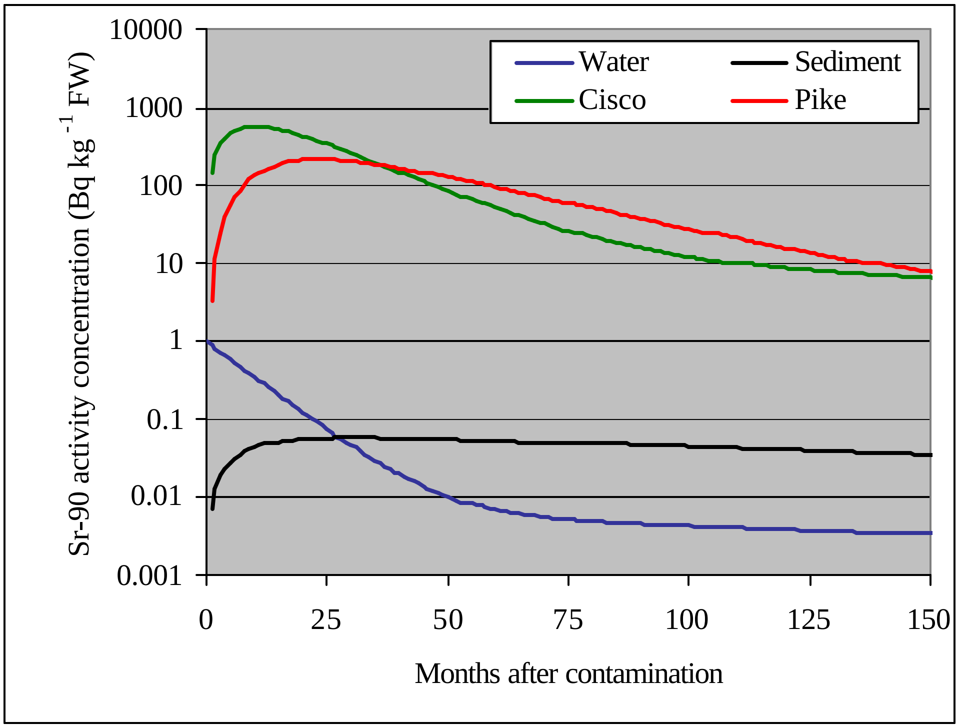

Figure 2.2. Predicted ^{90}Sr activity concentrations in different components of an Arctic lake ecosystem following an acute release resulting in a uniform 1 Bq L^{-1} of ^{90}Sr in water; predicted fish ^{90}Sr activity concentrations are for bone.

Predicted maximum radiocaesium and radiostrontium activity concentrations in fish from the Arctic lakes are higher than model predictions for lake fish in temperate regions (Kryshev & Ryabov 2000). This is because of higher CF values for radionuclides in Arctic lakes, which have comparatively low concentrations of stable elements. Furthermore, rates of radionuclide loss from fish in Arctic lakes are comparatively slow as a consequence of low water temperatures (Kryshev & Ryabov 2000).

2.3. Other Reference Organisms

Whilst we have identified reference freshwater mammal and bird species in EPIC, ECOMOD only provides predictions of radionuclide activity concentrations in invertebrate and fish species. It is possible that these 'missing' species could be modelled using allometric approaches. The potential use of allometric approaches to fill gaps within aquatic models is discussed and demonstrated within sections 3.2.2 and 4.1.2.1.

3. MARINE ECOSYSTEMS

Within this section we will consider the transfer of radionuclides, and its modelling, to reference marine organisms.

3.1. Radionuclide Transfer to Arctic Marine Organisms

3.1.1. Concentration Factor Approach

As with freshwater organisms, radionuclide uptake to marine biota is often based upon the use of equilibrium CF values (the ratio between the activity concentration in the organism (Bq kg^{-1} normally FW) to the ambient seawater (Bq kg^{-1} or more practically, Bq L^{-1}). The CF approach has the advantage of being simple and providing the assessor with a large and easily accessible database.

Numerous reviews and summaries of CF values have been made (e.g. IAEA 1985; Harrison 1986; Gomez *et al.* 1991). Within human dose assessments, CF values recommended by the International Atomic Energy Agency (IAEA 1985) are the most commonly used. Values from IAEA (1985) corresponding to radionuclides and organisms appropriate to the EPIC project, are given in Table 3.1.

Table 3.1. IAEA (1985) recommended CF values for generic marine organism groups.

Element	Phytoplankton	Macroalgae	Zooplankton	Mollusca[*]	Crustaceans	Fish
Caesium	2×10^{1}	5×10^{1}	3×10^{1}	3×10^{1}	3×10^{1}	1×10^{2}
Technetium	5	1×10^{3}	1×10^{2}	1×10^{3}	1×10^{3}	3×10^{1}
Strontium	3	5	1	1	2	2
Uranium	2×10^{1}	1×10^{2}	5	3×10^{1}	1×10^{1}	1
Thorium	2×10^{4}	2×10^{2}	1×10^{4}	1×10^{3}	1×10^{3}	6×10^{2}
Plutonium	1×10^{5}	1×10^{3}	1×10^{3}	3×10^{3}	3×10^{2}	4×10^{1}
Americium	2×10^{5}	2×10^{3}	2×10^{3}	2×10^{4}	5×10^{2}	5×10^{1}
Radium	2×10^{3}	1×10^{2}	1×10^{2}	1×10^{3}	1×10^{2}	5×10^{2}
Polonium	3×10^{4}	1×10^{3}	3×10^{4}	1×10^{4}	5×10^{4}	2×10^{3}
Carbon	9×10^{3}	1×10^{4}	2×10^{4}	2×10^{4}	2×10^{4}	2×10^{4}
Hydrogen	1	1	1	1	1	1
Iodine	1×10^{3}	1×10^{3}	3×10^{3}	1×10^{1}	1×10^{1}	1×10^{1}
Manganese	6×10^{3}	6×10^{3}	1×10^{3}	5×10^{3}	5×10^{2}	4×10^{2}
Cobalt	5×10^{3}	1×10^{4}	2×10^{3}	5×10^{3}	5×10^{3}	1×10^{3}
Zinc	3×10^{4}	2×10^{4}	2×10^{4}	3×10^{4}	5×10^{4}	1×10^{3}
Phosphorous[**]	-	-	2×10^{4}	2×10^{4}	3×10^{4}	5×10^{4}

[*] Excluding cephalopods

[**] IAEA (1985) do not present data for P; these have been derived from stable element data from Bowen (1979) and Morozov (1983).

Although the generic organism groups considered in IAEA (1985) are similar and, in some cases identical, to those selected as reference organisms within EPIC, the applicability of these data to the present work is partly limited because the emphasis of the IAEA (1985) review was on estimating human exposures. Therefore, data collation focused on those marine species consumed by humans. Furthermore, information was only collated for the edible body parts. When considering doses to biota, it is important to consider not only those parts of an organism eaten by man but also those body parts that might be of interest from a dosimetric or dose-effects perspective for the organism *per se* (e.g. the hepatic system where actinides and other heavy metal radionuclides can accumulation or the gonads which are important to consider with respect to fertility). Furthermore, the IAEA (1985) recommended CF values are generically applicable whilst EPIC is focusing on the Arctic where extreme physical conditions (e.g. temperature, seasonality in light intensity, ice cover etc.) may hypothetically significantly alter transfer to biota (Kryshev & Sazykina 1986, 1990; Sazykina 1995, 1998).

3.1.1.1. Collation of CF Data Specifically for the Arctic Environment

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 (see Figure 1.1). 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 1961-1999. 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. The compiled data are reviewed in Appendix A and presented as an electronic database in Appendix B; a summary of the available data is presented Table 3.2. Data have been broadly categorised on the basis of selected EPIC reference organisms (Beresford *et al.* 2001; see Table 1.1).

Table 3.2. Summarised information on number of data compiled from Arctic marine biota (see Appendix A and B).

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.

3.1.1.2. Recommendations for CF Values for Arctic Marine Reference Organisms

Collated CF data have been broadly organised under the reference organism headings considered within the EPIC project (Table 3.3). Summarised data for these species are presented in Table 3.4.

Table 3.3. Reference organisms in seas of the European Arctic

Reference organism	Habitat	Proposed reference species
Large fish	Predatory/mixed feeding	Cod
	Benthos-feeding	Haddock
Medium-size fish (non-predatory)	Pelagic	Herring
	Benthic	Plaice
Small fish	Pelagic	Polar cod
Bivalve mollusc	Benthic	Common mussel
Large crustacean	Benthic	Crab
Large crustacean	Pelagic	Northern pink shrimp
Sea mammal	Islands, coastal areas, ice	Greenland seal
Sea bird	Islands	Larus spp.

Table 3.4. CF values for the reference organisms estimated on the basis of the observed data from the EPIC database for the Arctic marine biota (L kg^{-1} FW).

Reference species	Caesium-137	Strontium-90	Technicium-99	Polonium-210	Plutonium-239,240	Americum-241
Cod	80±40	15±10	-	600	140±60	-
Herring	70±40	-	-	1000	<200	-
Plaice	100±30	8±5	-	5330	<200	-
Polar cod	100±50	5±3	-	3330	<200	-
Mussel (soft tissues)	50±14	-	300±200	6.0×10^4	150±110	2.0×10^4
Crab (muscles)	150±40	15±5 (Crustaceans)	1400±400	$(3.7\pm1.5)\times10^4$	300±200 (Crustaceans)	500 (lobster)
Shrimp (muscles)	35±11	15±5 (Crustaceans)	100	$(4.5\pm0.5)\times10^4$	300±200 (Crustaceans)	-
Gull	580±200	-	-	-	100±50	-
Greenland seal	70±20	10±5	-	$(2.1\pm0.3)\times10^4$ (sea mammals, muscles)	400±300 (sea mammals)	-

Estimated CF values for ^{137}Cs for fish (cod, *Gadus brosme*), sea mammals (whales and seals), and macroalgae (*Fucus vesiculosus*) display an obvious time dependence reflecting the slow response of organisms to the ambient seawater concentrations. The process of ^{137}Cs accumulation by marine biota was not in equilibrium over the long observational time periods considered in this study, illustrating the limitations associated with the application of the CF approach in marine models and impact assessments.

Several tentative conclusions relating to differences between uptake in Arctic environments compared to a world average can be drawn:

- Stontium-90 CF values in macroalgae, benthos and fish of the Arctic Seas appear to be higher than world averaged values; although in the case of macroalgae this may reflect the types of seaweed used in the assessment (red, green and brown) versus brown only. For benthos, we are comparing 2 somewhat different organism groups, i.e. benthic invertebrates such as annelids and echinoderms with pelagic zooplankton, and therefore the conclusion concerning this group is highly tentative.
- Caesium-137 CF values in invertebrates of the Arctic Seas are higher than the average values from generalized world data; however, they are similar to the world-averaged values for fish and macroalgae. Nonetheless, in line with the argument given above for ^{90}Sr, a direct comparison between invertebrates and zooplankton may be misleading. For seabirds, the limited extent of the available data renders any conclusion concerning similarities or differences in datasets uncertain. Moreover, the ANWAP report concerns Arctic environments and therefore comparisons between Arctic and temperate seas is not possible.
- Plutonium-239,240 and ^{99}Tc CF values in fish, mammals, and macroalgae from the Arctic Seas have great variability and in some cases these CF values are higher than the world average data.

With so few data and the problems associated with compatibility of (generic and Arctic) data sets, little can be said on the effect of Arctic conditions upon uptake. What is clear though, is the paucity of data and associated large uncertainties. The CF values for many species are based on only one data value. Furthermore, in the context of environmental impacts assessments, there are a lack of data on radionuclide distributions within organisms. In view of these comments, it might be concluded that no urgent recommendation can be made to apply Arctic-specific CF values instead of generic values.

In the collation exercise above, only four radionuclides have been considered. The initial list of radionuclides to be considered within the EPIC project comprised a further 9 radionuclides. A preliminary search has indicated that very few Arctic species data exist for a number of the other radionuclides of interest including ^{241}Am, U, Th and Po. In some cases, stable analogues could be used to supplement datasets. It can be argued that collating CF data for some of these radionuclides may be of limited value (e.g. in the case of ^{40}K where a release scenario which could lead to activity levels in the environment significantly above those occurring naturally cannot be envisaged).

3.1.1.3. Limitations of the CF Approach

Aside from problems in deriving suitable CF values on the basis of the available sparse data, a major drawback of the CF approach is that the assumption of equilibrium is often invalid (see Figure 3.1). Alternative approaches for dynamically modelling the transfer from water/sediment to biota are discussed within the following section.

3.2. Dynamic Modelling of Radionuclide Uptake by Marine Organisms

3.2.1. Application of ECOMOD to Acute Marine Discharges

Elements of the ECOMOD model presented within Section 2.2 for freshwater ecosystems can be used to predict radionuclide activity concentrations in marine biota. Time-dependent radionuclide activity concentrations in marine organisms can be estimated using Equation (2.7); as with its application in freshwater ecosystems, Equation (2.7) can be used to predict radionuclide activity concentrations in specific tissues of marine organisms (see Section 22.2). As with freshwater ecosystems, radionuclide activity concentrations in marine invertebrates and plants are predicted using radionuclide specific equilibrium CF values (which due to the small size and rapid biological turnover rates in these organisms is appropriate; Kryshev & Sazykina 1994).

Equations (2.8 and 2.9) can be used to predict radionuclide activity concentrations in prey and predatory fish species within Arctic marine ecosystems. The approach used by Winberg (1956) to calculate metabolic rate as a function of water temperature (Equation (2.11)) has also been used for marine fish. Parameters Q_1^A, Q_0^A, CF_{food} have been selected from Tables 3.4 and 3.5 and the growth rate of fish was simulated using a logistic growth equation. Weights from the reference organism descriptions (to be presented in EPIC Deliverable 4) were also used.

Dynamic predictions of ^{137}Cs, ^{90}Sr, ^{32}P, ^{60}Co, ^{65}Zn, ^{54}Mn, ^{131}I and ^{226}Ra activity concentrations in selected Arctic marine reference organisms assuming an acute release sufficient to result in initial (t=0) seawater radionuclide activity concentrations of 1 Bq L^{-1} have been made using ECOMOD. The calculations were performed for a hypothetical marine area with: a volume of 1 km^3; an average depth of 100 m; a water exchange rate of 10 y^{-1}; a particulate matter concentration in seawater of 0.01 kg·m^{-3}; and a sedimentation rate of 0.5 kg·m^{-2}·year^{-1}. Radionuclide activity concentrations in sea water and sediments were made using the standard EC methodology (EC 1995). To consider the effect of water exchange rate upon predicted activity concentration in reference organisms a water exchange rate of 100 y^{-1} was also modelled. Following radionuclide release, immediate uniform mixing within the hypothetical marine area was assumed. Polar cod are assumed to be the prey species of cod, polar cod and herring consume zooplankton and plaice consume molluscs.

Model predictions for plaice are presented in Figure 3.1: the figure presents results for the 10 y^{-1} water exchange rate scenario (typical for a bay with a relatively slow exchange of water with the open sea). The temporal variation in predicted radionuclide activity concentrations made assuming a high rate of water exchange equal to 100 y^{-1} (typical for areas of open sea; Figure 3.2) do not differ significantly to those predictions for a low water exchange rate of 10 y^{-1}. However, the peak radionuclide activity concentrations in fish tissues are approximately one order of magnitude lower for each radionuclide because of the higher rate of removal of radionuclides from the model marine area.

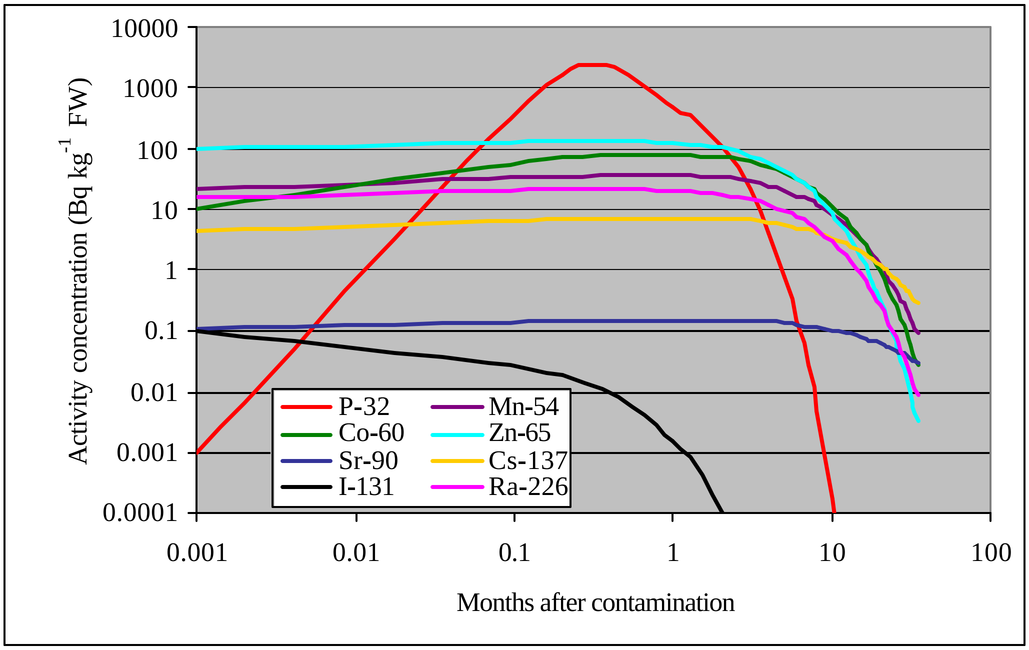

Figure 3.1. Model predictions of activity concentrations in plaice assuming an acute release scenario. Results are presented for a water exchange rate of 10 $year^{-1}$.

The dynamics of the decrease of long-lived radionuclides in fish are determined by the rate coefficient of biological loss, e_A, which is proportional to the overall metabolic rate. The metabolic rate of fish is dependent on water temperature; metabolic rate being slower at lower temperatures. Therefore, for Arctic organisms both the general metabolic rate and consequently the rate of radionuclide loss may be slower than for organisms from temperate seas.

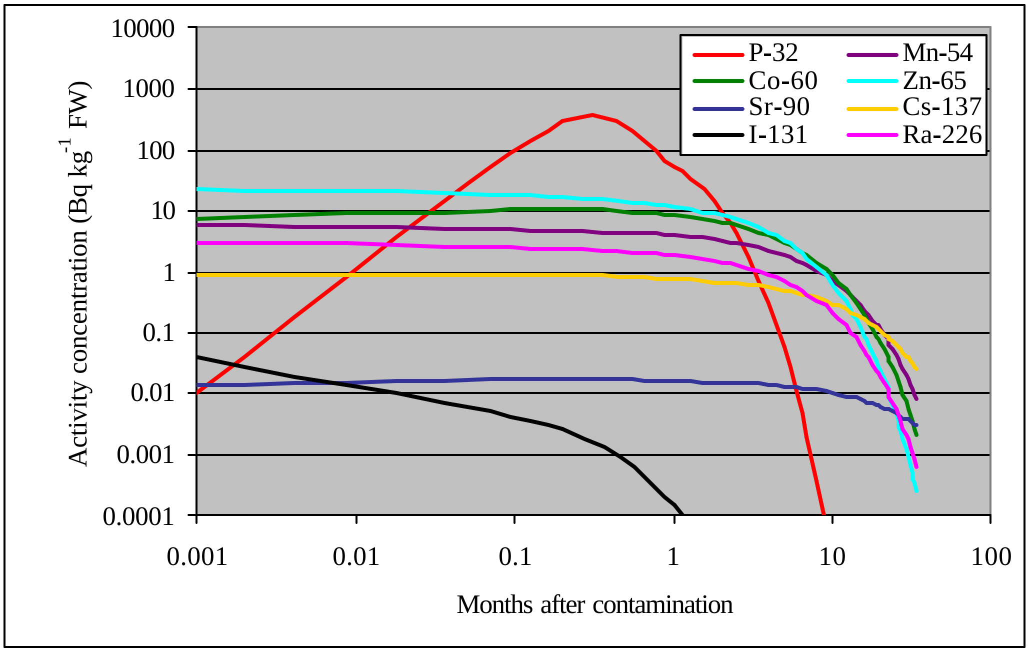

Figure 3.2. Model predictions of activity concentrations in plaice assuming an acute release scenario. Results are presented for a water exchange rate of 100 year^{-1}.

Figure 3.3 demonstrates temporal variation of ^{137}Cs within the foodchain *zooplankton – polar cod – cod* (assuming a water exchange rate of 10 y^{-1}). The time delay in reaching peak activity concentrations can be seen to increase with successive trophic levels. These predictions are supported by observation in the Baltic Sea following the Chernobyl accident (Kryshev 1992).

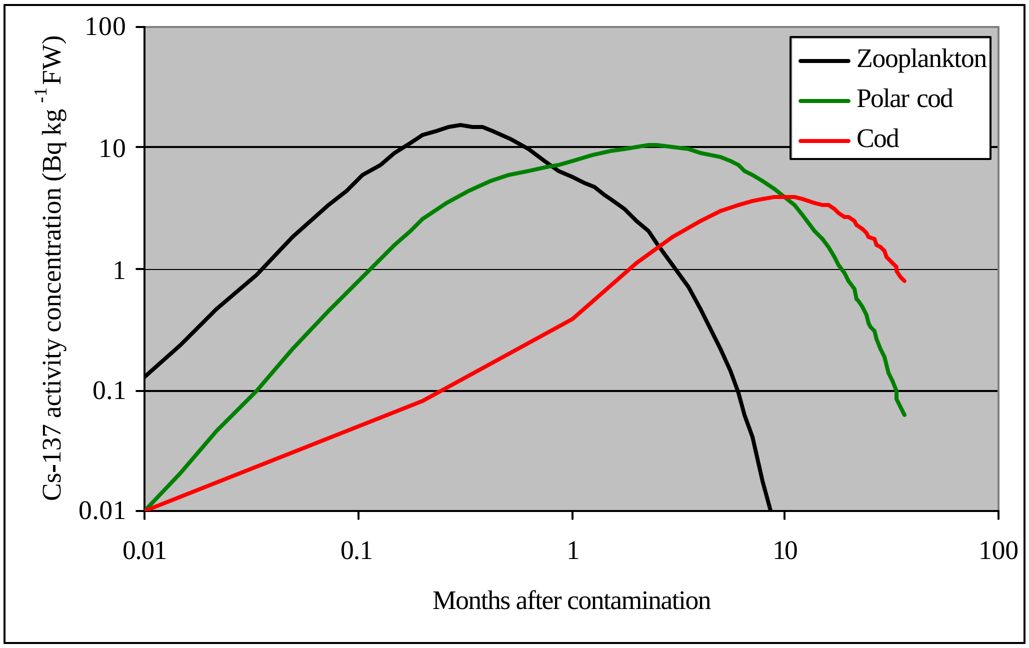

Figure 3.3. Model predictions of ^{137}Cs activity concentrations in the foodchain *zooplankton – polar cod – cod* assuming an acute release resulting in a uniform 1 Bq L^{-1} in seawater. Results are presented for a water exchange rate of 10 year^{-1}.

Figure 3.4 compares temporal variation in the predicted ^{137}Cs activity concentrations in different reference fish species. The effect of size and metabolic rate can be seen by comparing polar cod and herring: polar cod is the smaller species and consequently has the highest basal metabolic rate resulting in a higher rate of radionuclide uptake and elimination.

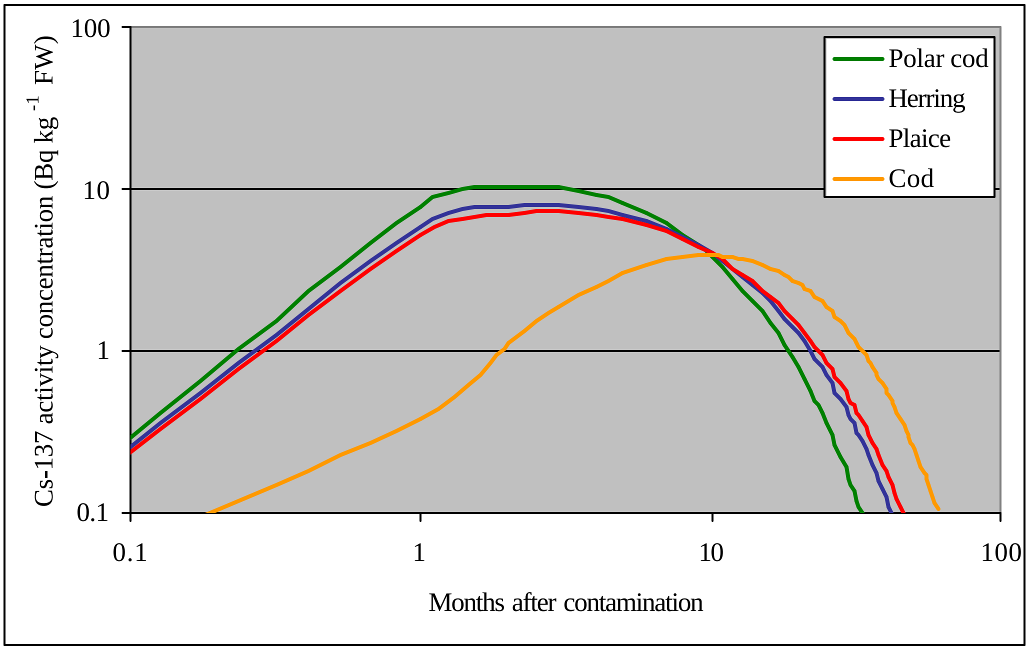

Figure 3.4. Model predictions of ^{137}Cs activity concentrations in different reference fish species assuming an acute release resulting in a uniform 1 Bq L^{-1} in seawater. Results are presented for a water exchange rate of 10 year^{-1}.

3.2.2. Biokinetic Allometric Model

It is obvious, from a consideration of Table 3.4, that Arctic specific CF values are unavailable for many of the reference organism-radionuclide combinations for which the environmental protection framework is required. Even if the generic data for the world oceans are employed (Table 3.1), with the limitations on use considered in Section 3.1 having been accepted, the uptake of many radionuclides to certain reference organism types are poorly, if at all, described. A good example can be presented for sea mammals and birds for which data coverage extends only to a handful of radionuclides and the few data available are for ^{137}Cs. In such cases, biokinetic models may allow equilibrium CF values to be estimated Where data are lacking on some of the parameters required for simulation, allometric relationships may provide surrogate values. The allometric approach is based on the observation that metabolic parameters, including basal metabolic rates, ingestion rates, biological half times, etc., are proportional to the size of an organism (this is further discussed in Section 4.1).

To demonstrate how this type of model might be employed to fill knowledge gaps, a simple food-chain model has been developed to consider the transfer of selected radionuclides (^{137}Cs and ^{239,240}Pu) to reference organisms in a pelagic foodchain: *phytoplankton-zooplankton–polar cod-harp seal*. The structure of the foodchain is based on information in the open literature (Dommasnes *et al.* 2001) and is represented in Figure 3.5.

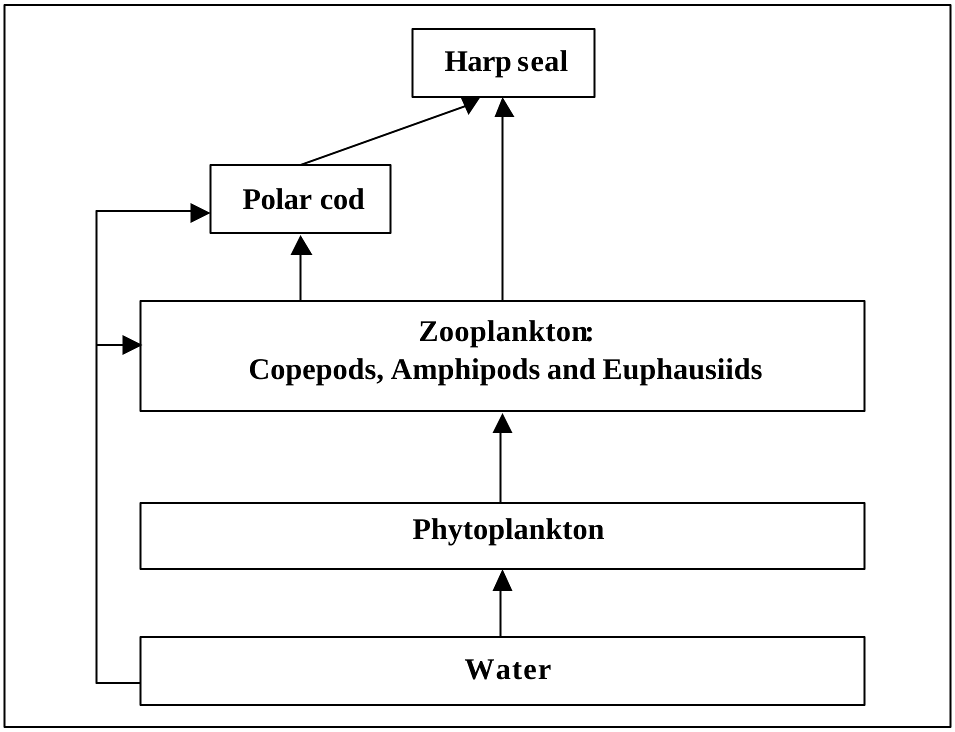

Figure 3.5. Foodchain model for harp seal in the Barents Sea, simplified from Dommasnes *et al.* (2001).

3.22.1. Biokinetic Allomteric Model Structure

The model, based on the work of Thomann (1981), Landrum *et al.* (1992) and Fisher (2002), considers uptake via food and water for aquatic organisms. Excretion/elimination rate is considered to be independent of the uptake route and the assimilation efficiency is considered to be independent of food type. A further simplification is that the phytoplankton and the zooplankton (trophic levels 1 and 2) are considered as homogeneous groups described by specified parameter values rather than ranges. We also make the simplifying assumption that the growth rate for all organisms is 0. This latter assumption may be a particularly poor one (Thomann 1981), but the complexity of the weight dynamics for the organisms in question will require more detailed study currently possible.

The time-dependent transfer of radionuclides within the foodchain can be described by simple first order differential equations for each of the trophic levels.

Trophic level 1: Phytoplankton (equilibrium with water concentration):

$$C_p = BCF \cdot C_w \tag{3.1}$$

where: C_p is the radionuclide activity concentration in phytoplankton (Bq kg^{-1} FW);
BCF is the bioconcentration factor for phytoplankton (L kg^{-1}); and
C_w is the radionuclide activity concentration in sea water (Bq L^{-1}).

Trophic level 2: Zooplankton (uptake via water and food):

$$\frac{dC_z}{dt} = AE_z \cdot IR_z \cdot C_p + k_{uz} \cdot C_w - C_z \cdot k_{ez} \tag{3.2}$$

where: AE_z is the assimilation efficiency (dimensionless) for zooplanton;

IR_z is the ingestion rate per unit mass of zooplankton (kg FW d^{-1} per kg FW);
C_p is the activity concentration in phytoplankton (Bq kg^{-1} FW);
k_{uz} is the uptake rate of radionuclide to zooplankton directly from water column (d^{-1});
C_w is the activity concentration in water (Bq L^{-1});
C_z is the activity concentration in zooplankton (Bq kg^{-1} FW);
k_{ez} is the excretion rate from zooplankton (d^{-1}).

Trophic level 3: Polar Cod (uptake via water and food):

$$\frac{dC_{pc}}{dt} = AE_{pc} \cdot IR_{pc} \cdot C_z + k_{upc} \cdot C_w - C_{pc} \cdot k_{epc} \tag{3.3}$$

where AE_{pc} is the assimilation efficiency (dimensionless) for polar cod;
IR_{pc} is the ingestion rate per unit mass of polar cod (kg FW d^{-1} per kg FW);
k_{upc} is the uptake rate of radionuclide to polar cod directly from water column (d^{-1});
C_{pc} is the activity concentration in polar cod (Bq kg^{-1} FW);
k_{epc} is the excretion rate from polar cod (d^{-1}).

Trophic level 4: Harp Seal (uptake via food only):

We assume that the uptake of radionuclides directly from the water column to the harp seal is negligible and that the harp seals diet, in simplified terms, consists of 50 % polar cod and 50 % zooplankton.

$$\frac{dC_{hs}}{dt} = 0.5 \cdot (AE_{hs} \cdot IR_{hs} \cdot C_z) + 0.5 \cdot (AE_{hs} \cdot IR_{hs} \cdot C_{pc}) - C_{hs} \cdot k_{ehs} \tag{3.4}$$

where: AE_{hs} is the assimilation efficiency (dimensionless) for harp seal;
IR_{hs} is the ingestion rate per unit mass of harp seal (kg FW d^{-1} per kg FW);
C_{hs} is the activity concentration in harp seal (Bq kg^{-1} FW);
k_{ehs} is the excretion rate from harp seal (d^{-1}).

From studies conducted under laboratory conditions, it is assumed that the uptake of actinides by phytoplankton cells reaches equilibrium with their ambient media within a few days (Fisher *et al*. 1983). This is also true for other actinides including Am, Cf, and Np. This supports (at least partially) our simplifying assumption at the basis of the model, i.e. that equilibrium between seawater and phytoplankton occurs instantaneously.

3.2.2.2. Parametrisation of Biokinetic Allometric Model

Bioconcentration Factors for Phytoplankton

IAEA's Technical Report 247 (IAEA 1985) derives a fresh weight Cs CF of 20 based on the discussion made by Styron *et al.* (1976). It is interesting in the context of EPIC to note that a wide range of CF values were reported by Styron *et al.* (1976) for marine phytoplankton (CF range 1-403 based on a dry weight basis) in response to changes in temperature (experimental range between 4-40 °C) and salinity (experimental range between 3.5-44 ppt). Another key parameter that can influence the CF is phytoplankton population growth.

Assuming that marine phytoplankton contain approximately 96 % water (Styron *et al.* 1976), more recent experimental data reported by Heldal *et al.* (2001) can be transformed to a FW CF for ^{137}Cs. CF values (DM basis) of up to 1×10^3 for growing cells and 2.5×10^3 for non-growing cells (temperature of 12± 1 °C in both experiments) were reported by Heldal *et al.* (2001). This converts to a FW CF values of up to 40 and 100 for growing and non-growing cells, respectively. No significant differences in the uptake of ^{137}Cs between species were observed.

Due to a lack of more detailed information, the generic values reported in IAEA's Technical Report 247 (IAEA 1985) have been used for the radionuclides considered. CF values of 20 and 1 ×10^5 have been reported for Cs and Pu, respectively.

Feeding Parameters for Organisms

Food consumption or ingestion rates (normalised to the FW of the organism) have been tabulated by Thomann (1981) for different trophic levels (Table 3.5). Polar cod have been defined as a large fish, although in reality they probably intersect trophic levels 3 and 4 as defined by Thomann (1981). Adult polar cod may attain lengths of up to 40 cm and weigh several hundred grams.

Table 3.5. Assumed feeding parameters (Thomann 1981).

Organism (Trophic level)	Assumed weight range (g FW)	Food consumption (kg d^{-1} per kg FW)
Zooplankton (2)	0.001-1	0.105
Small fish (3)	0.005-50	0.017
Large fish (4)	5-5000	0.009

Innes *et al.* (1987) have provided the following allometric relationship for the ingestion rate, *IR* (kg FW d^{-1} per kg FW), for adult seals:

$$\mathrm{IR} = 0.079M^{0.71} \tag{3.5}$$

where: *M* is the weight of the seal (kg).

Assuming a seal weighing 160 kg, the derived (weight–normalized) ingestion rate is 0.018 kg FW d^{-1} per kg FW. This predicted value is higher than the ingestion rate presented in Table 3.20 for Trophic level 4, but might be accounted for by the fact that homoeotherms need to assimilate greater quantities of food to maintain body temperatures.

Water Uptake, Excretion Rates and Assimilation Efficiencies

Radionuclide-specific parameters defining uptake rates from water, excretion rates and assimilation efficiencies for zooplankton and fish are presented in Table 3.6. The parameter values for Trophic level (4), large fish, have been taken to be representative of polar cod.

Table 3.6. Parameters for ^{239}Pu and ^{137}Cs (Thomann 1981).

Trophic level	Plutonium-239			Caesium-137		
	k_u	k_e	AE	k_u	k_e	AE
Zooplankton (2)	18.7	0.05	0.01	0.49	0.03	0.5
Small fish (3)	0.3	0.02	0.01	0.07	0.003	0.5
Large fish (4)	0.01	0.01	0.01	0.01	0.0018	0.5

For the seal, assimilation efficiencies for both ^{137}Cs and ^{239}Pu have been set to the same value, that representative of lower levels in the food-chain. Direct radionuclide uptake from the water column is assumed to be zero.

An allometric relationship may be used to estimate the ^{137}Cs excretion rate for seal. The following equation has been applied by the United States Department of Energy (USDoE 2002) based on earlier studies (Whicker & Shultz 1982).

$$l_i = \frac{\ln 2}{3.5\, M^{0.24}} \tag{3.6}$$

where: ?$_i$ is the biological decay constant (d^{-1}); and
M is the mass of animal (g FW).

Equation (3.13) yields an excretion rate of 0.0112 d^{-1} for seal. Although this value has been used in this preliminary version of the model, it is apparent that using elimination rates derived using allometric relationships lead to a more rapid than expected loss from high level predators such as seal. The data in Table 3.6 suggest that the excretion rate decreases as trophic level increases although this trend may be offset because mammals are homoeothermic with concomitantly higher metabolic rates (for a stated mass). More work is required in deriving more robust excretion rate data for radiocaesium.

Similarly, a biological half-life can be derived for Pu based on a simple allometric relationship. This is defined as (USDoE 2002):

$$l_i = \frac{\ln 2}{0.8\, M^{0.81}} \tag{3.7}$$

and yields an excretion rate of 5×10^{-5} d^{-1} for a 160 kg seal.

However, this allometric relationship requires further investigation. The uptake and translocation of Pu is complex and will depend on a number of factors including the age of the mammal and variable removal rates are likely to be associated with different tissues (e.g. blood, muscle, bone, etc).

3.22.3. Implementation of Biokinetic Allometric Model

The compartmental model described above, with the parameter values described, has been implemented in the ECOLEGO modelling software. Caesium-137 and ^{239}Pu water activity concentrations have been set to unit concentrations and radioactive decay from each compartment is included. Simulation results of the biokinetic allometric model for ^{137}Cs and ^{239}Pu are shown in Figures 3.6 and 3.7, respectively.

For ^{137}Cs, the results suggest that equilibrium is not attained for higher trophic levels - polar cod and harp seal – after initial contamination for 2000 days. This has obvious implications in relation to the interpretation of field data if activity concentrations in water are changing rapidly with time. Biomagnification[1] appears to occur for the lower trophic levels, but is not occurring at the highest trophic level i.e. seal. However, the uncertainty associated with the excretion rate of ^{137}Cs for seal is large and this parameter has a significant effect on the equilibrium CF. Setting the ^{137}Cs excretion rate to 0.0018 (Table 3.6) results in a CF of several hundred for seal. Equilibrium ^{137}Cs CF values are approximately 50, 130 and 70 for zooplankton, polar cod and seal, respectively. These values appear sensible. They compare well with to IAEA (1985) recommended values of 30 for zooplankton and 100 for generic fish.

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[1] Biomagnification is an increase in body mass concentration of a contaminant as it passes from low trophic levels to higher ones

The ^{137}Cs value of 70 for seal corresponds directly to the value included in Table 3.4 for Greenland seal.

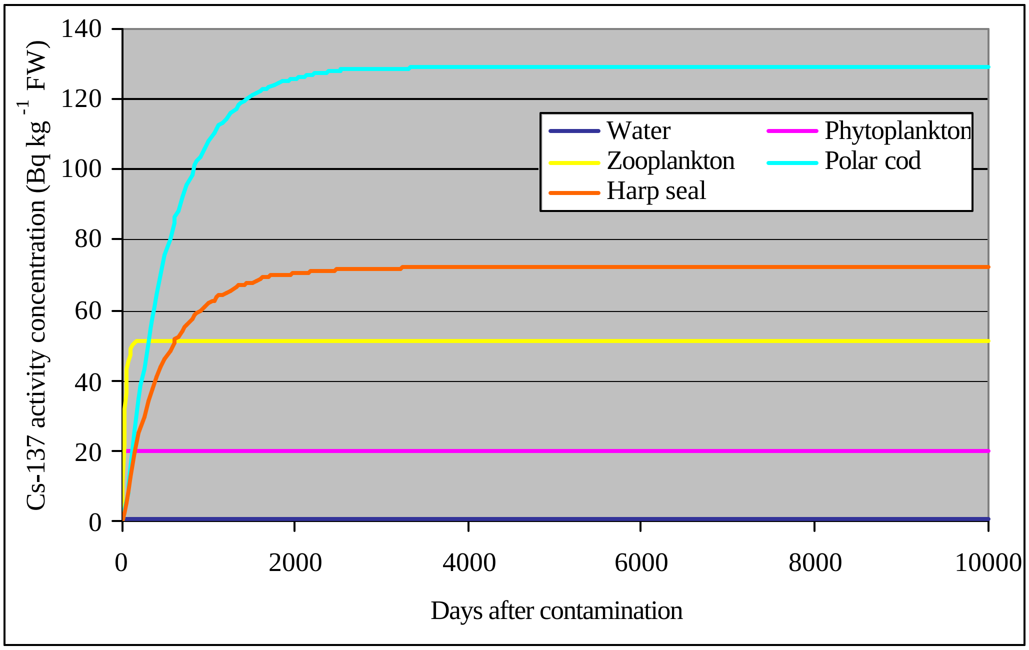


Figure 3.6. Predicted whole-body ^{137}Cs activity concentrations (FW) for selected marine organisms derived from the biokinetic allometric model.

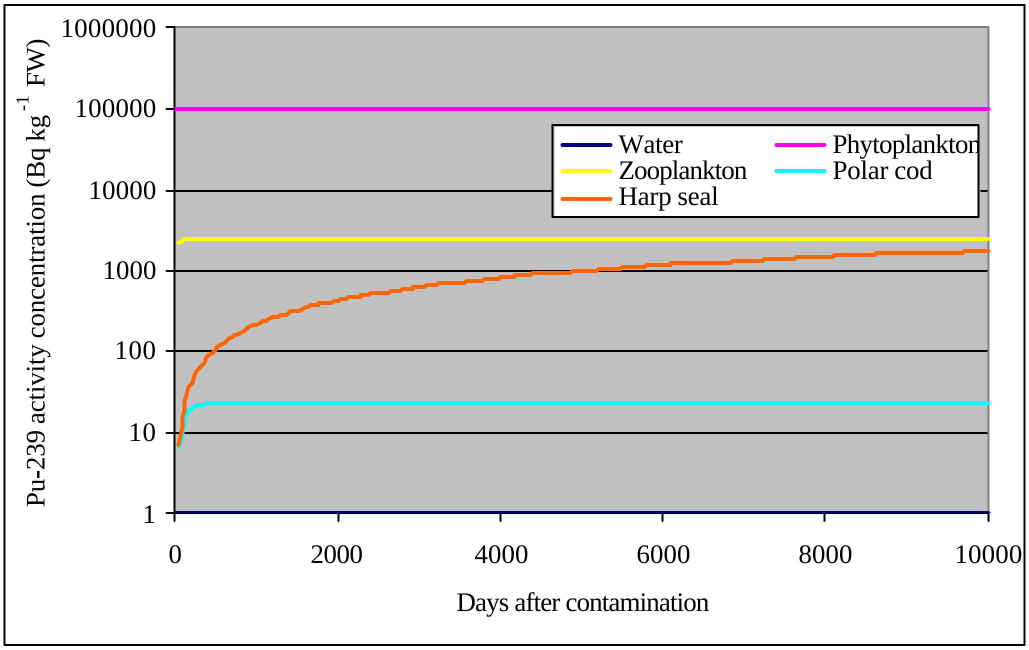


Figure 3.7. Activity concentrations (FW) of ^{239}Pu for selected marine organisms derived from biokinetic allometric modelling. Results for Polar cod and seal are for whole body.

Several points of interest arise from the simulation for ^{239}Pu (Figure 3.7). Transfer to successively higher trophic levels is low – there is a fall of several orders of magnitude between primary producers, represented by phytoplankton, and polar cod representing trophic level 3-4. However, the model predicts that this decreasing trend in activity concentrations along the food-chain is reversed for the highest trophic level, represented by seal. The simulated results for seal display activity concentrations in the region of 2 orders of magnitude higher than those observed for polar cod (one of its prey species) once the system has equilibrated. This prediction is strongly influenced by the other component of the seal's diet, zooplankton, which has a high activity concentration associated with it. Equilibrium is attained very slowly for seals (reflecting, in part, the very low, allometrically-derived excretion rate). In this case, equilibrium is only truly obtained after 6×10^4 days (165 years) of simulation. Clearly, equilibrium, even in the unlikely circumstance where water concentrations remain unchanged over highly protracted time scales, is unlikely to be attained over the life-time (in the order of decades) of the seal.

The model predictions compare quite favourably with the recommended values reported by the IAEA (IAEA 1985). The equilibrium Pu CF values of 2.5×10^3 and 25 predicted from model runs for zooplankton and polar cod, respectively, compare with IAEA recommended values of 1×10^3 and 40 (range 0.1-100) for zooplankton and generic fish, respectively. For seal, as discussed above, equilibrium is not obtained between the water and seal body compartments over the life time of the organism: a true equilibrium CF value of 4.5×10^3 is obtained after 165 years. However, following a 5 year equilibration period, a CF value of *circa* 390 is predicted. This latter value compares strikingly well with the empirically-derived value presented in Table 3.4 of 400 ± 300. However, the appropriateness of applying a Pu CF value to a high level predator, like seal, is clearly open to question.

3.3. Contaminant Transfer Models for Marine Ecosystems

A wide range of models have been developed to predict radionuclide transfer in marine ecosystems, although the majority were initially developed to estimate doses to humans via the ingestion of contaminated marine food products.

3.3.1. Model Structures

A number of modelling approaches have been used to simulate the physical transport of tracers or contaminants in marine environments varying from uniform and instantaneous mixing to three-dimensional (3-D) models where the movement of contaminants can be simulated in the vertical and horizontal planes. Three main model structures are used:

(i) Box models which subdivide the marine environment into large areas (or volumes) over which parameters are averaged. Uniform and instantaneous mixing is assumed to occur in each area and transfer at area boundaries is calculated depending upon model parameters (e.g. interface cross-section and flow rates). Empirical data sets or other models may be required to derive parameter values (e.g. hydrodynamic flow field) or to parameterise the model.

(ii) Finite element models integrate processes over small cells, typically triangular in shape. Cell sizes can vary so that the grid can fit complicated coastlines more realistically.

(iii) The finite difference method is another method for solving partial differential equations. The model structure replaces the model domain with a grid, which typically is rectangular.

3.3.2. Common Model Components

A number of (physical) processes are commonly simulated by many of the available models (IAEA 2003). In particular, any model that simulates the transport of a contaminant in a marine system will account, in some way, for water movement and the advection and dispersion of the contaminant within the water body. Some models additionally simulate the transport of sediment-bound contaminants. Some of these key processes are considered below.

3.3.2.1. Hydrodynamic Processes

Hydrodynamic processes which determine the characteristics of the water flow, i.e. water levels, pressure, velocity, fluxes, salinity, density and temperature can be modelled. The continuity equation (e.g. Bird *et al.* 1960) is used to compute vertical velocities or water levels from the horizontal velocity field, depending on its domain of integration (local cell or water column). Navier-Stokes equations (e.g. Bird *et al.* 1960) are used to define the relationship between the velocity and pressure. When the hydrostatic assumption is made, the pressure is proportional to the water level. Additonal equations may also be required to simulate processes including: transfer of momentum by advection, turbulent dispersion, bed friction, pressure gradients due to the surface elevations (barotropic mode) and to the density differences (baroclinic mode), the Coriolis force generated by the earth rotation on geophysical flows, etc. Physical processes that influence the hydrodynamics and are generated at the boundaries of the domain by external phenomena (tides, waves, wind, heating and cooling, discharge of a river) or occur within the domain (diffusion and dispersion, bed friction) can also be modelled.

3.3.2.2. Advection-Dispersion

Models have been developed to simulate the advection-dispersion of contaminants assuming that concentration changes, etc. have no significant effect on the hydrodynamics. The concentration of the substance in time and space is computed using advection-diffusion equations. In addition to the transport of the substance by advection and turbulent dispersion, the equation can include buoyancy, decay terms, or source-sink terms to represent the adsorption-desorption on cohesive sediments. Various kinds of substances can be considered in advection-dispersion models: dissolved or particulate matter, conservative or decaying tracers interacting or not with other substances (sediment, salt, etc.), and substances having different weights or densities (e.g. oil slicks). The salinity can be considered as a purely conservative tracer, (i.e. an element that reacts negligibly with the particulate phase and the concentration for which follows a linear mixing line). Therefore it can be used for the calibration of purely advective and diffusive effects (i.e. effects that exist in the absence of sediment interactions etc.).

The majority of radionuclides discharged into the aquatic environment are metallic elements. Hence, processes involved in modeling heavy metal transport can also be used for radioactive discharge modelling. Distribution coefficients (K_d's, defined as the ratio between the solid and solution phase concentrations) are often used to describe the equilibrium balance between dissolved and particulate phases (normally for the pelagic environment) assuming that exchanges of radionuclides between particulate phases and water are wholly reversible.

3.3.2.3. Sediment Models

Modelling radionuclide dispersion may require modelling of the transport of radionuclides associated with mineral sediments. A range of sediment transport models have been developed. The most suitable models are box or two-dimensional (2-D) horizontal models, that include a wide range of processes (e.g. hydrodynamics, advection-dispersion process, sediment dynamics and biological activity). Sediment dynamics modelling will need to consider the type of sediment (i.e. non-cohesive sands and gravels, and cohesive silts and clays). Advection-dispersion equations that include vertical settling (Stokes' Law and empirical laws of settling velocity) and erosion terms represent the transport of sediments by the bed load (rolling on the bottom), saltation (transport of sediments by bouncing along the surface) or suspended load (in suspension in the water column). More complex formulations (Mehta *et al*. 1982; and Hayter 1986) have been developed to take into account bioturbation of consolidated bed sediments.

3.3.3. Examples of Transfer Models

Numerous contamination transport models have been developed for use in European marine areas (for estuarine, coastal and open sea environments). The models more widely used in impact assessments include:

- The 2-D model VERSE is capable of simulating the hydrodynamics, sediment dynamics, radionuclide and trace metal dispersion in partially mixed estuaries (Gleizon 2002).
- Thw MIKE21 (DHI 2001) model which is a modular 2-D system for free surface flows. It is widely used for hydraulic modelling in estuaries, coastal waters, seas and also lakes.
- The Delft Hydraulics pilot model is a two dimensional depth-integrated model of the North Sea (Postma *et al.* 1987) developed to study the long-term impact of pollution from river discharges.
- The BSH model, developed to study the dispersion of ^{99}Tc from Cap de la Hague, in the English Channel and the North Sea (Schönfeld 1995), is a 3-D baroclinic circulation and Lagrangian dispersion model.
- The GHER model is a 3-D model used to determine the residual dispersion of ^{137}Cs on the European continental shelf seas (Djenidi *et al.* 1987).
- The IFREMER model is a 2-D depth-integrated Lagrangrian model of the English Channel (Salomon *et al.* 1987) and has been used to determine the residual dispersion of ^{125}Sb from Cap de la Hague, in the Golfe Breton-Normand.
- The POLCOMS model has been developed to model the dispersion of ^{137}Cs in and out of the Irish Sea (Prandle 1984) including the European continental shelf seas (Irish Sea, North Sea and English Channel). The model is depth-integrated and includes tides and winds, as well as the effects of horizontal density gradients.
- CSERAM is a model for prediction of marine radionuclide transport in both particulate and dissolved phases (Aldridge 1998). The model attempts to go beyond the traditional box model approach in describing the underlying physical processes in a more realistic way. CSERAM includes a 2-D hydrodynamic description of the tidal and wind-induced flows; a wind-wave model to provide the wave-induced bed stress that controls the behaviour of the suspended and settled sediments; and, a physically-based transport model to simulate the movement of both the dissolved and particle-bound radionuclides.

3.3.4. Examples of Transfer Models With Specific Application to the Arctic

Several models have been specifically applied within European Arctic marine environments including:

- NAOSIM (North Atlantic-Arctic Ocean Sea Ice Model) is a 3-D coupled ice-ocean model covering the Arctic Ocean, the Nordic Seas and the North Atlantic north of 50° N. The model has been used to investigate the circulation of ice and ocean currents in the Arctic Ocean and Nordic seas. It has been applied to simulate: (i) the dispersion of ^{99}Tc released from the Sellafield reprocessing plant to northern seas (Karcher *et al.* 2002); and (ii) the potential spread of radioactivity following a hypothetical release from the Kursk submarine (Gerdes *et al.* 2001).
- HAMSOM/VOM (reference) is a 3D, baroclinic, coupled ice-ocean circulation model. The circulation model includes a transport algorithm for temperature, salinity and passive tracers, based on the advection-diffusion equation. HAMSOM/VOM is coupled to a thermodynamic and dynamic sea ice model, which calculates space and time dependent variations of ice thickness and ice concentration. Sea surface heat fluxes are used to determine the ocean temperature and thermodynamic ice formation. The model has been recently applied in the modelling of contaminant transport in Arctic shelf seas and estuaries (Harms 1997; Harms *et al.* 2002).
- The Norwegian Radiation Protection Authority (NRPA) marine box model is an improved version of the compartmental model developed by Nielsen *et al.* (1997). The model is based on the modified approach for box modelling (Iosjpe *et al.* 2002a), which includes dispersion of radionuclides during time (non-instantaneous mixing in oceanic space).

Compartmental/box modelling has been recommended by the European Commission for radiological assessment (EC 1995). Reasons for using box models, in spite of 3-D hydrodynamic modelling being able to provide detailed predictions especially for short time and distance scales, include:

- Three-dimensional hydrodynamic models often require complete, site-specific information concerning meteorological conditions over short time intervals. Although these data are available historically they are obviously not available for the future and predictions will therefore contain a high degree of uncertainty. Predictions made using temporally and spatially averaged (input) data, within a box modelling environment, are likely to have less uncertainty associated with them in assessments where prognoses for long time scales are of interest.
- The most sensitive parameter affecting doses assessments are the CF values used to predict radionuclide activity concentrations in biota (Iosjpe & Borghuis 2000). The uncertainty associated with CF outweighs the advantages offered by 3-D hydrodynamic models.
- The high spatial resolution associated with 3-D hydrodynamic models means that a similar level of resolution describing the movement of marine biota in oceanic space is required so that points of coincidence between contaminant plumes and organisms can be identified and biological uptake determined. These type of data are rarely available.

However, 3-D hydrodynamic models can be used to improve the oceanic space structure and water fluxes in box models (Karcher & Harms 2000).

3.3.5. Prediction of Radionuclide Contamination in Arctic Seas using the NRPA Marine Box Model

The NRPA marine box model, which is routinely used by NRPA for marine dose estimates for humans, has been used for the prediction of Arctic sea radionuclide contamination in EPIC. Whilst in part this is because the model is available for us to use, it also has a number of advantages for environmental impact assessment in Arctic environments.

3.3.5.1. Detailed Description of the NRPA Marine Box Model

Equations of the transfer of radionuclides between model boxes used to represent different marine areas are of the form:

$$\frac{dA_i}{dt} = \sum_{j=1}^{n} k_{ji} A_j - \sum_{j=1}^{n} k_{ij} A_i g\,(t \geq T_j) - k_i A_i + Q_i,\ t \geq T_i \tag{3.8}$$

$$\mathrm{A_i = 0, t < T_i}$$

where: $k_{ii}=0$ for all I;

A_i and A_j are activities (Bq) at time t in boxes i and j;

k_{ij} and k_{ji} are rates of transfer (y^{-1}) between boxes i and j;

k_i is an effective rate of transfer of activity (y^{-1}) from box i taking into account loss of material from the compartment without transfer to another, for example radioactive decay;

Q_i is a source of input into box i (Bq y^{-1}); and

n is the number of boxes in the system.

T_i is the time of availability for box i (the first time when box i is open for dispersion of radionuclides) and ? is a unit function such that when $t = T_i$?= 1 and when $t < T_i$, ? = 0. The times of availability T_i are calculated as a minimized sum of the weights for all paths $\mu_0(v_0,\ldots,v_i)$ from the initial box (v_0) with discharge of radionuclides to the box i on the oriented graph $G=(V, E)$ with a set V of nodes v_j correspondent to boxes and a set E of arcs e_{jk} correspondent to the transfer possibility between the boxes j and k. Every arc e_{jk} has a weight w_{jk} which is defined as the time required before the transfer of radionuclides from box j to box k can begin (without any way through other boxes). M_i is a set of feasible paths from the initial box (v_0) to the box i (v_i). Therefore:

$$T_i = \min_{m_m(v_0,v_i)\in M_i} \sum_{j,k} w_{jk} \tag{3.9}$$

Figure 3.8 shows the structure of the model compartments for the Arctic Ocean, the Nordic Seas and the North Atlantic; each box has surface, mid-depth and deep water layers (Figure 3.9) as developed by Karcher & Harms (2000) and site-specific information. The volume of the water layers in each box has been calculated using detailed bathymetry (IBCAO 2001; ETOPO5 2002). The model includes the processes of advection of radioactivity between compartments, sedimentation, diffusivity of radioactivity through the pore water, resuspension, mixing due to bioturbation and burial of contamination in deep sediment. Radioactive decay is included in all compartments. The contamination of biota is calculated from the radionuclide concentrations in filtered seawater (often nominally defined by 0.45 micron or 1 micron filters) in the different water regions.

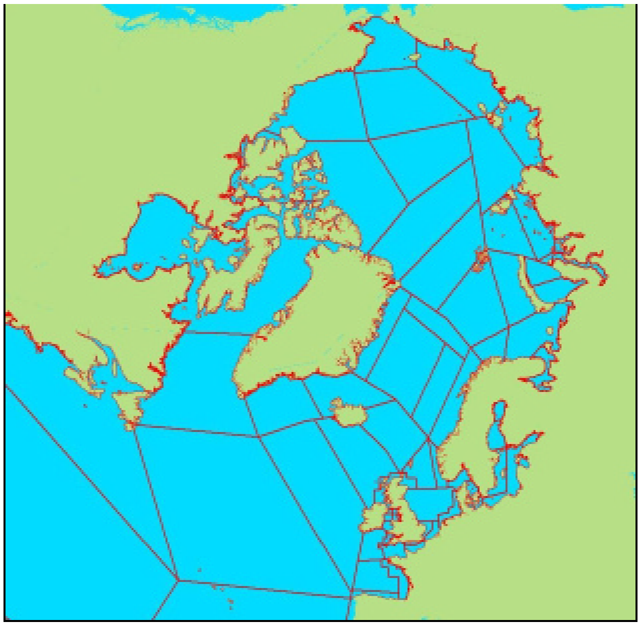


Figure 3.8. The structure of the surface water boxes in the NRPA marine box model.

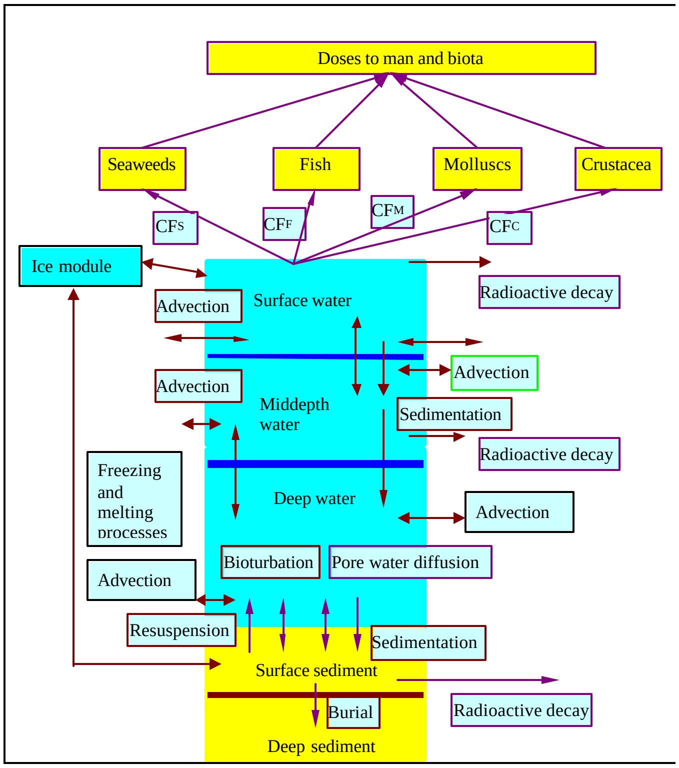


Figure 3.9. Schematic structure of the processes modelled in each box of the NRPA marine box model.

3.3.5.2. Adaptation to the Arctic - the Ice Module

The NRPA marine box model can predict radionuclide exchanges between water and ice phases (Iosjpe 2002a,b). Transfer of radioactivity, A_i (Bq), from the liquid phase and the suspended sediment in the water column of the water box *i* with sediment distribution coefficient K_d and suspended sediment load SSL_i from the marine boxes of the NRPA marine box model to the ice box is described by:

$$l_L = A_i \frac{R^{(iw)} \cdot f_i^{(f)}}{1 + K_d \cdot SSL_i}$$

$$l_s = A_i \frac{K_d \cdot SL_i^{(I)}}{1 + K_d \cdot SSL_i} \cdot j_i^{(ss)} \cdot f_i^{(f)} \qquad (3.10)$$

where: l_L is the transfer of radioactivity from the liquid phase of the water column of box *i* to the ice box;

l_S is the transfer of radioactivity from the suspended particulate phase of the water column of box *i* to the ice box;

$R^{(iw)}$ is the ice-water transfer factor, corresponding to the fraction of radioactivity, which is transferred from the liquid phase of the sea water box to the ice box during the freezing process (dimensionless);

$F_i^{(f)}$ is the freezing rate for the ice box *i* ($m^3\ y^{-1}$);

$SL_i^{(I)}$ is the total ice sediment load for the ice box *i* ($t\ m^{-3}$); and

$f_i^{(ss)}$ is a fraction of suspended sediment in water column of the water box *i* in sediment of the ice box ($\sum_i j_i = 1$) (dimensionless).

The transfer of radioactivity from the sediment box *i* to the ice box is described as:

$$l_{SI} = A_i^{(s)} \frac{K_d \cdot SL_i^{(I)}}{w + (1-w) \cdot r_s K_d} \cdot j_i^{(s)} \cdot f_i^{(f)} \qquad (3.11)$$

where: l_{SI} is the transfer of radioactivity from the sediment box i to the ice box;

$A_i^{(s)}$ is activity in the sediment box *I* (Bq);

$f_i^{(s)}$ is a fraction of sediment from the sediment box *i* in sediment of the ice box;

? is a the porosity; and

$?_s$ is a sediment density from the marine part of the NRPA marine box model.

Equations (3.10 and 3.11) are written assuming that transfer of radioactivity varies as a linear function of the freezing rate (i.e. radioactive inventory is directly proportional to the ice volume the rate of formation of which is positively and linearly correlated with the freezing rate). The transfer of radioactivity from the ice box *i* to the ice box *j* is described as:

$$A_i^{(I)} \cdot t_{ij}^{(r)} \qquad (3.12)$$

where: $A_i^{(I)}$ is radioactivity in the ice box *I*; and

$t_{ij}^{(r)}$ is the ice flux from the ice box *i* to the ice box *j*.

The transfer of radioactivity through melting process from the ice box *i* to the box *j* of the NRPA marine box model, which underlies the ice box *i* is described as:

$$A_i^{(I)} \cdot (f_j^{(m)} - \sum_k t_{ik}^{(r)}) \qquad (3.13)$$

where: $f_i^{(m)}$ is a melting rate for the ice box *i*.

Parameters $f_i^{(f)}$, $f_i^{(m)}$ and $t_{ij}^{(r)}$ must satisfy the expression

$$f_i^{(f)} - f_i^{(m)} - \sum_k t_{ik}^{(r)} = 0 \tag{3.14}$$

for each ice box *i*.

3.3.5.3. Example Simulations

Illustrative environmental impact assessments made using the NRPA marine box model are shown in Figures 3.10–3.12. All simulations have been made for a 1 TBq discharge of radionuclides into Obskaya Guba (the estuary of the Ob River which discharges into the Kara Sea). Dynamic concentrations of ^{137}Cs and ^{239}Pu are shown for cod, crab (muscles) Greenland seal for the Obskaya Guba and the Barents Sea in Figures 3.10 and 3.11. Calculations relating to the uptake by, and transfer to, biota are based on generic CF values derived specifically for Arctic marine reference organisms (see Section 3.1. 1.3 and Table 3.4).

The influence of radionuclide transport by ice as modelled with the NRPA marine box model is illustrated in Figure 3.12. The simulation corresponds to the dispersion of 1 TBq of ^{241}Am discharged into Obskaya Guba and accounts for ice transport of ^{241}Am from the Kara Sea to the Greenland Sea through the Central Arctic Basin. The dynamics of ^{241}Am activity concentrations in lobsters living in the Greenland Sea is calculated with the generic Arctic CF value discussed above (Section 3.1.1.3 and Table 3.4). Figure 3.12 clearly demonstrates that ice transport of radionuclides can be a significant factor for some scenarios and radionuclides. It has been shown that the influence of ice transport increases with increasing K_d values for radionuclides (Iosjpe 2002a; Iosjpe *et al.* 2002b).

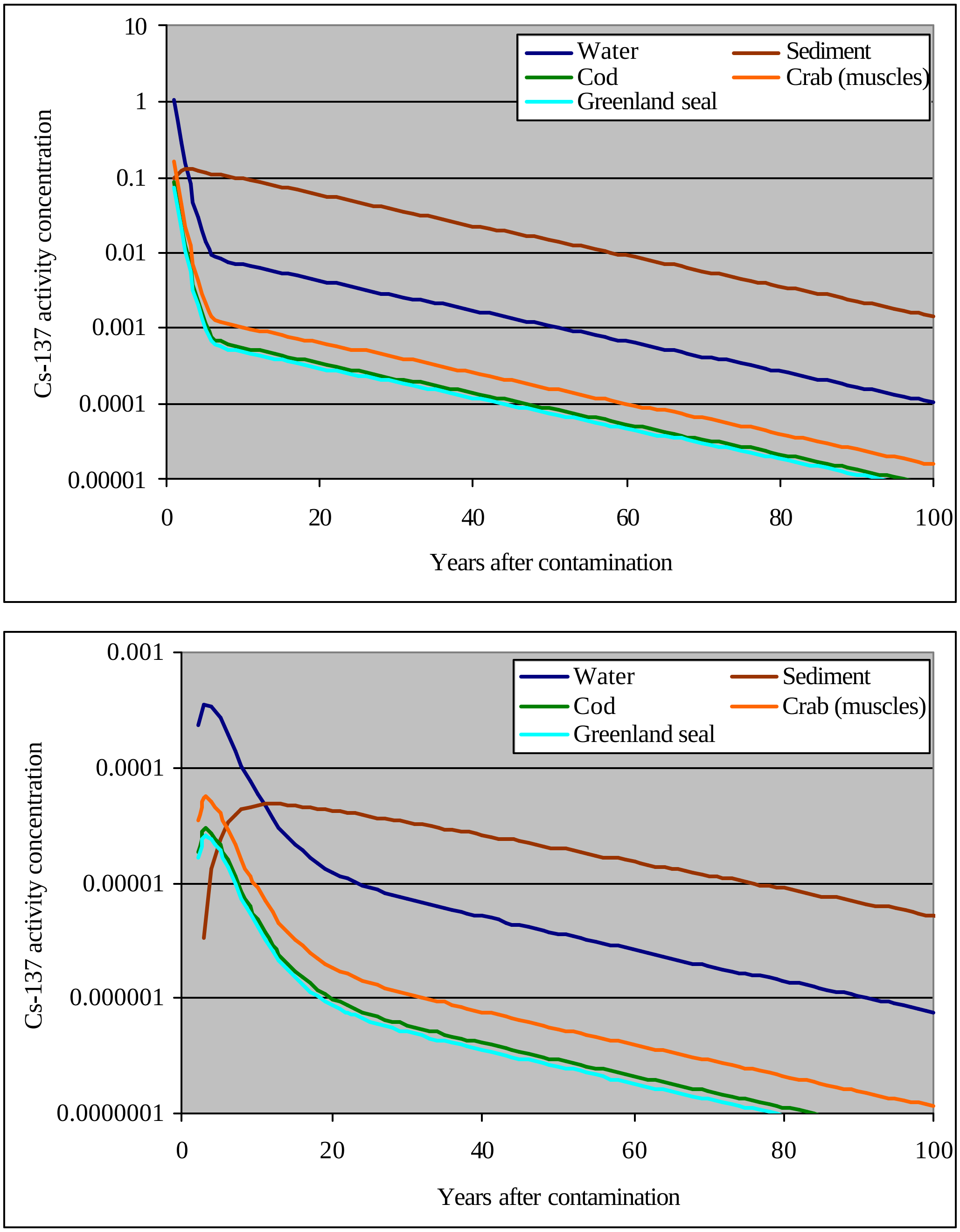
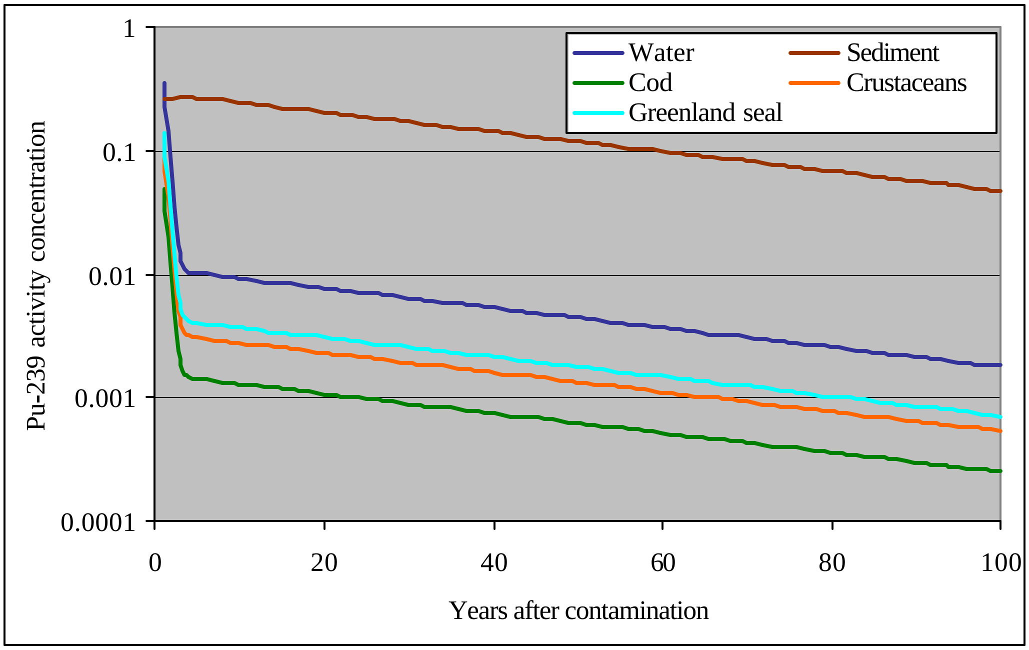


Figure 3.10. Predicted ^{137}Cs activity concentrations in water (Bq m^{-3}), sediments (Bq kg^{-1} DM) and reference organisms (Bq kg^{-1} FW) the Obskaya Guba (top) and the Barents Sea (bottom)



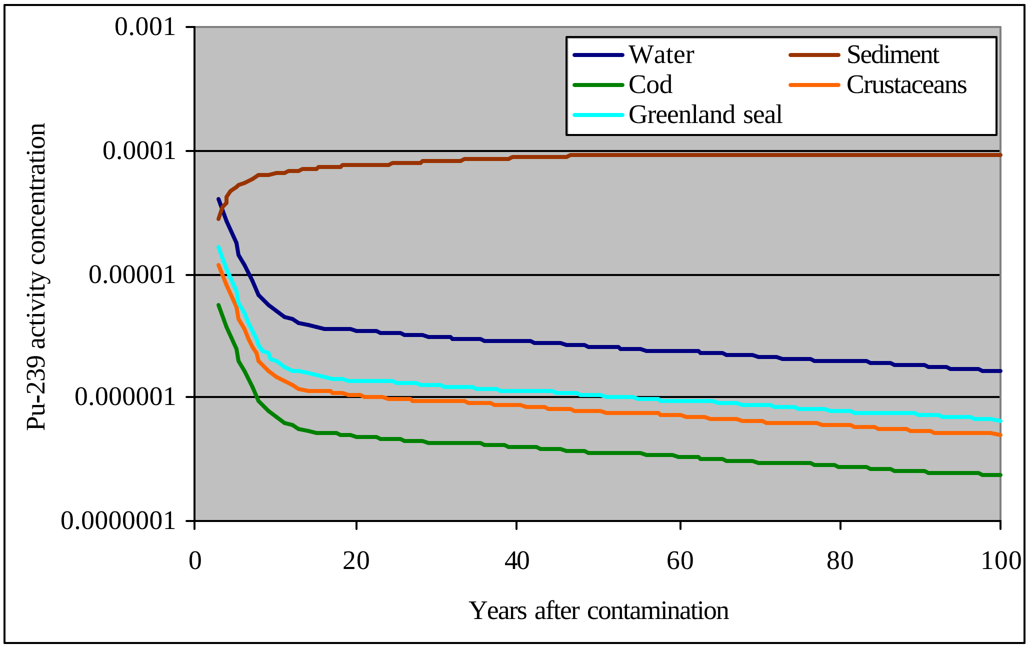


Figure 3.11. Predicted ^{239}Pu activity concentrations in water (Bq m^{-3}), sediments (Bq kg^{-1} DM) and reference organisms (Bq kg^{-1} FW) in the Obskaya Guba (top) and the Barents Sea (bottom).

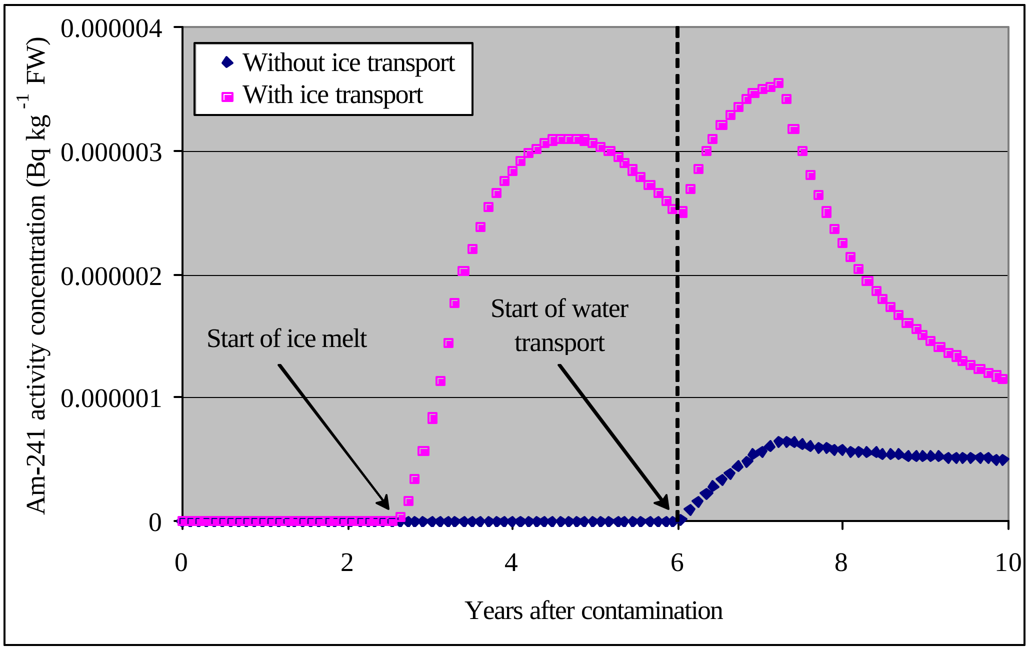


Figure 3.12. Predicted ^{241}Am activity concentration in lobster with and without ice transport of radionuclide.

4. TERRESTRIAL ECOSYSTEMS

4.1. Transfer Data Applicable to Arctic Reference Organisms

4.1.1. Data Collation and Review

A database of the transfer of the EPIC radionuclides (as selected within Beresford *et al.* (2001)) from soil to reference organisms was generated predominantly from the following sources:

i) Literature review (using Web of Science[2]) of English language refereed publications and citied works within these;

ii) Data supplied by EPIC partner Institute of Radiation Hygiene (IRH) for areas with elevated natural radionuclides within the Komi Autonomous Republic of the Russian Federation (Litver *et al.* 1976; Pokarzhhevskii & Krivolutzkii 1997; RCSI 1974-1998; Troitskaya 1981; Verhovskaya 1972[3]);

iii) Data supplied by EPIC partner IRH (from published Russian language sources and in-house databases) on the transfer of a range of radionuclides to wildlife species from throughout European Russia (with an emphasis on Arctic regions and post Chernobyl studies in the Bryansk Oblast);

iv) Data for wildlife species within the Chernobyl Exclusion Zone (Gaschak *et al.* submitted); and

v) The Arctic Monitoring and Assessment Programme (AMAP; see AMAP 1998).

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. However, when data originated from/were likely[4] to have originated from, the European Arctic this was noted within the database.

A considerable number of data were rejected from the review as the level of detail within the original publications was insufficient to enable its use with any degree of confidence (e.g. all collated Th data for gymnosperms had to be rejected).

The transfer of ^{3}H and ^{14}C from soil to biota was not considered: an approach to predicting the activity concentrations of these two radionuclides in reference organisms is described within section 4.3.

4.1.1.1. Data Manipulation

Radiostrontium and radiocaesium data collected during either the period of weapons fallout (assumed to be before 1970) or the year of the Chernobyl accident (1986) were not used to derive transfer parameter values to avoid surface contamination.

For the purpose of estimating internal doses of wild animals, we need transfer parameters to enable the prediction of whole body activity concentrations. However, much of the available data is reported for specific organs. Where information on the relative distribution of a given radionuclide within animals was available, whole body activity concentrations were generated by assuming the proportion of total live-weight and radionuclide contributed by the organ for which transfer was reported (from

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[2] http://wos.mimas.ac.uk/

[3] Original references mostly in Russian – see also Maslov *et al.* (1966) for site description in English.

[4] For instance data were attributed to the European Arctic if they were for a representative reference organism species from an unspecified area within a European country with Arctic territory.

literature values). For instance, it was assumed that 97 % of the body radiostrontium was present in bone (analyses of available data in the database) and that bone contributed 10 % of the live-weight of mammalian species (Beresford *et al.* 1997; Gaare & Staaland 1994) to generate whole-body activity concentrations on the basis of reported data for bone. As radiocaesium is known to be approximately homogenously distributed throughout body tissues (Coughtrey & Thorne 1983), reported transfer values to muscle were considered to be representative of whole-body transfer.

Colated data for plants were reported for a range of plant parts (e.g. data for *Vaccinium* spp. were dominated by berries); no differentiation between plant parts has been taken into account in the derivation of mean transfer values. All transfer data for plant species have been converted to a dry matter basis (DM) (from ash or fresh weights within original references not reporting as dry matter). Similarly all animal data has been transformed to fresh weight.

Some sources present individual data values whilst others present mean transfer estimates; in the derivation of (arithmetic) mean transfer values, previously reported mean estimates have been treated as single data values.

4.1.2 Soil–Reference Organism Transfer Parameters

The majority of available Arctic specific soil-biota transfer data are for natural radionuclides from the uranium decay series, and ^{137}Cs and ^{90}Sr from global fallout and, to a lesser extent, the Chernobyl accident. Soil-biota transfer is expressed in the original references as either:

- *concentration ratio* (CR; the ratio of the radionuclide activity concentration in an organism (Bq kg^{-1} FW or DM) to the radionuclide activity concentration in soil (Bq kg^{-1} DM); or
- *aggregated transfer coefficient* (Tag; defined as the ratio of the radionuclide activity concentration in an organism (Bq kg^{-1} FW or DM) to the radionuclide deposition in soil (Bq m^{-2}) and having units m^{2} kg^{-1}).

A summary of the available transfer values for reference organisms and their representative species are presented in Tables 4.1-4.7. Transfer values are shown as either Tag or CR within the tables depending upon how they were originally reported. For the purposes of consistency, CR values could be converted to Tags (or *vice-a-versa*) by assuming a soil bulk density of 0.78 g DM cm^{-3} for Arctic soils (Batjes 1995) and a sampling depth of 10 cm. The assumption of soil depth within such a conversion may be in error in some instances. However, the degree of error is likely to be less than one order of magnitude which is within the range of reported transfer values for most organism-radionuclide combinations. Indeed it is likely that the reported transfer values we have used here do not all represent the same soil sampling depth; this information is not always given within original references.

The most abundant data are for radiocaesium with values available for all reference organisms and representative species. Radiostrontium data are also virtually complete, exceptions being: (i) the lack of data for representative gymnosperm species and EPIC area specific data for this reference organism group in general although data are available for gymnosperm species sampled elsewhere; (ii) data available for the representative species of (small) herbivorous mammals were from highly contaminated areas close to the Chernobyl nuclear power plant (Chesser *et al.* 2000), however radiocaesium data for these species from this data source appeared to be considerably lower than from other data sources (and was not included in the evaluation for radiocaesium). Consequently we have not used these data for the derivation of either radiostrontium or radiocaesium transfer parameters. 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; few appropriate data are available for reference organism groups from studies conducted elsewhere. No data expressing the transfer of either technetium or radioiodine from soil – reference organisms were found during this work.

Data for *Cladonia* spp. and *Vaccinium* spp. dominated their respective reference organism groups, therefore only representative species data are presented (Tables 4.1 and 4.3).

Table 4.1. Summary of transfer parameters for *Cladonia* spp..

	Radionuclide					
	Caesium	Strontium	Polonium	Radium	Thorium	Uranium
n	388	356	5	6	6	1
Mean	9.67×10^{-2}	8.28×10^{-2}	2.76×10^{-1}	8.33×10^{-1}	2.67×10^{-1}	1.99×10^{-1}
Min	1.65×10^{-3}	2.87×10^{-3}	1.33×10^{-2}	4.80×10^{-1}	1.61×10^{-1}	-
Max	2.92×10^{-1}	5.46×10^{-1}	8.80×10^{-1}	1.39	6.17×10^{-1}	-
Transfer parameter	Tag DM	Tag DM	CR DM	CR DM	CR DM	CR DM
References	1-6	1-6	2,7	8,9	8,9	8

References: 1. Miretsky *et al.* (1993); 2. Regional Centre for Sanitary Inspection (RCSI; 1974-1998); 3. Bakunov *et al.* (1998); 4. Balanov (1999); 5. Balanov (2000); 6. Matishov *et al.* (1994); 7. Mahon & Mathews (1983); 8. Verhovskaya (1972); 9. Litver *et al*. (1976).

For monocotyledons, Table 4.4 presents EPIC area specific data for graminaceous species and compares these to values for grass as collated by the IAEA (1994). IAEA (1994) reports CR values and these have been transformed into estimated Tag values for comparison with compiled data for radiostrontium and radiocaesium assuming a sampling depth of 10 cm and soil bulk density of 1.4 g DM cm^{-3} (as quoted in IAEA (1994) for grasslands). Where IAEA (1994) presents transfer by soil class, values for peat soils are presented in Table 4.4. Collated values for graminaceous species sampled within the EPIC area are within the range expected from the recommendations of IAEA (1994).

A considerable amount of available transfer data for herbivorous mammals originates from measurements of reindeer (see Table 4.5). The transfer of some radionuclides to reindeer is known to be comparatively high as a consequence of the importance of lichens in their diet (e.g. Howard *et al*. 1991). Therefore, to investigate any bias induced by the reindeer data, transfer estimates are summarised for *all herbivorous mammals* and *all herbivorous mammals excluding reindeer* in Table 4.5. For radiocaesium and radiostrontium, the exclusion of reindeer data results in a lower mean Tag values by factors of *circa* 7 and 3 respectively. However, the overall range in collated values is similar.

No data were available describing the transfer of radionuclides from soil to herbivorous bird eggs.

Where sufficient data enabled analysis, the distribution of available transfer values was highly skewed. Figure 4.1 illustrates this for radiocaesium Tag values for herbivorous mammals (the reference organism-radionuclide combination for which most data were available). This suggests that it may have been more appropriate to express mean transfer values as geometric means and not arithmetic means as presented in Tables 4.1-4.7. However, the use of arithmetic mean values as presented is likely to result in conservative assessments.

Table 4.2. Summary of transfer parameters for gymnosperms and representative species of this class.

Radionuclide		*Juniperus* spp.	*Larix* spp. / *Picea* spp.	Gymnosperms
Caesium	n	5	6	22
	Mean	5.07×10^{-1}	2.61×10^{-3}	1.22×10^{-2}
	Min	2.83×10^{-1}	4.48×10^{-4}	4.48×10^{-4}
	Max	1.20	6.49×10^{-3}	7.00×10^{-2}
	Transfer parameter	CR DM	Tag DM	Tag DM
	References	1,2	3	3-5
Strontium	n	-	-	13
	Mean			1.71×10^{-2}
	Min			1.45×10^{-3}
	Max			4.86×10^{-2}
	Transfer parameter			Tag DM
	References			6
Polonium	n	-	1	-
	Mean		3.25×10^{-3}	
	Transfer parameter		CR DM	
	References		7	
Radium	n	2	1	4
	Mean	4.26	5.25×10^{-3}	2.13
	Min	1.25	-	1.25×10^{-3}
	Max	7.26	-	7.26
	Transfer parameter	CR DM	CR DM	CR DM
	References	8	7	8
Thorium	n	-	-	2
	Mean			2.24×10^{-1}
	Min			1.65×10^{-1}
	Max			2.84×10^{-1}
	Transfer parameter			CR DM
	References			8
Uranium	n	2	1	11
	Mean	2.99×10^{-1}	1.75×10^{-4}	2.88×10^{-1}
	Min	5.07×10^{-2}	-	1.75×10^{-4}
	Max	5.47×10^{-1}	-	1.16
	Transfer parameter	CR DM	CR DM	CR DM
	References	8	7	7-9

References: 1. Bunzl & Kracke (1984); 2. Livens *et al.* (1991); 3. Ertel & Ziegler (1991); 4. Johanson (1994); 5. Johanson *et al*. (1994); 6. Gaschak *et al.* (*submitted*); 7. Mahon & Mathews (1983); 8. Verhovskaya (1972); 9. Walker (1979).

Table 4.3. Summary of transfer parameters for *Vaccinium* spp. and *Salix* spp..

Radionuclide		*Vaccinium* spp.	*Salix* spp.
Caesium	n	457	51
	Mean	3.67×10^{-2}	6.48×10^{-3}
	Min	8.95×10^{-4}	8.96×10^{-5}
	Max	2.26×10^{-1}	2.32×10^{-2}
	Transfer parameter	Tag DM	Tag DM
	References	1-5	6-8
Strontium	n	63	9
	Mean	7.45×10^{-3}	4.29×10^{-2}
	Min	4.08×10^{-4}	2.29×10^{-3}
	Max	7.74×10^{-2}	1.39×10^{-1}
	Transfer parameter	Tag DM	Tag DM
	References	2, 4-6	1,7
Polonium	n	4	1
	Mean	1.23	8.50×10^{-3}
	Min	1.92×10^{-1}	-
	Max	3.17	-
	Transfer parameter	CR DM	CR DM
	References	2	10
Radium	n	7	1
	Mean	3.56	1.25×10^{-3}
	Min	6.00×10^{-3}	
	Max	7.64	
	Transfer parameter	CR DM	CR DM
	References	10,11	10
Thorium	n	6	-
	Mean	1.57×10^{-1}	
	Min	2.36×10^{-2}	
	Max	2.36×10^{-1}	
	Transfer parameter	CR DW	
	References	11	
Uranium	n	10	1
	Mean	3.16×10^{-1}	1.00×10^{-4}
	Min	2.00×10^{-4}	-
	Max	7.50×10^{-1}	-
	Transfer parameter	CR DM	CR DM
	References	10-12	10

References: 1. Howard *et al*. (2002); 2. RCSI (1974-1998); 3. Matishov *et al.* (1994); 4. Miretsky *et al*. (1993); 5. Balonov (1999); 6. Balonov (2000); 7. Gaschak *et al.* (*submitted*); 8. Pálsson *et al.* (1994); 9. Johanson *et al*. (1994); 10. Mahon & Mathews (1983); 11. Verhovskaya (1972); 12. Walker (1979).

Table 4.4. Summary of transfer parameters for monocotyledons from within the European Arctic compared to CR values for grass as recommended by the IAEA (1994)[+].

Radio-nuclide		Monocotyledon species	IAEA grass transfer ratio	Radio-nuclide	Monocotyledon species	IAEA grass transfer ratio
Caesium	n	435		Plutonium	-	
	Mean	1.26×10^{-2}	5.30×10^{-3}			3.40×10^{-4}
	Min	7.22×10^{-4}	5.30×10^{-4}			5.00×10^{-5}
	Max	2.36×10^{-1}	5.30×10^{-2}			6.50×10^{-1}
	TP[++]	Tag DM	Tag DM			CR DM
	References	1-7				
Strontium	n	321		Iodine	-	
	Mean	4.45×10^{-3}	3.40×10^{-3}			3.40×10^{-3}
	Min	1.18×10^{-3}	3.40×10^{-4}			3.40×10^{-4}
	Max	1.88×10^{-2}	3.40×10^{-2}			3.40×10^{-2}
	TP	Tag DM	Tag DM			CR DM
	References	3,4,6,7				
Technetium	n	-		Radium	1	
	Mean		7.60×10^{1}		5.66×10^{-3}	8.00×10^{-2}
	Min		1.00×10^{1}		-	1.60×10^{-2}
	Max		7.60×10^{2}		-	4.00×10^{-1}
	TP		CR DM		CR DM	CR DM
	References				7	
Polonium	n	2		Thorium	-	
	Mean	4.41×10^{-1}	9.00×10^{-2}			1.10×10^{-2}
	Min	3.23×10^{-1}				1.10×10^{-3}
	Max	5.60×10^{-1}				1.10×10^{-1}
	TP	CR DM	CR DM			CR DM
	References	3,4				
Americium	Mean	-	1.30×10^{-3}	Uranium	-	2.30×10^{-2}
	Min		5.40×10^{-4}			2.30×10^{-3}
	Max		1.70×10^{-1}			2.30×10^{-1}
	TP		CR DM			CR DM
	References					

[+] IAEA (1994) quotes expected values and 95 % confidence limits for most radionuclides (shown here against mean, minimum and maximum); for Pu and Am expected estimates are presented with minimum and maximum observed values.

[++] Transfer parameter

References: 1. Anderson *et al*. (1992); 2. Howard *et al.* (2002); 3. Balonov (1999); 4. Balonov (2000); 5. Johanson *et al.* (1994); 6. Miretsky *et al.* (1993); 7. RCSI (1974-1998).

Table 4.5. Summary of transfer parameters for herbivorous mammals and representative Arctic species for this group.

Radionuclide		Reindeer	Lemming/ Vole	Herbivorous mammals *- all species*	Herbivorous Mammals *- excluding reindeer*
Caesium	n	845	4	1375	518
	Mean	1.27×10^{-1}	4.48×10^{-2}	8.32×10^{-2}	1.26×10^{-2}
	Min	8.88×10^{-4}	2.17×10^{-2}	1.37×10^{-4}	1.37×10^{-4}
	Max	5.78×10^{-1}	5.69×10^{-2}	9.75×10^{-1}	9.75×10^{-1}
	TP	Tag FW	Tag FW	Tag FW	Tag FW
	References	1-8	22	1-9, 15-21,23	3,4,6,8,9,15-21,23
Strontium	n	365	-	445	80
	Mean	4.46×10^{-2}		3.70×10^{-2}	1.40×10^{-2}
	Min	3.40×10^{-5}		3.21×10^{-5}	6.57×10^{-5}
	Max	1.08×10^{-1}		1.02×10^{-1}	7.92×10^{-2}
	TP	Tag FW		Tag FW	Tag FW
	References	2-6,8,9		2-6,8,9	2-6,8,9
Polonium	n	42	-	42	-
	Mean	4.17		4.17	
	Min	3.97×10^{-1}		3.97×10^{-1}	
	Max	1.43×10^{1}		1.43×10^{1}	
	TP	CR FW		CR FW	
	References	8,10,11		8,10,11	
Americium	n	-	-	1	-
	Mean			2.90×10^{-5}	
	TP			Tag FW	
	References			15	
Plutonium	n	-	-	1	-
	Mean			1.30×10^{-5}	
	TP			Tag FW	
	References			15	
Radium	n	16	17	49	33
	Mean	6.07×10^{-2}	6.91×10^{-2}	4.77×10^{-2}	4.13×10^{-2}
	Min	3.14×10^{-3}	1.28×10^{-2}	2.14×10^{-3}	2.14×10^{-3}
	Max	1.59×10^{-1}	1.95×10^{-1}	1.95×10^{-1}	1.95×10^{-1}
	TP	CR FW	CR FW	CR FW	CR FW
	References	8,12,14	12	8,12-14	12,13
Thorium	n	6	2	8	2
	Mean	3.69×10^{-1}	7.74×10^{-3}	6.39×10^{-1}	7.74×10^{-3}
	Min	2.33×10^{-1}	2.14×10^{-3}	2.14×10^{-3}	2.14×10^{-3}
	Max	4.66×10^{-1}	1.33×10^{-2}	4.66×10^{-1}	1.33×10^{-2}
	TP	CR FW	CR FW	CR FW	CR FW
	References	14	14	13,14	13
Uranium	n	-	2	3	-
	Mean		2.60×10^{-3}	1.80×10^{-3}	
	Min		2.40×10^{-3}	1.22×10^{-4}	
	Max		2.80×10^{-3}	2.84×10^{-3}	
	TP		CR FW	CR FW	
	References		13	13	

References: 1. AMAP (1998); 2. Bakunov *et al.* (1998); 3. Balonov (1999); 4. Balonov (2000); 5. Lubashevsky *et al.* (1993); 6. Miretsky *et al*. (1993); 7. Ramzaev (1967); 8. RCSI (1974-1998); 9. Gaschak *et al*. (*submitted*); 10. Kauranen & Miettinen (1969); 11. Troitskaya (1981); 12. Pokarzhevskii & Krivolutzkii (1997); 13. Verhovskaya (1972); 14. Litver *et al*. (1976); 15. Copplestone *et al.* (1999); 16. Johanson & Bergstrom (1989); 17. Johanson & Bergstrom (1994); 18. Johanson *et al*. (1994); 19. Nelin (1995); 20. Rantavaara (1990); 21. Rantavaara (*pers. com.*); 22. Cristaldi *et al.* (1991); 23. Avila *et al*. (1999).

Table 4.6. Summary of transfer parameters for carnivorous mammals and representative Arctic species for this group.

Radionuclide		Fox	Carnivorous mammals
Caesium	n	5	12
	Mean	8.30×10^{-3}	3.54×10^{-2}
	Min	1.26×10^{-3}	1.26×10^{-3}
	Max	2.16×10^{-2}	1.65×10^{-1}
	Transfer parameter	Tag FW	Tag FW
	References	1	1
Strontium	n	-	8
	Mean		9.26×10^{-3}
	Min		1.58×10^{-3}
	Max		2.39×10^{-2}
	Transfer parameter		Tag FW
	References		1
Polonium	n	-	3
	Mean		1.68
	Min		1.51
	Max		1.85
	Transfer parameter		CR FW (see 4.1.2.1)
	References		3
Radium	n	1	17
	Mean	4.00×10^{-3}	3.53×10^{-2}
	Min	-	4.28×10^{-3}
	Max	-	9.56×10^{-2}
	Transfer parameter	CR FW	CR FW
	References	2	2,4
Thorium	n	-	2
	Mean		5.52×10^{-3}
	Min		1.04×10^{-3}
	Max		1.00×10^{-2}
	Transfer parameter		CR FW
	References		4
Uranium	n	-	1
	Mean		7.09×10^{-4}
	Min		-
	Max		-
	Transfer parameter		CR FW
	References		4

References: 1. Gaschak *et al.* (*submitted*); 2. Pokarzhevskii & Krivolutzkii (1997); 3. Thomas *et al.* (1994); 4. Verhovskaya (1972)

Table 4.7. Summary of transfer parameters for herbivorous birds and representative Arctic species for this group.

Radionuclide		*Lagopus* spp.	Herbivorous bird
Caesium	n	54	56
	Mean	9.70×10^{-3}	1.14×10^{-2}
	Min	2.49×10^{-4}	2.49×10^{-4}
	Max	4.13×10^{-2}	1.16×10^{-1}
	Transfer parameter	Tag FW	Tag FW
	References	1-3	1-4
Strontium	n	51	Data only available for *Lagopus* spp.
	Mean	4.51×10^{-4}	
	Min	2.30×10^{-5}	
	Max	2.85×10^{-3}	
	Transfer parameter	Tag FW	
	References	1-3	
Radium	n	7	31
	Mean	2.53×10^{-2}	3.38×10^{-2}
	Min	9.13×10^{-3}	2.14×10^{-3}
	Max	5.07×10^{-2}	1.95×10^{-1}
	Transfer parameter	CR FW	CR FW
	References	5,6	5,6
Thorium	n	1	4
	Mean	3.52×10^{-4}	3.89×10^{-4}
	Min	-	3.08×10^{-4}
	Max	-	5.44×10^{-4}
	Transfer parameter	CR FW	CR FW
	References	6	6
Uranium	n	1	4
	Mean	4.05×10^{-4}	4.98×10^{-4}
	Min	-	4.05×10^{-4}
	Max	-	6.76×10^{-4}
	Transfer parameter	CR FW	CR FW
	References	6	6

References: 1. Miretsky *et al.* (1993); 2. RCSI (1974-1998); 3. Troitskaya (1981); 4. Gaschak *et al.* (*submitted*); 5. Pokarzhevskii & Krivolutzkii (1997); 6. Verhovskaya (1972)

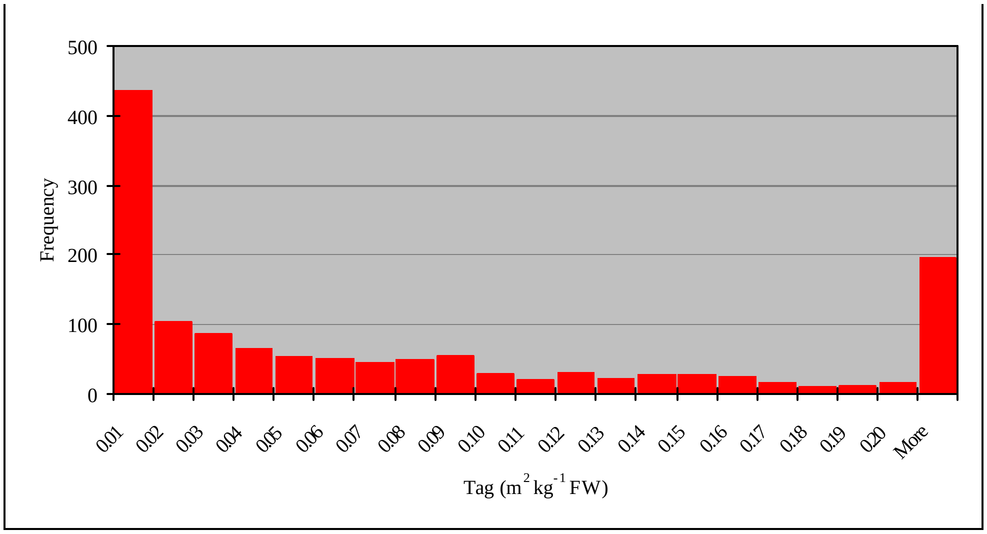

Figure 4.1. An example of the distribution of available transfer parameter data. Data shown are Tag values (n=1375) describing the transfer of radiocaesium to all herbivorous mammals.

4.1.2.1 Derivation of Missing Values

It is evident from Tables 4.1-4.7 that for many reference organism-radionuclide combinations there are no reported data. In this section, approaches to derive transfer estimates where measured values are missing are discussed.

No data were available describing the transfer of ^{210}Po from soil-carnivorous mammals. However, Thomas *et al.* (1994) report values for the transfer from reindeer to wolf muscle. Assuming a distribution of ^{210}Po in carnivorous mammals consistent with that in herbivores this was used to adapt the soil-herbivorous mammal transfer value in Table 4.5 to a value of transfer from soil-carnivorous mammal (Table 4.6).

Use of Allometry

Size influences rates of many biological structures and of a variety of processes from cellular metabolism to population dynamics (West *et al.* 1997). Many biological phenomena scale as quarter powers of mass (West *et al.* 1997). For example: metabolic rates scale as $M^{0.75}$; rates of cellular metabolism and maximal population growth rate as $M^{-0.25}$; life-span and embryonic growth and development as $M^{0.25}$; cross sectional areas of mammalian aortas and tree trunks as $M^{0.75}$. Discussions for these mechanisms can be found within the literature (West *et al.* 1997; Kurz *et al.* 1998).

A number of authors have proposed allometric relationships describing the (long-component of) biological half-life ($T_{0.5bio}$) for a range of radionuclides derived from data including a number of phyla (Higley *et al.* 2003; Whicker & Schultz 1982; USDoE 2002; Kitchings *et al.* 1976; Reichle *et al.* 1970; Coughtrey & Thorne 1983). For many of the radionuclides considered (including Cs, Sr, Co, U and organically bound ^{3}H), the scaling constant is close to 0.25, as observed for many biological parameters. This is perhaps to be expected as biological processes control the uptake and turnover of all elements, including radionuclides, by animals. Of the radionuclides considered to date, exceptions which do not scale to *circa* 0.25 include the actinide elements (USDoE 2002). Application of allometric relationships as a mechanism to provide estimates of transfer for those radionuclide-biota combinations for which we have no data has already been demonstrated within section 3.3 for marine biota. Here we will consider their application to terrestrial Arctic reference organisms.

Allometric constants describing $T_{0.5bio}$ for radionuclides considered within EPIC are presented in Table 4.8, where:

$$T_{0.5bio} = aM^{b} \tag{4.1}$$

where: M is body mass (kg); and
$T_{0.5bio}$ has units of d.

The relationship for radiocaesium has been fitted to data presented by Whicker & Schultz (1982), Gaare & Staaland (1994) and Battiston *et al.* (1991). The relationships from Table 4.7 have been used to estimate Tag values for reindeer, Arctic fox, vole and willow ptarmigan using the following model:

$$\frac{d[WB_{RN}]}{dt} = \frac{f_1 \cdot [Diet_{RN}] \cdot DMI}{M} - \frac{0.693}{T_{0.5bio}} \cdot [WB_{RN}] \tag{4.2}$$

where: $[WB_{RN}]$ is the animal whole body activity concentration of a given radionuclide (Bq kg^{-1} FW);
$[Diet_{RN}]$ is the radionuclide activity concentration of the diet (Bq kg^{-1} DM);
DMI is the daily dry matter intake (kg d^{-1});
f_1 is the fractional gastrointestinal absorption (see Table 4.8 for values used); and
t is time (d).

The average daily dry matter intakes of grass (1.1 kg DM d^{-1}) and lichen (2.1 kg DM d^{-1}) from Golikov (2001) were used for reindeer (see Table 4.13 later). To estimate the daily dietary dry matter intake of the other representative species, the following allometric relationships of Nagy (2001) were used:

$$\text{Carnivorous mammal } DMI = 0.0658M^{0.628} \tag{4.3}$$

$$\text{Rodent } DMI = 0.0801M^{0.705} \tag{4.4}$$

$$\text{Galliformes } DMI = 0.0414M^{0.891} \tag{4.5}$$

The diet of willow ptarmigan was assumed to be *Vaccinium* spp., and that of voles grass. The activity concentration of radionuclide in the diet was estimated using mean transfer parameters for lichen, *Vaccinium* spp. and grass from Tables 4.1, 43 and 4.4 respectively. Where radionuclide specific data for transfer to dietary components was missing, predictions were not made. Arctic foxes were assumed to eat voles, the activity concentration of their diet being that predicted by Equation (4.2). Live-weights assumed for each species are presented in Table 4.9. Because of the long biological half-lives of some of the radionuclides (e.g. Sr, Am, Pu) over-predictions would be obtained if the model were run to reach equilibrium between the animal and its diet. Therefore predictions have been made for animals at typical maximum and average ages (see Table 4.9). For Arctic fox, dietary concentrations for maximum age predictions are based on results for voles at maximum age; those for average age are based on results for voles at average age. Bone contributes significant proportions of whole body Sr, Pu, Am, U, Th and Ra and it has been assumed that this is unavailable for transfer to Arctic fox. Relative activity concentrations in soft tissues: whole body of 0.09 (Sr), 0.6 (Pu and Am), 0.4 (U), 0.3 (Th) and 0.1 (Ra) have been assumed to correct the dietary radionuclide activity concentrations of Arctic foxes to account for this (ICRP 1979; Coughtrey & Thorne 1983; Coughtrey *et al.* 1984a,b).

Table 4.8. Constants for allometric relationships describing the dependence of biological half-life on body mass for radionuclides considered within EPIC.

Radionuclide	a	b	Reference for allometric constants	f_1	Reference for f_1
Caesium	13.2	0.24	EPIC	1	Coughtrey & Thorne (1983)
Strontium	645	0.26	Higley *et al.* (2003)	0.2	Coughtrey & Thorne (1983)
Iodine	16.7	0.13	Higley *et al.* (2003)	1	Beresford *et al.* (2000)
Technetium	4.8	0.4	Higley *et al.* (2003)	0.1	Bishop *et al.* (1989)
Plutonium	1140	0.73	FASSET (*in-preparation*)	0.0005	Coughtrey *et al.* (1984a)
Americium	1140	0.73	FASSET (*in-preparation*)	0.0005	Coughtrey *et al.* (1984b)
Uranium	5.5	0.28	USDoE (2002)	0.05	ICRP (1979)
Thorium	888.1	0.8	USDoE (2002)	0.0002	ICRP (1979)
Radium	276.6	0.28	USDoE (2002)	0.2	ICRP (1979)

Table 4.9. Body mass and age characteristics assumed for representative Arctic species[5].

Species	Body mass (kg)	Maximum age (y)	Average age (y)
Vole	0.03	3	1.5
Reindeer	130	13	4.5
Arctic fox	5.5	5.5	3
Willow ptarmigan	0.06	7	3.5

Predicted Tag values are presented within Table 4.10; for radionuclides with a long biological half-life (e.g. Sr, Pu, Am) predicted Tag values at maximum and average age are considerably different. Some comparisons can be made with the observed data within Tables 4.5-4.7.

For Cs, predicted values are in good agreement with observations, a concentration from prey-carnivore is similar to those expected from the literature (Beresford *et al.* 2001). Predictions for Sr tend to be somewhat higher than observed data with the concentration from prey-carnivore being predicted, which to our knowledge has not been observed within the environment (see Tables 4.5-4.6). The apparent over prediction may in part be due to an assumed average age which is too long. The predicted Tag values for Am and Pu are low compared with the very limited observed data (see Table 4.5). The model we have presented is simplistic and does not take soil ingestion into account which may account for the majority of ingested Pu and Am (and other radionuclides with a low soil:plant transfer). USDoE (2002) present a methodology for including soil ingestion within allometric models for predicting transfer to wild-animals. To compare the predicted Tag values from Table 4.10 with observed data reported as CR values in Tables 4.5-4.7 a soil bulk density of 0.78 g dry weight cm^{-3} for Arctic soils (Batjes 1995) and a depth of 10 cm can be assumed. Predicted U transfer values are in reasonable agreement with the limited observed

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[5] Note details taken from live-history datasheets which will be presented in EPIC Deliverable 4.

data. Predictions for Th and Ra are respectively comparatively low and high compared with the available data.

It would have been possible to conduct the above assessments using published relationships for DMI which vary with ambient temperature and latitude in addition to body mass (Speakman 2000). However, if metabolic rate influences the behaviour of radionuclides in animals (as inferred above), it is likely that low temperatures will influence the rates of excretion of radionuclides by animals and this has been demonstrated for some radionuclides (Lengemann 1970; Lengemann & Wentworth 1979). Intra-species relationships between food intake and radiocaesium transfer have also been demonstrated (Beresford *et al* 2002); therefore, we felt it unjustified to correct one parameter of the model for Arctic conditions (i.e. DMI) without being able to do so for the other (i.e. $T_{0.5bio}$)

Table 4.10. Tag values (m^2 kg^{-1} FW) derived using allometric relationships for radionuclide biological half-life.

Species	Age	Caesium	Strontium	Technetium	Americium	Plutonium	Iodine	Uranium	Thorium	Radium
Vole	Max	2.4×10^{-2}	7.1×10^{-2}	3.8×10^{-2}	2.4×10^{-7}	6.3×10^{-8}	1.5×10^{-4}	9.9×10^{-6}	5.3×10^{-7}	7.0×10^{-3}
	Average	2.4×10^{-2}	5.8×10^{-2}	3.8×10^{-2}	2.4×10^{-7}	6.2×10^{-8}	1.5×10^{-4}	9.9×10^{-6}	5.3×10^{-7}	6.8×10^{-3}
Reindeer	Max	1.0×10^{-1}	6.8×10^{-1}	-	-	-	-	6.8×10^{-5}	5.0×10^{-5}	5.4×10^{-2}
	Average	1.0×10^{-1}	3.6×10^{-1}	-	-	-	-	6.8×10^{-5}	1.8×10^{-5}	3.7×10^{-2}
Arctic fox	Max	9.9×10^{-2}	2.0×10^{-1}	7.5×10^{-3}	1.7×10^{-8}	4.6×10^{-9}	6.7×10^{-4}	3.7×10^{-7}	7.6×10^{-9}	1.0×10^{-2}
	Average	9.9×10^{-2}	1.2×10^{-1}	7.5×10^{-3}	1.0×10^{-8}	2.7×10^{-9}	6.7×10^{-4}	3.7×10^{-7}	4.6×10^{-9}	1.3×10^{-2}
Willow ptarmigan	Max	2.7×10^{-2}	5.1×10^{-2}	-	-	-	-	5.9×10^{-5}	1.3×10^{-5}	1.3×10^{-1}
	Average	2.7×10^{-2}	4.2×10^{-2}	-	-	-	-	5.9×10^{-5}	1.1×10^{-5}	1.3×10^{-1}

4.2. Terrestrial Arctic Radioecology Models

There are no bespoke models available for predicting the temporal changes in transfer of radionuclides deposited in Arctic terrestrial ecosystems to biota. Models applied within the Arctic to estimate exposure of humans consider some wild species (e.g. reindeer). However, these are restricted to radiocaesium and to a lesser extent radiostrontium (Golikov 2001, Howard *et al.* 2002; Wright *et al.* 2002). They are predominantly based on simple empirical approaches (predominantly using aggregated transfer parameters) with time dependency being modelled using ecological half-lives. A model of radiocaesium transfer to reindeer incorporating Arctic specific seasonally varying vegetation uptake rates, dietary selection, gut absorption and biological half-lives has been developed by Åhman & Nylen (1997).

In a previous collaborative programme, EPIC partner IRH developed the ECOMARC ECOlogical Modelling in the ARCtic) model to estimate exposure of Arctic human populations considering both radiocaesium and radiostrontium (Golikov 2001). This semi-dynamic model is an adaptation of the ECOSYS-87 agricultural foodchain model (Müller & Pröhl 1993) with the inclusion of Arctic specific parameters, including: months and amounts of snowfall; time of snow melt; seasonally varying dietary intake of reindeer; transfer coefficients and biological half-lives for reindeer. ECOMARC represents the most comprehensive Arctic specific model: given this, and that it was developed by EPIC participants, it has been selected for consideration for adaptation to predict radionuclide concentrations in Arctic terrestrial reference organisms which is discussed below.

4.2.1 Application of the ECOMARC Model to Reference Organisms

4.2.1.1. Model Description

Information from Arctic areas on the deposition and food chain transfer of ^{137}Cs and ^{90}Sr from nuclear weapons fallout and ^{137}Cs and ^{134}Cs from the Chernobyl accident were used in the development and parameterisation of the ECOMARC model. ECOMARC has a number of different components but only the dynamic modelling of radionuclide transfer appropriate for estimating radionuclide activity concentrations in biota are described here.

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 (Muller & Prohl 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[6], 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, animal feeding, and culinary preparation) are considered.

Deposition and Interception for Grass and Lichen

Radionuclide deposition to grass and lichen is modelled as the sum of wet and dry deposition using the same approach as in ECOSYS-87 for grass (see Muller & Prohl 1993).

Dry deposition is calculated from the radionuclide time-integrated air concentration and a plant specific deposition velocity. For grass the deposition velocity is dependent upon the stage of development and is assumed to be proportional to the leaf area index (LAI). In ECOMARC a LAI of 7 is assumed for grass and default deposition velocities from ECOSYS-87 for radiocaesium and ^{90}Sr of 0.0015 m s^{-1} and 0.0005 are used for grass and soil, respectively (Muller & Prohl 1993). As the LAI for lichen is *circa* 10-100 times greater than that for grass (Ramzaev 1967), a deposition velocity of 0.0025 m s^{-1} for both radiocaesium and ^{90}Sr is assumed (based upon a maximum observed ratio of 5 for deposition to lichen compared to soil during the summer in Arctic Sweden; see Table 4.11 later).

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

Wet deposition to plant surfaces is estimated from the product of the total radionuclide wet deposition and the proportion of activity retained by the plant (the interception fraction). In ECOSYS-87, interception fractions, having been estimated from experimental observations, are related to the LAI and water storage capacity (measured using a retention coefficient) of the plants leaves (Muller & Prohl 1993). For radiocaesium, default ECOSYS-87 retention coefficient values are used in ECOMARC of 0.2 mm for grass and 0.3 mm for other plants. For ^{90}Sr, a default ECOSYS-87 retention coefficient of 0.4 mm is used for grass whilst 0.5 mm is used for lichen (default ECOSYS-87 value for 'other' plants 0.6 mm). For Arctic lichen, interception fractions have been derived from published data (Lidén & Gustafsson 1967; Carlsson 1976) for different times of the year (Table 4.11). Interception fractions for winter are 1.5 times less than the annual average due to loss of deposited radionuclides during snow melt. Interception fractions for summer are greater than 1 suggesting deposition via both wet and dry deposition. In ECOMARC, adopting the approach of Muller & Prohl (1993) and assuming a lichen LAI value of 70, the effective snow thickness (the amount of precipitation necessary to reduce the winter interception fraction to 0.41 as a consequence of snow melt) is estimated to be 50 mm. As interception fractions cannot exceed 1, estimated interception fractions greater than 1 (which can occur when precipitation amounting to less than 20 mm occurs during deposition) are assumed to be 1.

Table 4.11. Seasonal variation in lichen interception fractions (Lidén & Gustafsson 1967; Carlsson 1976).

Period	Interception fraction (relative units)		
	n	Mean±SD	Range
Annual value	11	0.60±0.21	0.38-0.94
Winter value	4	0.41±0.24	0.19-0.75
Summer value	7	2.54±1.30	1.11-5.00

Calculation of Activity Concentration in Grass and Lichen

As in ECOSYS-87, the temporal variation in grass radionuclide activity concentration is predicted from the direct contamination of plant leaves and radionuclide uptake from soil (Muller & Prohl 1993).

The foliar uptake of radionuclides is predicted from: the activity deposited onto the grass; the yield of the grass at the time of deposition (default ECOSYS-98 values are used in ECOMARC with monthly values being equal to 0.0001 kg m^{-2} between December-February and set to 0.01, 0.01 1.5, 1.5, 1.5, 1.5, 1.5, 0.5, 0.01 kg m^{-2} for March-November); the fraction of radiocaesium and ^{90}Sr activity translocated to the root zone (default ECOSYS-87 value of 0.05 used); dilution due to increases in plant biomass (default ECOSYS-87 values used with monthly values being equal to 0 between November-April and set to 0.0385, 0.0347, 0.0365, 0.0289, 0.0257 and 0.0165 d^{-1} for the growing period May-October); half-life of 25 days (ECOSYS-87 default) for the weathering of surface activity of both radiocaesium and ^{90}Sr; default ECOSYS-87 half-life of 60 days for the decrease in radiocaesium and ^{90}Sr activity due to translocation to the root zone; and days after deposition.

In ECOMARC, as in ECOSYS-87, the radiocaesium and ^{90}Sr activity concentrations in grass from root uptake are calculated from the product of the activity concentration in the soil rooting zone and a transfer factor. In ECOMARC, transfer factors (Bq kg^{-1} plant FW per Bq kg^{-1} soil DM) of 2.2 for radiocaesium and 1.8 for ^{90}Sr are used (default ECOSYS-87 values are 0.05 and 0.5 Bq kg^{-1}, respectively). Soils are characterised using default ECOSYS-87 values: a water percolation rate of 2 m y^{-1}; for radiocaesium and ^{90}Sr K_d's of 1000 and 100 g cm^{-3}, respectively; and soil water content of 0.2 g g^{-1}. The concentration of activity in the rooting zone of the soil is estimated from the total deposition to soil assuming a pasture rooting zone depth of 0.1 m (ECOSYS-87 default); a soil bulk density of 1400 kg m^{-3} (ECOSYS-87 default); the rate of radionuclide migration out of the root zone (estimated from water percolation rate, K_d, soil water content, root zone depth and soil density) set to 1.3 × 10^{-5} d^{-1} for radiocaesium (ECOSYS-87 default is 2.86 × 10^{-6}) and 2.86 × 10^{-5} d^{-1} for ^{90}Sr (ECOSYS-87 default); default ECOSYS-87 fixation rates for radiocaesium and ^{90}Sr in soil of 2.2 × 10^{-4} d^{-1} and 9 × 10^{-5} d^{-1}, respectively; radioactive decay; and the days after deposition. A weathering half-life of 25 days is used for radiocaesium and ^{90}Sr in grass in ECOMARC.

The parameter values used to estimate foliar and root uptake of radionuclides in ECOMARC are therefore not Arctic specific.

In ECOMARC, the temporal variation in lichen radiocaesium and ^{90}Sr activity concentrations are determined using a double exponential function:

$$C_L(t) = \frac{A_L}{Y_L^{eff}} \cdot \exp(-l_r \cdot t) \cdot (a_1 \cdot \exp(-\frac{\ln 2}{T_1^L} \cdot t) + a_2 \cdot \exp(-\frac{\ln 2}{T_2^L} \cdot t)) \quad (4.6)$$

where: $C_L(t)$ is the activity concentration of in lichen at time t (Bq kg^{-1} DM);
A_L is the total estimated deposition onto the lichen (Bq m^{-2});
Y_L^{eff} is the effective yield of lichen (kg m^{-2});
l_r is radioactive decay (d^{-1});
t is days after deposition; and
a_1, a_2, T_1^L, and T_2^L simulate the observed double exponential loss of activity from lichen.

Region specific parameters describing the double exponential decline in radionuclide activity concentration from lichen can be derived from long-term observations for different Arctic Russian areas. Default values of a_1, a_2, T_1^L and T_2^L used in ECOMARC for radiocaesium are 0.8, 0.2, 730 days and 7300 days, respectively and 0.86, 0.14, 248 days and 17885 days, respectively for ^{90}Sr.

The effective lichen yield is used to account for reindeer consuming the upper 3 cm of lichen and can be estimated using data from Lidén and Gustafsson (1967). The upper 3 cm of lichen has a water content of *c.* 60 % and an average surface density of 0.6 kg m^{-2} FW (0.24 kg m^{-2} DM). *Circa* sixty-five percent of the total radiocaesium activity is concentrated in this 3 cm upper part of lichen. Therefore, assuming an interception fraction of 0.6, the average annual mass interception fraction is 1.6 m^2 kg^{-1} (DM), which agrees well with lichen radiocaesium interception fractions estimated for areas studied by Golikov (2001). For radiostrontium, assuming a uniform activity depth distribution in lichen, *c.* 30 % of the total activity occurs in the top 3 cm. In ECOMARC the effective yield of lichen is assumed to be 0.4 kg m^{-2} DM for radiocaesium and 0.8 kg m^{-2} DM for ^{90}Sr. If the interception fraction was 1, the value of mass interception fraction will be equal to 2.5 m^{-2} kg (as compared with annual value 1.6m^{-2} kg, obtained for global fallout). This value agrees well with the value of 3 m^{-2} kg (IAEA, 1996), suggested for use with deposition of small particles with dry deposition or deposition with a small amount of rain.

If radionuclide deposition takes place onto snow, lichen will become contaminated after snow melt. In ECOMARC, if deposition occurs onto snow, radionuclide contamination is assumed to have occurred as wet deposition occurring with a rainfall amount corresponding to the effective thickness of the snow cover (see above).

Contamination of Animal Products

The amount of activity ingested by an animal is calculated from the sum of the products of the activity concentration in the different feedstuffs and feeding rate. The transfer of radionuclides from fodder into individual animal products is described by the equilibrium transfer factor, TF_m, and biological half-lives:

$$C_m(T) = TF_m \sum_{j=1}^{J} a_{mj} \sum_{t=0}^{T} A_{am}(t) \exp[-(l_{b,mj} + l_r)(T-t)] \qquad (4.7)$$

where: $C_m(T)$ is the activity concentration in animal product m at time t;
TF_m is the transfer factor for animal product m (d kg^{-1} DM);
j is the biological transfer rate;
a_{mj} is the fraction of biological transfer rate j; and
$l_{b,mj}$ is the biological transfer rate j for animal product m, (d^{-1}).

Radiocaesium and ^{90}Sr transfer factors used in ECOMARC are given in Table 4.12 and monthly reindeer diets are given in Table 4.13.

Table 4.12. Radiocaesium and ^{90}Sr transfer factors and biological half-lives for reindeer meat used in ECOMARC.

Radionuclide	Transfer factor (d kg^{-1} DM)	First biological half-life (days)
Radiocaesium	0.45	25
Sr-90	0.003	25

Table 4.13. Reindeer diet assumed in ECOMARC.

Month	Consumption rate (kg d^{-1} DM)	
	Lichen	Grass
January	2.6	0.2
February	2.6	0.2
March	2.4	0.3
April	2.4	0.4
May	2.4	1.0
June	0.6	2.3
July	0.6	3.0
August	1.0	2.8
September	1.6	1.8
October	3.0	0.2
November	3.0	0.2
December	2.4	0.2

4.2.2. Demonstration predictions for Arctic reference organisms

As ECOMARC is the most comprehensive Arctic specific model (and has been developed by EPIC participants), it is the most appropriate model to adapt for the dynamic prediction of radionuclide concentrations in Arctic terrestrial reference organisms.

Figure 4.2 presents ECOMARC predictions of the ^{137}Cs and ^{90}Sr concentrations in reindeer muscle for 4 y following a single deposition of 1 Bq m^{-2} of each isotope occurring in June; temporal fluctuations are the consequence of changes in dietary composition (see Table 4.13). The predicted ^{137}Cs and ^{90}Sr activity concentrations in reindeer muscle have been used to predict the whole body ^{137}Cs and ^{90}Sr activity concentrations in wolves, hypothetically consuming reindeer as their sole dietary intake. Allometric relationships for biological half-life (see Table 4.7) and DMI (see Equation 4.3) have been used to enable these predictions; the body mass of wolves was assumed to be 50 kg.

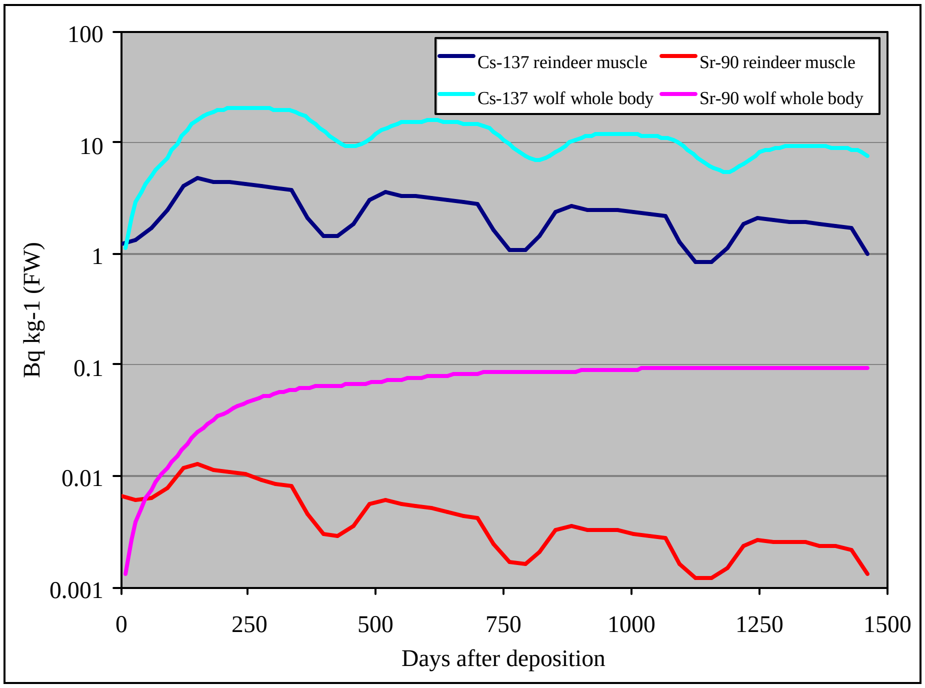

Figure 4.2. Caesium-137 and ^{90}Sr activity concentrations in reindeer meat predicted using the ECOMARC model assuming a single deposition of 1 Bq m^{-2} of each radionuclide occurring in June. Predicted ^{137}Cs and ^{90}Sr radionuclide activity concentrations in wolf are for whole body and assume wolf only eat reindeer.

There is a clear seasonal pattern in the predicted ^{137}Cs activity concentrations in both reindeer muscle and wolf whole body reflecting the annual changes in reindeer diet (see Table 4.13). However, the annual minimum whole body ^{137}Cs activity concentration in wolves is predicted to occur when activity concentrations in reindeer are approaching their annual maximum demonstrating a potential implication for the interpretation of monitoring data. The wolf whole body ^{90}Sr activity concentration is not predicted to reach a maximum value until five years after deposition (although not shown predicted activity concentrations begin to decline after this). Strontium-90 activity concentrations in bone (the accumulating organ) will determine wolf whole body levels. Similar adaptations to ECOMARC using observed or predicted biological half-lives could be readily made for some other EPIC reference organism representative species (e.g. voles, foxes).

ECOSYS-87, from which ECOMARC was derived, considers a wide range of radionuclides and 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 recommendations in Tables 4.2 and 4.3. However, radionuclide specific parameters (e.g. weathering half-lives, deposition velocities) may not be available for these vegetation types in Arctic ecosystems.

4.3. Prediction of ^{3}H and ^{14}C Transfer

Tritium and ^{14}C are radionuclides of macro-elements which are structural components of plant and animal tissues and water. Therefore, conventional modelling techniques for modelling radionuclide transfer are not appropriate. Also, as these radionuclides are primarily present in the environment as reversible gases ($^{14}CO_2$ and ^{3}HHO), we have adopted the common practice of expressing activity concentrations in biota relative to an annual average activity in air of 1 Bq m^{-3}.

4.3.1. Tritium

The simplest method of estimating ^{3}H activity concentrations in biota under equilibrium conditions is to use the specific activity approach (USEPA 1989). This assumes that ^{3}H is in equilibrium in any environmental compartment and that plant and animal activity concentrations of tritiated water (HTO) are derived from air moisture. Whilst full equilibrium is unlikely to be reached under field conditions (Spencer & Vereecken-Sheehan 1994), the specific activity approach is accepted within radiation protection for conservative assessments. The specific activity approach used here is based upon existing models (Galeriu 1994; Peterson & Davis 2001; Galeriu & Belot 2002). The prediction of both HTO and organically bound ^{3}H (OBT) activity concentrations in biota are allowed for in these models. Model inputs include precipitation, relative humidity and temperature. For adaptation to the Arctic, ^{3}H deposition with snow fall (Davis 1997), the time of snow melt, and the contribution of snow melt to soil ^{3}H (Galeriu 1993) and water have been included. The HTO and OBT activity concentrations in animal tissues are estimated using the approach recently published by Galeriu *et al.* (2001).

The tritium activity concentration in plant water is estimated by (Galeriu 2002; Belot 1996):

$$C_{plantHTO} = 1.1\left(\frac{r_a}{r_v}\right)\cdot C_a + 1.17\left(1 - \frac{r_a}{r_v}\right)\cdot C_s \qquad (4.8)$$

where: $C_{plantHTO}$ is the HTO concentration in leaf water (Bq L^{-1});
C_a is the HTO concentration in air moisture (Bq L^{-1}):
$?_a$ is the water vapour mass per unit air volume (average value for summer is used; kg m^{-3});
$?_v$ is the saturated water vapour mass per unit volume at leaf temperature, average value for summer (kg m^{-3})
C_s is the HTO concentration in the routing depth of soil (Bq L^{-1}); and

$$C_a = C_{av}/?_a \qquad (4.9)$$

where: C_{av} is the HTO concentration in air volume (Bq m^{-3}).

In practice, the average leaf temperature can be considered equal to the average air temperature and the ratio in Equation (4.9) is equal to the relative humidity (during the growing season).

If FD is the plant dry matter fraction, then the HTO concentration in edible plant parts is simply:

$$C_{fresh,HTO} = (1 - FD) \cdot C_{plantHTO} \tag{4.10}$$

The fresh weight OBT concentration in plants part is given by:

$$C_{OBT} = 0.6 \cdot FD \cdot C_{plantHTO} \tag{4.11}$$

The ^{3}H concentration in soil water C_s (rooting depth average) is estimated as the sum of wet and dry deposition:

$$C_s = D_w / I_r + 0.15 C_a \tag{4.12}$$

The wet deposition contribution (D_w/I_r) is derived from the average HTO concentration in rainwater during the vegetation growing period where D_w is the total wet deposition (Bq m^{-2}) during the growing period and I_r the average precipitation during the growing period (mm). D_w is given by:

$$D_w = C_{av} \cdot l \cdot MH \cdot \Delta t \tag{4.13}$$

where: l is the washout rate (h^{-1});
MH is the mixing height in neutral weather condition (m);
Dt is the total duration of rainfall (h) during the growing season;

The dry deposition component in Equation (4.5) is derived from $0.15C_a$, where 0.15 is a best estimate constant (IAEA 2001)

For the Arctic we need to consider deposition on snow, snowmelt and the contribution of snowmelt to the soil water concentration during the growing season. The contribution of snowmelt to the soil water HTO activity concentration is given by:

$$0.7[5160 \cdot C_{av} \cdot V_g] + 0.7[C_{av} \cdot l_s \cdot MH \cdot \Delta t_s] \tag{4.14}$$

where: V_g is the dry deposition velocity for winter (a value of 5.8 m h^{-1} as measured in Arctic Canada (Davis 1997) is assumed);
l_s is the snow washout ratio (a value of 0.052 h^{-1} as measured in Arctic Canada (Davis 1997) is assumed); and
Dt_s the duration of snowfall (h).

The numerical constant 0.7 in Equatrion (4.14) is a measure of the fraction of deposited HTO present in snow at snowmelt as measured in Arctic Canada (Galeriu 1993); 5160 is the period of snow cover in hours.

For the purposes of estimating ^{3}H activity concentrations in Arctic reference organisms, the required climatic input parameters were derived from the University of East Anglia Climate Research Units' gridded (0.5° × 0.5° resolution) regional climatology for Europe data set (Hulme *et al.* 1995[7]). Averaged climate data for areas of Finland, Norway and Sweden above 67° N latitude were used.

The resultant ^{3}H activity concentrations in plant material are assumed to represent the diet of herbivorous animals. Subsequently, the activity concentrations estimated for herbivores is used to estimate the diet of carnivores. The transfer of ^{3}H to animals has been estimated using the approach derived recently by Galeriu *et al.* (2001; 2002). The ^{3}H activity concentration is estimated as the sum of four transfer processes:

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[7] See also http://www.cru.uea.ac.uk/~mikeh/datasets/regional/europe.htm

$$F_{HH} = I_{HTO} \cdot \frac{v_{bw}}{WF} \tag{4.15}$$

$$F_{HO} = I_{HTO} \cdot \frac{0.25 m_{ot}}{0.111 WF} \tag{4.16}$$

$$F_{OH} = I_{OBT} \cdot F_{Dom} F_{HH} \tag{4.17}$$

$$F_{OO} = I_{OBT} \cdot \frac{0.75 m_{ot}}{I_{OBH}} \tag{4.18}$$

where: F_{HH} is the transfer from dietary HTO to body HTO (d kg^{-1});
F_{HO} is the transfer from dietary HTO to body OBT (d kg^{-1});
F_{OO} is the transfer from dietary OBT from diet to body OBT (d kg^{-1});
F_{OH} is the transfer from dietary to body HTO (d kg^{-1});
I_{HTO} and I_{OBT} are the daily intakes of HTO and OBT respectively (Bq d^{-1});
v_{bw} is the body water fraction;
m_{ot} is the bound hydrogen content (kg kg^{-1} FW);
F_{Dom} is the digestibility coefficient of organic matter in food;
WF is the total daily water flux (L d^{-1}); and
I_{OBH} is the daily intake of bound hydrogen (kg d^{-1})

The animal metabolism parameters required for Equations 4.15-4.18 can be derived from the literature. The body compositions of wild animals and diet digestibility's were taken from Robbins (1993) and Crocker (2002). The allometric relationships of Nagy (2001), as discussed in Section 4. 1.2.1, were used to estimate dry matter intake rates.

To determine the water flux, allometric relationships based upon organism live weight (*Lwt*) presented by Robbins (1993) were used:

$$\text{Herbivorous mammal water flux (L d}^{-1}\text{)} = 0.178 Lwt^{0.8} \tag{4.19}$$

$$\text{Carnivorous mammal water flux (L d}^{-1}\text{)} = 0.063 Lwt^{0.8} \tag{4.20}$$

$$\text{Non-passerine bird water flux (L d}^{-1}\text{)} = 0.13 Lwt^{0.87} \tag{4.21}$$

4.3.1.1. Results

Table 4.14 presents predicted ^{3}H activity concentrations in representative animals of Arctic reference organisms assuming a constant air concentration of 1 Bq ^{3}H m^{-3}. The predicted activity concentrations are similar for all animals considered. The contribution of OBT to total body ^{3}H activity concentrations is in the range 35-45 %. Predicted ^{3}H activity concentrations in the Arctic are higher than in other European climatic regions being 60-70% higher than those predicted for Mediterranean climates for instance[8]. The predominant input variable resulting in variation between climatic regions is the air moisture content during the plant growing season.

Table 4.14. Predicted ^{3}H activity concentrations in representative animals of Arctic reference organisms assuming a constant air concentration of 1 Bq ^{3}H m^{-3}.

Organism	Lemming /Vole	Reindeer	Fox	Willow ptarmigan (whole body)	Willow ptarmigan (egg)
^{3}H (Bq kg^{-1} FW)	150	130	150	130	130

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[8] From Deliverable 5 of the FP5 FASSET project (*in-preparation*).

4.3.2. Carbon-14

A simpler specific activity approach is used to model ^{14}C (Killough & Rohwer 1978; Wirth 1982). As we are assuming a constant concentration of ^{14}C in air of 1 Bq m-3, the specific activity in air, SA_{air} (Bq g^{-1} C), is:

$$SA_{air} = 1/0.18 \tag{4.22}$$

where: 0.18 g m^{-3} is the current carbon content of air.

The specific activity in herbage, SA_{herb}, will equal that in air:

$$\frac{1}{0.18} = \frac{^{14}C_{herb}}{C_{herb}} \tag{4.23}$$

where: $^{14}C_{herb}$ (Bq kg^{-1} DM) and C_{herb} (g kg^{-1} DM) are the ^{14}C activity and stable carbon concentrations in herbage, respectively.

Therefore, the ^{14}C activity concentration in herbage is:

$$^{14}C_{herb} = 5.56(C_{herb}) \tag{4.24}$$

Similarly, the ^{14}C activity concentration in animals, $^{14}C_{anim}$ (Bq kg^{-1} FW), is:

$$^{14}C_{anim} = 5.56(C_{anim}) \tag{4.25}$$

where: C_{anim} is the stable carbon concentration in animals (g kg^{-1} FW).

The stable carbon content of herbage and different animal species were taken from Robbins (1993) and Crocker (2002).

4.32.1 Results

Predicted ^{14}C activity concentrations (assuming a constant 1 Bq ^{14}C m^{-3} air) are: mammal – 1340 Bq kg^{-1} (FW); willow ptarmigan 1140 Bq kg^{-1} (FW); willow ptarmigan egg 890 Bq kg^{-1} (FW). If predictions are made for small mammals (e.g. lemming) with higher fat contents the ^{14}C activity concentration increases to 1760 Bq kg^{-1}.

5. DISCUSSION

The transfer parameters and modelling techniques derived and reviewed within this report will form the basis for estimating internal doses within the remainder of the EPIC project. A brief discussion of available transfer parameters and models for Arctic biota is given below.

5.1. Freshwater Ecosystems

There are few Arctic specific concentrations ratios for freshwater biota.

A dynamic model (ECOMOD) is available for describing the behaviour of selected radionuclides in abiotic and biotic components of freshwater ecosystems (Sazykina 2000). The model has previously been demonstrated to give predictions in good agreement with observations made primarily after the Chernobyl and Kyshtym accidents (Kryshev & Ryabov 2000; Kryshev 2002a,b).

For some radionuclides (Cs, Sr, P, Mn, Zn, I and Co) rates of uptake by fish are modelled using temperature dependence 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 (Ra, Po, Pu, Tc, Th and U) non-Arctic specific CF values are used to describe transfer to fish; generic Cf values for invertebrates and aquatic plants are also used. Aquatic mammals and birds are not considered within ECOMOD. However, it may be possible to obtain adequate estimates of transfer for a number of radionuclides using allometric relationships.

Whilst modelling approaches have only been described for Arctic lakes they could be adapted to Arctic rivers in combination with an appropriate river transport model.

5.2. Marine Ecosystems

CF values have been determined for many marine biota within international reviews (IAEA 1985). Whilst these tend to be for edible tissues, in some cases they can be transformed into whole body burdens using published distributions of radionuclides within organisms. However, they are not specific to the Arctic where transfer may be influenced by environmental factors such as low temperature, seasonal variation in light intensity and ice cover. Arctic–specific data have been collated for Cs, Pu, Sr and Tc from the open literature and are recommended to be used as supplementary information to that of the IAEA (1985). This is despite the fact that the number of individual data values forming the data base is low especially for radionuclides other than Cs. Generally the collated Arctic CF values are similar to those for temperate environments.

The CF approach has two major problems. Firstly, under normal field conditions the abiotic and biological compartments of the environment may not be under equilibrium. Activity concentrations in water can change rapidly in response to variable contaminant discharge regimes and relatively short water “flushing” times. Biological uptake and depuration rates are normally low, i.e. half-times are large, when compared with these physical process rates. CF values may therefore poorly characterise the water-biota partitioning. Secondly, CF data are not available for all radionuclide-biota combinations. In both cases, the adoption and adaptation of dynamic models might allow more robust impact assessments.

The application of the ECOMOD model, initially developed for freshwaters, to marine assessments has been demonstrated. In an attempt to fill gaps in reference organism–radionuclide transfer parameters, a biokinetic model has been developed specifically for an Arctic pelagic marine food-chain. Allometric relationships have been used in several cases where empirical data were unavailable for parameterisation. The preliminary model appears to give reasonable predictions for ^{137}Cs and ^{239}Pu and demonstrates the fact that high trophic level organism may take very long time periods to become equilibrated with ambient water concentrations.

Many marine contaminant transport models are available, some of which have been applied to the Arctic and include parameters of ice flow and formation. Amongst these is the box model initially developed by Nielsen *et al.* (1997) and improved to consider water-ice phase radionuclide transfer (Iosjpe, 2002). Here the model has been parameterised using Arctic specific CF values (derived during this work). It would be clearly advantageous to link this marine transport model to the dynamic models discussed above. However, further work is required in defining the assumptions that are necessary for this to be practicable and for defining under which circumstances the application of the model would be valid.

5.3. Terrestrial Ecosystems

Data have been collated from the literature and an in-house databases to describe the transfer of radionuclides from soil–reference biota. The most abundant data were for radiocaesium and radiostrontium. Data for natural radionuclides considered were dominated by studies conducted within the EPIC area. No data were available for describing the transfer of some radionuclides (Tc and I) to Arctic biota and few data for others (e.g. actinides). It was generally not possible to comment on the transfer of radionuclides to biota within the Arctic compared to other areas.

In an effort to provide estimates of transfer for radionuclide-biota combinations for which data were lacking, the use of allometric-kinetic models were investigated; soil–plant transfer parameters derived during the review were used as inputs to these models. Predicted values were in good agreement with observed data for some radionuclides (e.g. Cs, U) although less so for others. However, for some radionuclides where comparison appeared poor there was relatively little observed data with which to compare. Furthermore, our assumption of all dietary radionuclide entering the animal food chain via root uptake is simplistic with regard to radionuclides with low soil-plant transfers were soil ingestion will be important.

There are no bespoke models to enable the dynamic prediction of radionuclide transfer to Arctic biota. One available human foodchain model includes limited parameterisation for Cs and Sr transfer in Arctic ecosystems (Golikov 2001). This has been relatively easily adapted to estimate ^{137}Cs and ^{90}Sr transfer to some Arctic biota and could be readily adapted to other radionuclide – reference organism combinations. However, there are many factors of Arctic ecosystems which may influence radionuclide behaviour including short growing seasons, prolonged freezing of soil, and effects of low temperatures on biological rates. The influence of some of these have been documented: (i) redistribution within the soil profile as a result of freezing (Butler *et al.* 1996; Saxena *et al.* 1994); (ii) reduction of soil $^{14}CO_2$ degassing rates as a consequence of freezing (Sheppard *et al.* 1994); (iii) effects of temperature, metabolic rate and dietary intake on radionuclide transfer to animals (Lengemann1970; Lengemann & Wentworth 1979; Beresford *et al.* 2002); (iv) reduced sorption rate in soils at lower temperature (Bunzl & Schimmack 1991); and

(v) reduced uptake of Cs by soil invertebrates at low temperatures (Janssen *et al.* 1996). However, these are not included within existing predictive models. If exposure to ionising radiation within Arctic terrestrial ecosystems is to be robustly predicted such factors must be fully understood and properly incorporated into models.

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APPENDIX A

DISCUSSION OF ARCTIC-SPECIFIC RADIONUCLIDE CONCENTRATION VALUES FOR MARINE ECOSYSTEMS

In this Appendix, the data collated in the EPIC Arctic marine ecosystems transfer database is reviewed on the basis of organism group.

For data measured prior to 1991, CF values were derived using average radionuclide activity concentrations in sea water for a given sea and year, whilst for data for 1991 and later, CF values were estimated using coupled organism-water measurements.

A.1. Fish

Estimated CF values for ^{137}Cs in different Arctic fish within the Norwegian, Barents and Kara seas are presented in Table A1. From the limited data available it is difficult to comment on differences in ^{137}Cs transfer between species although there seems to be little difference between the seas.

Table A1. Mean±standard deviation (counting uncertainty when n=1) CF values for ^{137}Cs in different species of Arctic fish (muscle FW.); number of data are indicated in parentheses.

Species	Norwegian Sea	Barents Sea	Kara Sea
Anarhichas lupus (wolffish)		80± 20 (4)	
Boreogadus saida (polar cod)		100± 50 (20)	600± 400 (2)
Brosme brosme	100±50 (2)		
Clupea harengus (herring)	110±60 (3)	70± 40 (3)	
Cottus spp. (sculpin)			150± 50 (1)
Gadus morhua (cod)	90± 60 (25)	80±40 (124)	140± 40 (1)
Hippoglossus hippoglossus (halibut)	120 ± 20 (2)	80± 30 (9)	
Liparis fabricci (olar snailfish)			1800± 200 (1)
Mallotus villosus (capelin)		40± 14 (3)	
Melanogrammus aeglefinus (haddock)	60± 30 (4)	70± 30 (24)	
Pleuronectes platessa (plaice)		100± 30 (25)	
Pollachius virens (saithe)	80± 30 (6)	70± 30 (16)	
Raya radiate (ray)		120± 40 (13)	
Salmo salar (Atlantic salmon)	130± 50 (1)	140±70 (6)	
Salvelinus alpinus (Arctic char)			250± 90 (1)
Sebastes marinus (redfish)		120± 50 (11)	

Figure A1 presents temporal data for ^{137}Cs CF values in *Gadus morhua* (cod) in the Barents Sea and fish in the Greenland Sea; Barents Sea data are annual averages whilst Greenland Sea data are five year averages. Both data sets indicate an increase in ^{137}Cs CF values followed by a decrease. For the Greenland Sea there is sufficient data to suggest that this may be significant, but there are too few data from the Barents Sea to say whether this is significant. The data therefore suggest that ^{137}Cs activity concentrations were not in equilibrium with ambient water ^{137}Cs concentrations over the observation period. This probably reflects the lag in temporal response of ^{137}Cs activity concentrations in biota compared with seawater as a result of the transfer of discharges from the UK Sellafield nuclear reprocessing plant (discharges from Sellafield peaked in the mid 1970s).

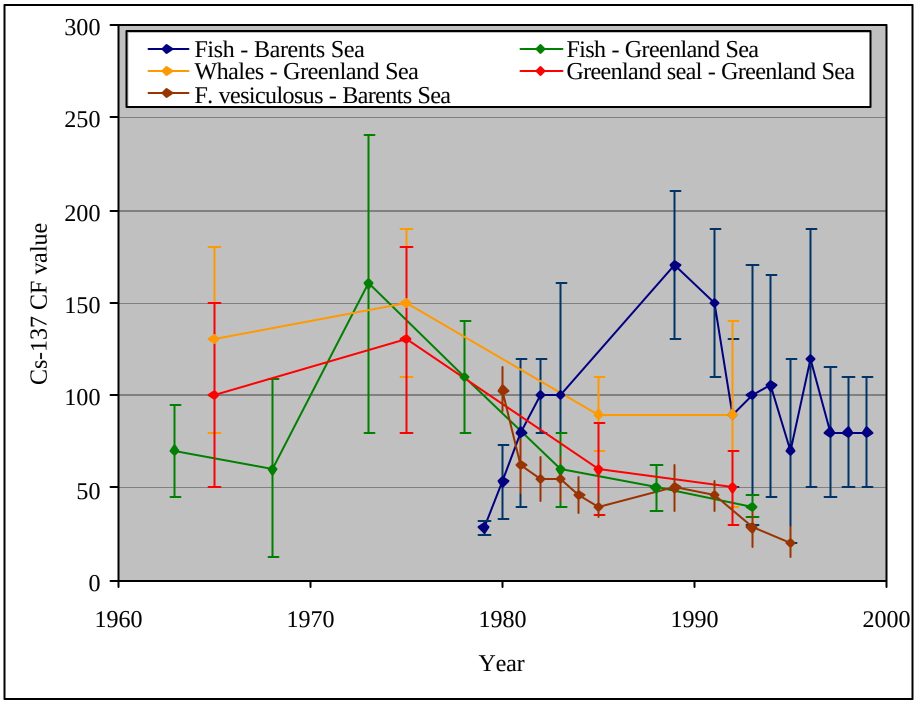

Figure A1. Temporal variation in ^{137}Cs CF values (FW) for: *Gadus morhua* in the Barents Sea (annual average ± standard deviation); fish in the Greenland Sea (five year averages ± standard deviation); whales and Greenland seals in the Greenland Sea (ten year average ± standard deviation); and *Fucus vesiculosus* in the Barents Sea (annual average ± standard deviation).

An equilibrium Cs CF value can be estimated from data on the concentration of stable Cs in sea water and in fish. The average concentration of Cs in the worlds oceans is 3.7×10^{-7} g L^{-1} and the average concentration of Cs in fish flesh has been reported to be *circa* $(16\pm6.9)\times10^{-6}$ g kg^{-1} (Fleishman 1982). Therefore, a world average CF value for Cs of 46±19 is estimated (Sazykina 1998). This is lower by a factor of 2 compared to the average CF value recommended for radiocaesium by the IAEA (1985) of 100 but is in agreement with the current ^{137}Cs CF value (40 ± 6) for fish in Greenland Sea (Figure A1). This suggests that for this sea at least, ^{137}Cs has equilibrated between water and fish compartments.

Estimated ^{90}Sr CF values for different species of Arctic fish are presented in Table A2. Because Sr is accumulates in bone, CF values for this organ have also been collated. Within IAEA (1985) the recommended value for Sr in fish is exceptional in the sense that it allows for bone and whole body consumption by humans. The publication cites a Sr CR value of <1 for flesh only.

Estimated ^{239,240}Pu CFs for different species of the fish are presented in Table A3. Plutonium was not detected above 0.002 Bq kg^{-1} in most samples of fish and therefore CF values are often quoted as less than values. Whilst the majority of CF values are for muscle, Pu accumulates in bone and liver; one CF value for liver is presented in Table A3.

Table A2 Mean±standard deviation (counting uncertainty when n=1) CF values for ^{90}Sr for different species of Arctic fish (FW); number of data are indicated in parentheses.

Species	Barents Sea (muscles)	Barents Sea (bone)	Kara Sea (bone)
Anarhichas lupus (wolffish)	3±1 (1)		
Boreogadus saida (polar cod)			450±90 (2)
Cottus spp. (sculpin)			310±200 (1)
Gadus morhua (cod)	15±10 (4)	100±40 (2)	
Liparis fabricci (polar snailfish)			390±160 (1)
Mallotus villosus (capelin)	3±1 (1)		
Melanogrammus aeglefinus (haddock)	5±3 (3)		
Pleuronectes platessa (plaice)	8±5 (3)		
Raya radiata (ray)	3±1 (1)		
Mixed species		110±50 (1)	

Table A3. Plutonium-239,240 CF values (±counting uncertainty) for different species of Arctic fish (FW); number of data are indicated in parentheses.

Species	Norwegian Sea	Barents Sea	Kara Sea	North Sea
Anarhichas lupus (wolffish)		< 200		
Boreogadus saida (polar cod)		< 200	< 200	
Cottus spp. (sculpin)			< 330	
Gadus morhua (cod)	120±40 (1)	140±60 (1)		100±30 (1)
Hippoglossus hippoglossus (halibut)		< 200		
Melanogrammus aeglefinus (haddock)		1700±500 (1) (Liver)		
Pleuronectes platessa (plaice)		< 200		
Pollachius virens (saithe)		< 200		
Raya radiate (ray)		900±300 (1)		
Salmo salar (Atlantic salmon)		< 200		
Sebastes marinus (redfish)		< 200		

A summary of CF values derived for Arctic seas is compared to IAEA (1985) recommendations in Table A4. Given the limited and highly variable nature of the data available for Arctic seas it is not possible to comment as to whether CF values for Arctic fish are any different from generic world-wide estimates.

Table A4. Comparison of CF values for fish (FW) derived from the EPIC marine database (estimated average with range) to IAEA (1985) recommended values (best estimate and range).

Radionuclide	EPIC database	IAEA (1985)
Sr	10 (3-15)	2 (0.3-10)
Cs	80 (40-1800)	100 (10-300)
Pu	130 (120-900)	40 (0.5-100)

A.2. Birds

Limited data are available for the derivation of CF values in seabirds; estimated ^{137}Cs CF values in different species of Arctic seabirds are presented in Table A5. No data were available to determine transfer to different body parts (in Table A5, estimated ^{137}Cs CF values for the Greenland Sea are for muscles, whilst it was not possible from the available literature to determine whether those for the Barents Sea are for the whole body or just muscles). Caesium-137 and ^{239,240}Pu CF values in Arctic seabirds are presented in Table A6 and compared to recommendations from the Arctic Nuclear Waste Assessment Program (ANWAP; ANWAP 1997).

Table A5. Mean±standard deviation (counting uncertainty when n = 1) ^{137}Cs CF values for different species of the Arctic seabirds (FW); number of data are indicated in parentheses.

Species	Barents Sea (1991-1996)	Greenland Sea (1980)
Calidris spp. (sandpipers)	150± 50 (10)	-
Cepphus grille (black guillemot)	70± 25 (1)	-
Fulmarus glacialis (nothern fulmar)	-	430±250 (6)
Larus argentatus (herring gull)	360± 140 (1)	-
Larus hyperboreus (polar gull)	160± 80 (1)	-
Larus spp. (gulls)	580± 200 (3)	-
Pagophila eburnean (ivory gull)	-	1200±600 (2)
Alle alle (little auk)	100± 30 (1)	-
Rissa triductyla (black-legged kittiwake)	280± 160 (5)	370±150 (7)
Somateria mollissima (eider)	50± 17 (4)	630±140 (7)
Stercorarius skua (great skua)	3750± 3250 (2)	-
Tringa erythopus (spotted redshank)	720± 250 (1)	-
Uria lomvia (Brunnich's guillemot)	-	770±400 (4)

Table A6. Comparison of CF values for seabirds (muscle; FW) derived from the EPIC marine database (estimated average with range) to ANWAP (1997) recommended values (best estimate and range).

Radionuclide	EPIC database	ANWAP (1997)
Cs	300 (50-7000)	100 (40-1100)
Pu	<100-200	100 (20-150)

A.3. Marine mammals

Estimated CF values for ^{137}Cs in different species of Arctic marine mammals are presented in Table A7. Figure A1 presents the temporal variation of ^{137}Cs CF values in whales and Greenland seals from the Greenland Sea; time trends for both mammals follow a similar pattern to that for fish in the Greenland Sea with an initial increase and then a decline. A summary of CF values for ^{90}Sr, ^{137}Cs, and ^{239,240}Pu in Arctic marine mammals is presented in Table A8 and compared to ANWAP (1997) recommended values. With the exception of Minke whales, there are few CF values available for Arctic marine mammals.

Table A7. Mean±standard deviation (counting uncertainty when n = 1) ^{137}Cs CF values for different species of the Arctic marine mammals (FW); number of data are indicated in parentheses.

Species	Norwegian Sea (1988-1994)	Barents Sea (1980-1999)	White Sea (1995-1996)	Greenland Sea (1980-1994)
Balaenoptera acutorostrata (Minke whale)	600±200 (33)	210±70 (17)	-	-
Other baleen whales	430±300 (4)	150±50 (4)	-	90±50 (1)
Pagophilus groenlandica (Greenland seal)	-	70±20 (1)	50±20 (9)	50±20 (8)
Ursus maritimus (Polar bear)	-	300±40 (2)	-	-

Table A8. Comparison of CF values for sea mammals (FW) derived from the EPIC marine database (estimated average with range) to ANWAP (1997) recommended values (best estimate and range).

Radionuclide	EPIC database	ANWAP (1997)
Sr	1 (0.7-1.5)	1 (0.2-3)
Cs	200 (50-600)	100 (13-180)
Pu	400 (20-700)	3

A.4. Crustaceans

Estimated ^{137}Cs CF values for the soft tissues of different species of Arctic crustaceans are presented in Table A9. Table A10 summarises derived ^{90}Sr, ^{137}Cs, ^{239,240}Pu, and ^{99}Tc CF values for the soft tissues of Arctic crustaceans and compares them to IAEA (1985) recommended values.

Table A9. Mean±standard deviation (counting uncertainty when n = 1) ^{137}Cs CF values for the soft tissues of different species of the Arctic crustacea (FW); number of data are indicated in parentheses.

Species	Norwegian Sea	Barents Sea	Pechora Sea
Balanus crenatus (acorn barnacle)	-	12±4 (1)	-
Gammarus spp.	-	70±20 (1)	-
Homarus vulgaris (lobster)	30±10 (4)	-	-
Hyas aroneus (crab)	-	<10	16±4 (2)
Pagurus pubescens (hermit crab)	-	<10	18±4 (2)
Paralithodes camtschatica (Kamchatka crab)	-	150±40 (2)	-
Pandalus borealis (shrimp)	-	35±11 (14)	-

Table A10. Comparison of FW CF values for soft tissues of crustacea (FW) derived from the EPIC marine database (estimated average with range) to IAEA (1985) recommended values (best estimate and range).

Radionuclide	EPIC database	IAEA (1985)
Sr	15	2
	(10-20)	(0.1-5)
Cs	50	30
	(10-150)	(10-50)
Pu	300	300
	(40-500)	(100-1000)
Tc	4000[*]	1000
	(300-9300)	(500-50000)

[*] Values from North Sea.

A.5. Molluscs

Estimated ^{137}Cs CF values for the soft tissues and whole body (soft tissues + shell) of different species of Arctic molluscs are presented in Table A11. Summarised CF values for ^{137}Cs, ^{239,240}Pu, and ^{99}Tc in molluscs are presented in Table A12 and compared to IAEA (1985) recommendations. Whilst ^{137}Cs CF values are similar to the IAEA recommendations those for Pu and Tc are considerably lower.

Table A11. Mean ± standard deviation (counting uncertainty when n = 1) ^{137}Cs CF values for the soft tissues of different species of the Arctic molluscs (FW); number of data are indicated in parentheses.

Species	White Sea	Barents Sea	Pechora Sea	Kara Sea
Bivalve species				
Arctica islandica - soft parts	26±4 (1)	-	-	-
Chlamys islandica	-			
- soft parts	-	80±50 (9)	-	-
- whole body	-	-	9±2 (1)	-
Ciliatocardium ciliatum - soft parts	-	54±18 (1)	46±14 (1)	<8
Macoma calcarea - whole body	17±4 (1)	< 10	22±6 (1)	<8
Modiolus modiolus - whole body	18±5 (1)	-	< 8	-
Muculus riger - whole body	50±8 (1)	-	-	-
Mytilus edulis				
- soft parts	22±4 (1)	50±14 (1)	-	-
- whole body	22±1 (1)	14±5 (1)	< 8	-
Serripes groenlandicus - soft parts	-	< 10	-	42±12 (1)
Tridonta borealis				
- soft parts	22±6 (1)	-	-	< 8
- whole body	12±3 (1)	<10	-	-
Yoldia hyperborean - whole body	-	50±18 (1)	20±6 (1)	-
Gastropod species				
Buccinum spp. (whelks)				
- soft parts	-	-	18±5 (1)	-
- whole body	-	-	< 8	-
Cryptonatica spp.				
- whole body	-	-	13±3 (1)	-

Table A12. Comparison of FW CF values for soft tissues of molluscs (FW) derived from the EPIC marine database (estimated average with range) to IAEA (1985) recommended values (best estimate and range).

Radionuclide	EPIC database	IAEA (1985)
Cs	40 (10-80)	30 (10-50)
Pu	150 (20-260)	3000 (500-5000)
Tc	300 (100-600)	1000 (500-50000)

A.6. Macroalgae

Estimated ^{137}Cs CF values for different species of Arctic macroalgae are presented in Table A13. Figure A1 shows the temporal variation in ^{137}Cs CF values for *Fucus vesiculosus* in the Barents Sea in the period 1980-1995; peak CF values for *F. vesiculosus* appear to have occurred at least one decade earlier than observed in fish from the same sea (Figure A1). A summary of CF values for ^{90}Sr, ^{137}Cs, ^{239,240}Pu, and ^{99}Tc for Arctic macroalgae is presented in Table A14. Although IAEA (1985) CF values are compared to the EPIC database in this table it should be noted that the IAEA review was biased towards edible species. Given edible species are often red and green macroalgae this may influence any comparison with the EPIC database which is predominantly for brown macroalgae.

Table A13. Mean± standard deviation (counting uncertainty when n = 1) ^{137}Cs CF values for different species of the Arctic macroalgae (FW); number of data are indicated in parentheses.

Species	Norwegian Sea	Barents Sea	White Sea	Pechora Sea	Kara Sea
Ascophyllum nodosum	-	15±5 (1)	-	-	-
Fucus distichus	-	18±6 (1)	-	-	-
Fucus evanescenes	-	-	-	-	110±30 (5)
Fucus vesiculosus	38±20 (26)	30±8 (9)	59±10 (1)	43±12 (1)	-
Fucus spp.	-	34±14 (15)	-	-	-
Laminaria digitata	-	-	-	-	160±60 (7)
Laminaria hyperboria	8±4 (8)	-	-	-	-
Laminaria saccharina	-	72±20 (4)	-	-	44±12 (1)
Laminaria spp.	-	46±16 (1)	-	-	170±70 (7)

Table A14. Comparison of CF values for macroalgae (FW) derived from the EPIC marine database (estimated average with range) to IAEA (1985) recommended values (best estimate and range).

Radionuclide	EPIC database	IAEA
Sr	100 (40-150)	5 (1-50)
Cs	40 (8-170)	50 (30-100)
Pu	1300 (800-34000)	2000 (500-5000)
Tc	40000 (1000-50000)	1000 (500-100000)

APPENDIX B

DATABASE ON RADIOACTIVITY OF ARCTIC MARINE BIOTA AND THE ENVIRONMENT

Maintained in Microsoft Excel format on the attached diskette.

APPENDIX B. DATABASE ON RADIOACTIVITY OF ARCTIC MARINE BIOTA

Organism type	**Species**			**Organ/tissue**	**Result expressed as fresh weight (FW) or dry matter (DM)**	**Radionuclide**	**Location**	**Reported concentration (Bq kg^{-1})**	**Standard deviation**	**Reported concentration in water (Bq l^{-1})**	**Standard deviation**	**Concentration factor**	**Standard deviation**	**Number of samples**	**Measurement date**	**Reference (see Deliverable 3 for further details)**
	Latin name	**English name**	**Russian name**													
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,35	0,15	0,0058	0,0015	60	30	24	1997-1998	Brungot et al 1999
Fish	*Pollachius virens*	Saithe	Sayda	Muscle	FW	Cs-137	Barents Sea	0,35	0,05	0,0058	0,0015	60	18	3	1997-1998	Brungot et al 1999
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Norwegian Sea	0,45	0,25	0,006	0,0022	75	50	21	1997-1998	Brungot et al 1999
Fish	*Pollachius virens*	Saithe		Muscle	FW	Cs-137	Norwegian Sea	0,5	0,1	0,006	0,0022	83	35	6	1997-1998	Brungot et al 1999
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Cs-137	Norwegian Sea	0,45	0,15	0,006	0,0022	75	37	3	1997-1998	Brungot et al 1999
Fish	*Brosme brosme*	Cusk	Menek	Muscle	FW	Cs-137	Norwegian Sea	0,6	0,2	0,006	0,0022	100	50	2	1997-1998	Brungot et al 1999
Fish	*Salmo salar*	Atlantic Salmon	Losos'	Muscle	FW	Cs-137	Norwegian Sea	0,8		0,006	0,0022	133	49	1	1997-1998	Brungot et al 1999
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,44		0,016	0,002	28	4	1	1979	Matishov, G.G. & Rodin, A.V. (Eds.). (1996).
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,95	0,37	0,018	0,002	53	21	2	1980	Matishov, G.G. & Rodin, A.V. (Eds.). (1996).
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	1,57	0,71	0,02	0,004	79	39	3	1981	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	2,09	0,08	0,021	0,004	100	19	2	1982	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	1,99	1,26	0,02	0,004	100	66	3	1983	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	1,55		0,009	0,002	172	38	1	1989	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,87		0,0058	0,0015	150	39	3	1991	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,66	0,13	0,0058	0,0015	114	40	5	1993	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Bone	FW	Cs-137	Barents Sea	0,42	0,04	0,0058	0,0015	72	20	4	1993	Matishov, et al. 1994
Fish	*Clupea harengus*	Herring	Seld		FW	Cs-137	Barents Sea	0,65		0,0058	0,0015	112	30	2	1991	Matishov, et al. 1994
Bird	*Larus argentatus*	Herring gull	Serebristaja chaika			Cs-137	Barents Sea	2,1	0,6	0,0058	0,0015	360	140	1	1991	Matishov, et al. 1994
Bird	*Rissa tridactyla*	Black-legged kittiwake	Moevka			Cs-137	Barents Sea	1,6	0,8	0,0058	0,0015	280	160	5	1991	Matishov, et al. 1994
Bird	*Larus hyperboreus*	Polar gull	Burgomistr			Cs-137	Barents Sea	0,9	0,4	0,0058	0,0015	155	80	1	1991	Matishov, et al. 1994
Bird	*Plautus alle*	Little Auk	Lurik			Cs-137	Barents Sea	0,6		0,0058	0,0015	100	30	1	1991	Matishov, et al. 1994
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle		Cs-137	Barents Sea	2,8		0,0058	0,0015	480			1992	Matishov, et al. 1994
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	1,7		0,006	0,002	280	100		1993	Matishov, et al. 1994
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	0,8		0,006	0,002	130	50		1993	Matishov, et al. 1994
Algae	*Fucus disticus*		Fukus		DM	Cs-137	Barents Sea	0,5		0,006	0,002	83	30		1993	Matishov, et al. 1994
Algae	*Ascophyllum nodosum*	Knotted wrack			DM	Cs-137	Barents Sea	0,45		0,006	0,002	75	26		1993	Matishov, et al. 1994
Algae	*Laminaria sp.*		Laminariya		DM	Cs-137	Barents Sea	1,4		0,006	0,002	230	80		1993	Matishov, et al. 1994
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	2	1	0,0058	0,0015	344	190		1991-1993	Matishov, et al. 1994
Algae	*Cladonia sp.*				DM	Pu-239,240	Barents Sea	0,93		0,000009	3E-06	103000	34000		1991-1992	Matishov, et al. 1994
Algae	*Cladonia sp.*				DM	Pu-239,240	Barents Sea	1,3		0,000009	3E-06	140000	50000		1991-1992	Matishov, et al. 1994
Algae	*Cladonia sp.*				DM	Pu-239,240	Barents Sea	2,4		0,000009	3E-06	270000	90000		1991-1992	Matishov, et al. 1994
Algae	*Laminaria sacharina*		Laminariya		DM	Pu-239,240	Barents Sea	0,049		0,000009	3E-06	5400	2000		1991-1992	Matishov, et al. 1994
Algae	*Cetraria sp.*				DM	Pu-239,240	Barents Sea	1,3		0,000009	3E-06	140000	50000		1991-1992	Matishov, et al. 1994
Mollusc	*Chlamus islandica, bivalvia*	Scallop	Islamdski grebeshok		DM	Cs-137	Barents Sea	1,1	0,1	0,0058	0,0015	190	50	2	1991	Matishov, et al. 1994
Mollusc	*Chlamus islandica, bivalvia*	Scallop	Islamdski grebeshok		DM	Cs-137	Barents Sea	4,5		0,0058	0,0015	780	230	5	1992	Matishov, et al. 1994
Invertebrate	*Echinoidea,echinodermata*	Sea-urchin	Morskoy ezh		DM	Cs-137	Barents Sea	0,9		0,0058	0,0015	155	40	2	1992	Matishov, et al. 1994
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		DM	Cs-137	Barents Sea	3,9	2,4	0,0058	0,0015	670	440	4	1992	Matishov, et al. 1994
Crustacea	*Paralithodes camtschaticus*	Kamchatka crab	Crab		DM	Cs-137	Barents Sea	4,5		0,0058	0,0015	780	220	1	1992	Matishov, et al. 1994
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Sr-90	Barents Sea	0,03		0,0035	0,0009	8,6	2,3		1993	Matishov, et al. 1994
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Sr-90	Barents Sea	0,004		0,0035	0,0009	1,1	0,3		1993	Matishov, et al. 1994
Fish	*Anarhichas lupus*	Wolffish	Zubatka	Muscle	FW	Sr-90	Barents Sea	0,009		0,0035	0,0009	2,6	0,8		1993	Matishov, et al. 1994
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Sr-90	Barents Sea	0,007		0,0035	0,0009	2	0,5		1993	Matishov, et al. 1994
Fish	*Raja radiata*	Ray	Scat	Muscle	FW	Sr-90	Barents Sea	0,01		0,0035	0,009	2,9	0,7		1993	Matishov, et al. 1994
Fish	*Mixed fish*			Muscle	FW	Sr-90	North Sea	0,012	0,007	0,003	0,0008	4	2,5		1988	Kanisch G. & Nagel G. (1992).
Fish	*Mixed fish*			Muscle	FW	Sr-90	North Sea	0,036	0,03	0,003	0,0008	12	10		1991	Kanisch G. & Nagel G. (1992).
Fish	*Mixed fish*			Muscle	FW	Cs-137	North Sea	4,25	2,8	0,014	0,003	300	200		1988	Kanisch G. & Nagel G. (1992).
Fish	*Mixed fish*			Muscle	FW	Cs-137	North Sea	1,55	0,9	0,01	0,002	155	100		1991	Kanisch G. & Nagel G. (1992).
Fish	*Pleuronectes platessa*	Plaice	Kambala		FW	Cs-137	Norwegian Sea	0,68	0,06	0,006	0,002	113	40	3	1992	Holm, E. (1994).
Fish	*Clupea harengus*	Herring	Seld		FW	Cs-137	Norwegian Sea	0,74	0,5	0,006	0,002	123	80	2	1992	Holm, E. (1994).
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Norwegian Sea	1,62	0,1	0,006	0,002	270	90	2	1992	Holm, E. (1994).
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	2,1	1,45	0,0058	0,0015	362	267		1995-1998	Matishov, et al.1999
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Cs-137	Barents Sea	0,6		0,0058	0,0015	103	93		1995-1998	Matishov, et al.1999
Fish	*Sebastes marinus*	Redfish	Morskoi okun'	Muscle	FW	Cs-137	Barents Sea	1,1	0,7	0,0058	0,0015	190	130		1995-1998	Matishov, et al.1999
Fish	*Anarhichas lupus*	Wolffish	Zubatka	Muscle	FW	Cs-137	Barents Sea	0,5		0,0058	0,0015	86	22		1995-1998	Matishov, et al.1999
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Cs-137	Barents Sea	0,7		0,0058	0,0015	121	31		1995-1998	Matishov, et al.1999
Mollusc	*Chlamus islandica, bivalvia*	Scallop	Islamdski grebeshok		DM	Cs-137	Barents Sea	2,75	1,9	0,0058	0,0015	474	350		1995-1998	Matishov, et al.1999

Crustacea	*Paralithodes camtschaticus*	Kamchatka crab	Crab		DM	Cs-137	Barents Sea	4		0,0058	0,0015	690	178		1995-1998	Matishov, et al.1999
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	1,4		0,0058	0,0015	24	6		1995-1998	Shutov et al 1999
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Cs-137	Barents Sea	3	2,2	0,0058	0,0015	517	402		1998-1999	Shutov et al 1999
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,5	0,6	0,0133	0,0027	113	51	4	1962	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	2,1	0,6	0,0352	0,007	60	21	5	1963	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,5	0,3	0,0224	0,0045	67	19	6	1964	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,9	0,2	0,0192	0,0038	47	14	4	1965	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,5	0,5	0,0125	0,0025	120	47	2	1966	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,1	0,7	0,0133	0,0027	83	55	7	1967	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,2		0,012	0,0024	17	3	1	1968	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,7	0,5	0,0224	0,0045	31	23	4	1969	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,4	0,3	0,009	0,0018	44	34	2	1970	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,76	0,5	0,009	0,0018	84	58	6	1971	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,77	0,73	0,009	0,0018	86	83	3	1972	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	2,4	1,2	0,008	0,0016	300	162	2	1973	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,3	0,9	0,005	0,001	180	130	14	1974	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	1,2	1	0,006	0,0012	167	143	19	1975	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,5	0,2	0,007	0,0014	71	14	11	1976	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,62	0,33	0,008	0,0016	78	44	21	1977	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,78	0,58	0,0065	0,0013	120	92	6	1979	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,46	0,25	0,003	0,0006	153	89	4	1980	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,41	0,11	0,0045	0,0009	91	30	4	1981	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,28	0,08	0,0076	0,0016	37	13	3	1982	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,27	0,08	0,0055	0,0011	49	18	3	1983	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,33	0,12	0,0064	0,0013	52	22	3	1985	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,43	0,19	0,007	0,0014	61	14	5	1986	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,53	0,2	0,0075	0,0015	71	30	3	1987	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,3		0,008	0,0016	38	8	1	1988	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,3		0,006	0,0012	50	10	1	1989	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,3		0,0065	0,0013	46	9	1	1990	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,23	0,12	0,007	0,0014	33	18	3	1991	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,25	0,05	0,0075	0,0015	33	9	2	1992	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,39	0,07	0,0085	0,0017	46	12	4	1993	AMAP,1998
Fish	*Mixed fish*			Muscle	FW	Cs-137	Greenland Sea	0,35	0,14	0,0085	0,0017	41	18	5	1994	AMAP,1998
Fish	*Mixed fish*			Bone	DM	Sr-90	Barents Sea	0,75	0,35	0,007	0,002	107	50		1974	Kilizhenko,1991
Fish	*Mixed fish*			Muscle	FW	Cs-137	Barents Sea	1,3	0,9	0,008	0,002	163	110		1974	Kilizhenko,1991
Fish	*Mixed fish*			Muscle	FW	Cs-137	Barents Sea	0,65	0,55	0,0058	0,0015	112	99	48	1994	Nanstvoll, et al. 1997
Fish	*Mixed fish*			Muscle	FW	Cs-137	Barents Sea	0,2	0,1	0,0058	0,0015	34	19	7	1995	Nanstvoll, et al. 1997
Fish	*Mixed fish*			Muscle	FW	Cs-137	Barents Sea	0,3	0,05	0,0058	0,0015	52	16	7	1996	Nanstvoll, et al. 1997
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,6	0,5	0,0058	0,0015	103	78	38	1993-1996	Nanstvoll, et al. 1997
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Cs-137	Barents Sea	0,3	0,05	0,0058	0,0015	52	16	6	1993-1996	Nanstvoll, et al. 1997
Fish	*Pollachius virens*	Saithe	Sayda	Muscle	FW	Cs-137	Barents Sea	0,4	0,2	0,0058	0,0015	69	39	6	1993-1994	Nanstvoll, et al. 1997
Fish	*Clupea harengus*	Herring	Seld	Muscle	FW	Cs-137	Barents Sea	0,2		0,0058	0,0015	34	9	1	1993-1996	Nanstvoll, et al. 1997
Fish	*Salmo salar*	Atlantic Salmon	Losos'	Muscle	FW	Cs-137	Barents Sea	0,8	0,4	0,0058	0,0015	138	70	6	1993-1996	Nanstvoll, et al. 1997
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Cs-137	Barents Sea	0,25	0,15	0,0058	0,0015	43	28	6	1993-1996	Nanstvoll, et al. 1997
Fish	*Sebastes marinus*	Redfish	Morskoi okun'	Muscle	FW	Cs-137	Barents Sea	0,6	0,15	0,0058	0,0015	103	37	2	1993-1996	Nanstvoll, et al. 1997
Fish	*Anarhichas minor*	Spotted wolf fish	Piatnistaja zubatka	Muscle	FW	Cs-137	Barents Sea	0,5		0,0058	0,0015	86	22	1	1993-1996	Nanstvoll, et al. 1997
Fish	*Reinhardtius hippoglossoides*	Greenland halibut	Paltus	Muscle	FW	Cs-137	Norwegian Sea	0,7		0,0058	0,0015	121	31	1	1993-1996	Nanstvoll, et al. 1997
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Cs-137	Barents Sea	0,7		0,0058	0,0015	121	31	1	1993-1997	Nanstvoll, et al. 1997
Crustacea	*Homarus vulgaris*	European lobster	Lobster	Meat	FW	Cs-137	Norwegian Sea	0,9	0,2	0,006	0,0022	150	64	4	Dec 1997	Brungot et al 1999
Crustacea	*Homarus vulgaris*	European lobster	Lobster	Meat	FW	Tc-99	North Sea	12,8	1,75	0,002	0,001	6400	3300	2	Nov 1997	Brungot et al 1999
Crustacea	*Homarus vulgaris*	European lobster	Lobster	Meat	FW	Cs-137	North Sea	0,14	0,02	0,006	0,0022	23	9	2	1998	Brungot et al 1999
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Meat	FW	Tc-99	Norwegian Sea	0,5		0,002	0,001	250	130	2	1997	Brungot et al 1999
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Meat	FW	Tc-99	North Sea	0,7		0,003	0,001	230	90	1	1997,Nov	Brungot et al 1999
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Meat	FW	Cs-137	North Sea	0,2		0,006	0,0022	33	12	1	1998Dec	Brungot et al 1999
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Tc-99	North Sea	0,5	0,25	0,003	0,001	170	100	2	1997,Nov	Brungot et al 1999
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Cs-137	North Sea	0,18		0,006	0,0022	30	11	1	1998,Dec	Brungot et al 1999
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Cs-137	Norwegian Sea	0,12		0,006	0,0022	20	7	1	June 1998	Brungot et al 1999
Bird	*Somateria mollissima*	Eider	Gaga	Muscle		Cs-137	Greenland Sea	1,9	0,2	0,003	0,0006	633	143	7	1980	Holm, et al 1983
Bird	*Rissa tridactyla*	Black-legged kittiwake	Moevka	Muscle		Cs-137	Greenland Sea	1,1	0,4	0,003	0,0006	367	152	7	1980	Holm, et al 1983
Bird	*Pagophila eburnea*	Ivory gull	Belaja chaika	Muscle		Cs-137	Greenland Sea	3,6	1,6	0,003	0,0006	1200	585	2	1980	Holm, et al 1983
Bird	*Uria lomvia*	Brunnich's guillemot	Tolstoklijvaja kaira	Muscle		Cs-137	Greenland Sea	2,3	1,1	0,003	0,0006	767	398	4	1980	Holm, et al 1983
Bird	*Fulmarus glacialis*	Northern fulmar	Glupish	Muscle		Cs-137	Greenland Sea	1,3	0,7	0,003	0,0006	433	249	6	1980	Holm, et al 1983
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Barents Sea	1,1	0,1	0,018	0,002	61	9		1980	Holm, et al 1983
Mammal	*Ursus maritimus*	Polar bear	Beliy medved'	Muscle	FW	Cs-137	Barents Sea	6	0,3	0,018	0,002	333	41	2	1980	Holm, et al 1983
Mammal	*Ursus maritimus*	Polar bear	Beliy medved'	Muscle	FW	Pu-239,240	Barents Sea	0,0044	0,001	0,00001	2E-06	440	140	2	1980	Holm, et al 1983
Crustacea	*Hyas sp.*	Crab	Crab		DM	Cs-137	Barents Sea	0,44	0,07	0,0058	0,0015	76	23		1992	Strand,1993

Crustacea	*Hyas sp.*	Crab	Crab		DM	Pu-239,240	Barents Sea	0,024	0,004	0,000009	3E-06	2667	994		1992	Strand,1993
Crustacea	*Gammaridae*	Gammarida	Gamarida		DM	Cs-137	Kara Sea	1,5	0,3	0,0076	0,0022	197	69	3	1992	Strand,1993
Crustacea	*Gammaridae*	Gammarida	Gamarida		DM	Pu-239,240	Kara Sea	0,011	0,002	0,000006	2E-06	1830	700	3	1992	Strand,1993
Invertebrate	*Ophiuridea*	Ophiroidae	Ophiura		DM	Cs-137	Kara Sea	0,57	0,39	0,0076	0,0022	75	54		1992	Strand,1993
Invertebrate	*Ophiuridea*	Ophiroidae	Ophiura		DM	Pu-239,240	Kara Sea	0,12	0,03	0,000006	2E-06	20000	8333	4	1992	Strand,1993
Algae	*Fucus evanescenes*		Fukus		DM	Cs-137	Kara Sea	2	0,5	0,005	0,0002	400	110	3	1993	NRPA,1994
Algae	*Laminaria digitata*	Oarweed	Laminariya		DM	Cs-137	Kara Sea	3,4	1	0,005	0,0002	680	200	5	1993	NRPA,1994
Algae	*Laminaria digitata*	Oarweed	Laminariya	Stem	DM	Cs-137	Kara Sea	6,2	0,6	0,005	0,0002	1240	130	1	1993	NRPA,1994
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Kara Sea	1,1	0,3	0,005	0,0002	220	60	1	1993	NRPA,1994
Algae	*Laminaria sp.*		Laminariya		DM	Cs-137	Kara Sea	4,8	2	0,005	0,0002	960	400	6	1993	NRPA,1994
Algae	*Laminaria digitata,L.sacharina*		Laminariya		DM	Sr-90	Kara Sea	3,3	1,3	0,005	0,0013	660	310	4	1993	NRPA,1994
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	Kara Sea	0,056	0,01	0,000004	2E-06	14000	7400	4	1993	NRPA,1994
Algae	*Laminaria digitata*	Oarweed	Laminariya		DM	Cs-137	Kara Sea	2,5	0,4	0,0052	0,0001	480	140	1	1993	NRPA,1994
Algae	*Fucus evanescenes*		Fukus		DM	Cs-137	Kara Sea	3,8	0,4	0,0055	0,0003	690	70	2	1993	NRPA,1994
Algae	*Fucus evanescenes*		Fukus		DM	Sr-90	Kara Sea	3,7	0,2	0,0051	0,0002	725	40	2	1993	NRPA,1994
Algae	*Fucus evanescenes*		Fukus		DM	Pu-239,240	Kara Sea	0,42	0,02	0,000005	2E-06	84000	35000	2	1993	NRPA,1994
Algae	*Laminaria sp.*		Laminariya		DM	Cs-137	Kara Sea	3,9	0,4	0,0055	0,0013	709	180		1994,Sep	NRPA,1996
Algae	*Laminaria digitata,L.sacharina*		Laminariya		DM	Sr-90	Kara Sea	1,75	0,8	0,0029	0,0006	600	300		1994,Sep	NRPA,1996
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	Kara Sea	0,12	0,04	0,000006	1E-06	20000	7500		1994,Sep	NRPA,1996
Algae	*Laminaria digitata,L.sacharina*		Laminariya		DM	Am-241	Kara Sea	0,013	0,005	0,000012		1080	400		1994,Sep	NRPA,1996
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Cs-137	Kara Sea	5	1	0,005	0,0002	1000	200		1993	NRPA,1994
Fish	*Boreogadus saida*	Arctic cod	Saika	Bone	DM	Sr-90	Kara Sea	2,9	0,2	0,0054	0,0014	540	150		1993	NRPA,1994
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Pu-239,240	Kara Sea	<0.001	1	0,000005	2E-06	<200			1993	NRPA,1994
Fish	*Liparis fabricii*	Polar snailfish	Liparis		FW	Cs-137	Kara Sea	9	1	0,005	0,0002	1800	200		1993	NRPA,1994
Fish	*Liparis fabricii*	Polar snailfish	Liparis	Bone	DM	Sr-90	Kara Sea	2,1	0,2	0,0054	0,0014	390	160		1993	NRPA,1994
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Cs-137	Kara Sea	1,4	0,2	0,0055	0,0013	250	70		1994	NRPA,1996
Fish	*Boreogadus saida*	Arctic cod	Saika	Bone	DM	Sr-90	Kara Sea	1,04	0,1	0,0029	0,0006	360	80		1994	NRPA,1996
Fish	*Cottus sp.*	Sculpin	Bychok		FW	Cs-137	Kara Sea	0,8	0,2	0,0055	0,0013	145	50		1994	NRPA,1996
Fish	*Cottus sp.*	Sculpin	Bychok	Bone	DM	Sr-90	Kara Sea	0,9	0,6	0,0029	0,0006	310	210		1994	NRPA,1996
Fish	*Salvelinus alpinus*	Arctic char	Arcticheskii golets		FW	Cs-137	Kara Sea	1,4	0,8	0,0055	0,0013	250	90		1994	NRPA,1996
Fish	*Boreogadus saida*	Arctic cod	Saika		DM	Pu-239,240	Kara Sea	<0.01		0,000006	1E-06	<1700	80		1994	NRPA,1996
Fish	*Cottus sp.*	Sculpin	Bychok		DM	Pu-239,240	Kara Sea	<0.02		0,000006	1E-06	<3300	50		1994	NRPA,1996
Invertebrate	*Foraminefera, protists*	Foraminifera	Foraminifera		DM	Sr-90	Norwegian Sea	0,34	0,1	0,003	0,0008	113	45		1991-1992	Kuznetsov, et al. 1993
Invertebrate	*Foraminefera, protists*	Foraminifera	Foraminifera		DM	Cs-137	Norwegian Sea	5,5	3,1	0,006	0,0022	917	617		1991	Kuznetsov, et al. 1993
Invertebrate	*Foraminefera, protists*	Foraminifera	Foraminifera		DM	Cs-137	Norwegian Sea	6	2	0,006	0,0022	1000	496		1992	Kuznetsov, et al. 1993
Invertebrate	*Foraminefera, protists*	Foraminifera	Foraminifera		DM	Pu-239,240	Norwegian Sea	0,049	0,003	0,00001	2E-06	4900	1025		1992	Kuznetsov, et al. 1993
Invertebrate	*Ophiroidae*		Ophiura		DM	Sr-90	Norwegian Sea	0,11	0,03	0,003	0,0008	37	14		1991-1992	Kuznetsov, et al. 1993
Invertebrate	*Ophiroidae*		Ophiura		DM	Cs-137	Norwegian Sea	3	0,4	0,006	0,0022	500	195		1991	Kuznetsov, et al. 1993
Invertebrate	*Ophiroidae*		Ophiura		DM	Pu-239,240	Norwegian Sea	0,033	0,006	0,00001	2E-06	3300	892		1992	Kuznetsov, et al. 1993
Invertebrate	*Asteroidea*		Asteroida		DM	Sr-90	Norwegian Sea	0,07	0,02	0,003	0,0008	23	9		1991-1992	Kuznetsov, et al. 1993
Invertebrate	*Asteroidea*		Asteroida		DM	Cs-137	Norwegian Sea	1,2	0,7	0,006	0,0022	200	139		1991	Kuznetsov, et al. 1993
Invertebrate	*Asteroidea*		Asteroida		DM	Cs-137	Norwegian Sea	4,3	1,3	0,006	0,0022	717	340		1992	Kuznetsov, et al. 1993
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Greenland Sea	1,8	0,6	0,003	0,0006	600	233		1980	Holm, et al 1983
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Greenland Sea	0,13	0,025	0,000012	1E-06	10800	2100		1980	Holm, et al 1983
Algae	*Laminaria sacharina*		Laminariya	Leaves	DM	Cs-137	Greenland Sea	1,1	0,5	0,003	0,0006	367	182	3	1980	Holm, et al 1983
Algae	*Laminaria sacharina*		Laminariya	Leaves	DM	Pu-239,240	Greenland Sea	0,07	0,03	0,000012	1E-06	5800	2500	3	1980	Holm, et al 1983
Algae	*Laminaria sacharina*		Laminariya	Stem	DM	Cs-137	Greenland Sea	1,7	0,6	0,003	0,0006	567	230	3	1980	Holm, et al 1983
Algae	*Laminaria sacharina*		Laminariya	Stem	DM	Pu-239,240	Greenland Sea	0,1	0,04	0,000012	1E-06	8300	3800	3	1980	Holm, et al 1983
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	0,9	0,4	0,0058	0,0015	155	80	3	1995-1998	Matishov, et al.1999
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	2,3		0,0058	0,0015	397	103		1995-1998	Matishov, et al.1999
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	46		0,0058	0,0015	7931	2051		1995-1998	Matishov, et al.1999
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	1,1	0,8	0,0058	0,0015	190	147		1993	Matishov, et al.1999
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Muscle	FW	Cs-137	Norwegian Sea	4,4	1,7	0,006	0,0022	733	390	29	1988-1994	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Bone	FW	Sr-90	Norwegian Sea	5,7	1	0,003	0,0008	1900	606	5	1988-1994	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Liver	FW	Pu-239,240	Norwegian Sea	0,01	0,008	0,00001	2E-06	1000	825	5	1988-1994	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Muscle	FW	Cs-137	Norwegian Sea	3,4	2,5	0,006	0,0022	567	466	4	1992	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Muscle	FW	Cs-137	Barents Sea	1,2	0,3	0,0058	0,0015	207	74	17	1992	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Bone	FW	Sr-90	Barents Sea	0,9	0,5	0,0035	0,0009	257	157	5	1992	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Balaenortera acutirostrata*	Minke whale	Karlikoviy polosatik	Liver	FW	Pu-239,240	Barents Sea	0,004	0,001	0,000009	3E-06	444	185	4	1992	Christensen, G.C. & Steinnes, E. (1999).
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle	FW	Cs-137	White Sea	0,86	0,05	0,01	0,002	86	18	2	1995	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle	FW	Pu-239,240	White Sea	0,001		0,000009	3E-06	110	40		1995	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle	FW	Sr-90	White Sea	0,01		0,0068	0,0025	1,5	0,6	1	1995	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle	FW	Cs-137	White Sea	0,36	0,12	0,01	0,002	36	14	7	1996	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Muscle	FW	Pu-239,240	White Sea	0,003		0,000009	3E-06	330	120		1996	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Ribs	FW	Sr-90	White Sea	0,18		0,0068	0,0025	26	10	1	1996	Rissanen,1999
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	Bone	FW	Sr-90	White Sea	0,1		0,0068	0,0025	15	6	1	1996	Rissanen,1999
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,4	0,12	0,0034	0,001	118	50		1990-1994	Aarkrog et al 1997

Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	2,2	0,13	0,0034	0,001	647	194		1960-1964	Aarkrog et al 1997
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Sr-90	Greenland Sea	0,0013		0,002	0,0002	0,7	0,1		1990-1994	Aarkrog et al 1997
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle		Sr-90	Greenland Sea	0,73	0,45	0,0133	0,0027	55	36	3	1960-1964	Aarkrog et al 1997
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	1,2		0,0133	0,0027	90	18	1	1961	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	2,5		0,0133	0,0027	188	38	1	1962	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	3,2		0,0224	0,0045	143	29	1	1964	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	2,5		0,0125	0,0025	200	40	1	1966	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,93	0,9	0,012	0,0024	78	77	2	1968	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	1,25	0,15	0,0224	0,0045	56	13	2	1969	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	1,1		0,009	0,0018	122		1	1970	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	2		0,009	0,0018	222	24	1	1971	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,9	0,2	0,006	0,0012	150	44	2	1975	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	1,1		0,009	0,0018	122	45	1	1978	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,7	0,2	0,0065	0,0013	108	24	2	1979	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,55	0,15	0,007	0,0014	79	38	2	1986	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,9		0,0075	0,0015	120	27	1	1987	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,6	0,1	0,008	0,0016	75	24	2	1988	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,6	0,3	0,006	0,0012	100	20	2	1989	AMAP,1998
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Greenland Sea	0,7		0,0075	0,0015	93	54	1	1992	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	3,6		0,0133	0,0027	271	19	1	1962	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,8	0,4	0,0352	0,007	23	54	4	1963	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,9	0,5	0,0224	0,0045	40	12	5	1964	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	3,6	3,4	0,0192	0,0038	188	24	8	1965	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	1		0,0125	0,0025	80	181	1	1966	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,8	0,4	0,0133	0,0027	60	16	4	1967	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,8		0,012	0,0024	67	32	1	1968	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,9		0,0224	0,0045	40	13	1	1969	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	1,6		0,009	0,0018	178	8	1	1972	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,95	0,36	0,007	0,0014	136	36	4	1976	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,5	0,2	0,008	0,0016	63	58	7	1977	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,36	0,24	0,009	0,0018	40	28	3	1978	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,35	0,05	0,0065	0,0013	54	28	2	1979	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,25	0,05	0,003	0,0006	83	13	2	1980	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,7		0,0045	0,0009	156	23	1	1981	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,55	0,3	0,0076	0,0016	72	31	4	1982	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,55	0,15	0,0063	0,0013	87	55	2	1984	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,2		0,0064	0,0013	31	30	1	1985	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,35	0,15	0,007	0,0014	50	6	2	1986	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,15	0,05	0,0075	0,0015	20	24	2	1987	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,2		0,006	0,0012	33	8	1	1989	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,4		0,0065	0,0013	62	7	1	1990	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,2		0,007	0,0014	29	12	1	1991	AMAP,1998
Mammal	*Phoca vitulina*	Common seal	Tulen'	Muscle	FW	Cs-137	Greenland Sea	0,7	0,3	0,0085	0,0017	82	6	6	1994	AMAP,1998
Algae	*Ptilota plumose*				DM	Cs-137	Barents Sea	0,28	0,02	0,000009	3E-06	31000	11000		1993-1994	Ikaheimonen et al 1995
Algae	*Laminaria sacharina*		Laminariya		DM	Pu-239,240	Barents Sea	0,057	0,006	0,000009	3E-06	6333	2214		1993	Ikaheimonen et al 1995
Algae	*Laminaria sacharina*		Laminariya		DM	Pu-239,240	Barents Sea	0,029	0,005	0,000009	3E-06	3222	1209		1994	Ikaheimonen et al 1995
Algae	*Laminaria sacharina*		Laminariya		DM	Pu-239,240	White Sea	0,039	0,01	0,000009	3E-06	4300	1800		1994	Ikaheimonen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,076	0,008	0,000009	3E-06	8444	2952		1993	Ikaheimonen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,11	0,01	0,000009	3E-06	12222	4223		1993	Ikaheimonen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,035	0,009	0,000009	3E-06	3900	1600		1993-1994	Ikaheimonen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,25	0,02	0,000009	3E-06	28000	10000		1994	Ikaheimonen et al 1995
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	Petshora Sea	0,042	0,008	0,000009	3E-06	4700	2000		1993	Ikaheimonen et al 1995
Algae	*Chorda filum*				DM	Pu-239,240	Barents Sea	0,02	0,005	0,000009	3E-06	2200	900		1993-1994	Ikaheimonen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Tc-99	Norwegian Sea	79	8	0,002	0,001	39500	20000		1997	NRPA,1998
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Tc-99	Norwegian Sea	124	12	0,002	0,001	62000	32000		1998	NRPA,1998
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Meat	FW	Tc-99	Norwegian Sea	0,54	0,05	0,002	0,001	270	140		1997	NRPA,1998
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Tc-99	Norwegian Sea	60	10	0,001	0,0005	60000	32000		1980-1985	Dahlgaard et al 1997
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Barents Sea	0,7	0,3	0,0078	0,0017	90	43		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska	Muscle		Sr-90	Barents Sea	0,11	0,05	0,0035	0,0009	31	16		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Pu-239,240	Barents Sea	0,0013	0,0004	0,000009	3E-06	144	65		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Norwegian Sea	1,7	0,3	0,008	0,001	212	46		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska	Muscle		Sr-90	Norwegian Sea	0,28	0,07	0,003	0,0008	93	34		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Pu-239,240	Norwegian Sea	0,0012	0,0004	0,00001	2E-06	120	43		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	North Sea	1,6	0,2	0,006	0,003	267	138		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska	Muscle		Sr-90	North Sea	0,06	0,03	0,003	0,0008	20	11		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Pu-239,240	North Sea	0,001	0,0002	0,00001	2E-06	100	28		1992,Nov.	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	North Sea	0,3	0,02	0,006	0,003	50	25		1993,Nov	NRPA,1995

Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Norwegian Sea	0,23	0,01	0,008	0,002	29	7		1993,Nov	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Barents Sea	0,45	0,02	0,008	0,002	56	14		1993,Nov	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska	Bone		Cs-137	Barents Sea	0,28	0,01	0,008	0,002	35	9		1993,Nov	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska	Bone		Sr-90	Barents Sea	0,5	0,1	0,0035	0,0009	143	47		1993,Nov	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Barents Sea	0,8	0,7	0,008	0,002	100	90	11	1993,Nov	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	North Sea	1,09	0,04	0,006	0,003	182	91		1994,Jan	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Norwegian Sea	0,23	0,06	0,006	0,001	38	12		1994,Sep	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Barents Sea	0,51	0,06	0,004	0,001	127	35		1994,Sep	NRPA,1995
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Cs-137	Norwegian Sea	0,3	0,06	0,006	0,001	50	13		1994,Oct	NRPA,1995
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	Norwegian Sea	0,7	0,07	0,006	0,001	117	23		1994,Oct	NRPA,1995
Fish	*Clupea harengus*	Herring	Seld		FW	Cs-137	Norwegian Sea	0,6	0,08	0,006	0,001	100	21		1994,Apr	NRPA,1995
Fish	*Hippoglossus hippoglossus*	Halibut	Paltus		FW	Cs-137	Norwegian Sea	0,7	0,06	0,006	0,001	117	22		1994,Jun	NRPA,1995
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Norwegian Sea	3,4	2,5	0,008	0,001	425	310	4	1992	NRPA,1995
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Barents Sea	0,9	0,3	0,0078	0,0017	115	46	3	1992	NRPA,1995
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Barents Sea	1	0,2	0,0078	0,0017	128	38	3	1992	NRPA,1995
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Barents Sea	1,4	0,2	0,0078	0,0017	180	47	2	1992	NRPA,1995
Mammal	*Balaenidae*	Whales	Kit	Muscle	FW	Cs-137	Barents Sea	1,3	0,2	0,0078	0,0017	167	45	9	1992	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	1,2	0,07	0,008	0,002	150	40		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,78	0,06	0,008	0,002	100	23		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	1,4	0,2	0,003	0,0008	470	140		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,08	0,02	0,00001	2E-06	8000	2560		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,78	0,08	0,0076	0,0013	103	20		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	1,95	0,17	0,0079	0,0011	247	40		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	1,39	0,07	0,008	0,002	174	44		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	2,47	0,1	0,008	0,002	309	80		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	1	0,1	0,003	0,0008	333	95		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,14	0,04	0,00001	2E-06	14000	4900		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	1,93	0,09	0,008	0,002	241	60		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	2,66	0,21	0,01	0,002	266	57		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	3,72	0,21	0,014	0,002	265	40		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	North Sea	2,1	0,3	0,003	0,0008	700	210		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	North Sea	0,15	0,04	0,00001	2E-06	15000	5000		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	9,39	0,25	0,036	0,008	261	58		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	9,3		0,018	0,002	517	60		1980	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	6,2		0,02	0,004	310	70		1981	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	5,7		0,021	0,004	270	60		1982	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	5,5		0,02	0,004	275	60		1983	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	4,2		0,018	0,004	230	50		1984	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	3		0,015	0,003	200	30		1985	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	2,8		0,009	0,002	310	70		1989	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	1,7		0,009	0,002	190	50		1989	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	1,2		0,008	0,002	150	40		1990	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	1,4		0,006	0,001	230	40		1991	NRPA,1995
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Norwegian Sea	0,18	0,01	0,008	0,002	23	6		1993	NRPA,1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	0,8	0,1	0,008	0,003	100	40		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,6	0,1	0,008	0,003	75	30		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	0,26	0,02	0,0021	0,0001	124	11		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,078	0,01	0,000014	3E-06	5570	1400		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,9	0,1	0,008	0,003	113	44		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	0,85	0,05	0,0027	0,0003	315	40		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,107	0,01	0,000011	2E-06	9730	2000		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Co-60	Norwegian Sea	0,4	0,1	0,008	0,003	50	23		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	2,9	0,3	0,008	0,003	362	140		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	0,69	0,04	0,0026	0,0002	265	26		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,123	0,01	0,000046	9E-06	2670	570		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	1,5	0,1	0,008	0,003	188	72		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	2,1	0,1	0,008	0,003	263	100		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Sr-90	Norwegian Sea	1,23	0,07	0,0026	0,0002	473	45		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Norwegian Sea	0,037	0,008	0,00002	0,00001	1850	1000		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	3	0,2	0,008	0,003	375	143		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	3,7	0,2	0,01	0,002	370	77		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	5,9	0,5	0,014	0,002	421	70		1995	NRPA,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	6,6	0,6	0,036	0,008	183	44		1995	NRPA,1997
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Barents Sea	0,25	0,15	0,008	0,003	31	22	5	1995	NRPA,1997
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Norwegian Sea	0,3	0,2	0,008	0,003	38	27	3	1995	NRPA,1997
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Exoskeleton	FW	Sr-90	Norwegian Sea	0,085	0,005	0,0034	0,001	25	7	3	1995	NRPA,1997
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Pu-239,240	Barents Sea	0,00033	0,00005	0,000009	3E-06	37	14	1	1995	NRPA,1997

Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,35	0,11	0,008	0,003	44	21	20	1995	NRPA,1997
Fish	*Gadus morhua*	Cod	Treska	Bone	FW	Cs-137	North Sea	0,45	0,15	0,008	0,003	56	28	4	1995	NRPA,1997
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	North Sea	1,05	0,05	0,01	0,002	105	22	3	1995	NRPA,1997
Fish	*Gadus morhua*	Cod	Treska		FW	Pu-239,240	North Sea	0,0055	0,0003	0,00001	2E-06	550	114	3	1995	NRPA,1997
Fish	*Mixed fish*	Cusk,haddock,saithe			FW	Cs-137	Barents Sea	0,6	0,17	0,008	0,003	75	27	22	1995	NRPA,1997
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Tc-99	North Sea	36	4	0,0012	0,0004	300000	10000		1996,Nov	NRPA,1998
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Tc-99	North Sea	170	20	0,0012	0,0004	140000	50000		1997,Nov	NRPA,1998
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Tc-99	North Sea	0,54	0,05	0,0012	0,0004	450	160		1997,Nov	NRPA,1998
Crustacea	*Homarus gammarus*	Common lobster	Lobster		FW	Tc-99	North Sea	11,2	1,1	0,0012	0,0004	9300	3200		1997,Nov	NRPA,1998
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya		FW	Tc-99	North Sea	0,68	0,07	0,0012	0,0004	570	200		1997,Nov	NRPA,1998
Fish	*Pollachius virens*	Saithe	Sayda		FW	Cs-137	North Sea	0,25	0,1	0,006	0,002	42	22	10	1997-1998	NRPA,1999
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Cs-137	North Sea	0,15	0,03	0,006	0,002	25	10	10	1997-1998	NRPA,1999
Fish	*Scomber scombrus*	Mackerel	Mackerel		FW	Cs-137	North Sea	0,25	0,1	0,006	0,002	42	22	10	1997-1998	NRPA,1999
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	North Sea	1,05	0,05	0,01	0,002	105	21	3	1997-1998	NRPA,1999
Fish	*Merlangius merlangus*	Whiting	Merlang		FW	Cs-137	North Sea	1,2		0,01	0,002	120	25	1	1998	NRPA,1999
Algae	*Laminaria hyberborea*		Laminariya		DM	Cs-137	Norwegian Sea	0,35	0,15	0,008	0,002	44	21	8	1998	NRPA,1999
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Cs-137	North Sea	3,6	0,2	0,016	0,0008	225	17	1	1996,Nov	NRPA,1999
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Cs-137	North Sea	2,7	0,14	0,0114	0,0006	240	18	1	1997,Nov	NRPA,1999
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Cs-137	North Sea	3	0,24	0,012	0,0006	250	24	1	1998,Dec	NRPA,1999
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Tc-99	North Sea	285	34	0,0016	0,0002	180000	31000	1	1998,Dec	NRPA,1999
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	North Sea	3,9	0,3	0,012	0,0006	325	30	1	1998,Dec	NRPA,1999
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Tc-99	North Sea	255	31	0,0016	0,0002	160000	28000	1	1998,Dec	NRRA,1999
Algae	*Fucus serratus*	Toothed wrack	Fukus		DM	Cs-137	North Sea	1,7	0,15	0,01	0,002	170	37	1	1998,Jan	NRPA,1999
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,55	0,25	0,008	0,002	70	36	4	1997	NRPA,1999
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Norwegian Sea	0,6	0,2	0,008	0,002	75	31	10	1998	NRPA,1999
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Cs-137	Barents Sea	0,7		0,006	0,002	117	40	11	1993	Rissanen,1997
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Cs-137	Barents Sea	0,9		0,006	0,002	150	50	6	1994	Rissanen,1997
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Cs-137	Barents Sea	0,5		0,006	0,002	83	30	6	1993	Rissanen,1997
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Cs-137	Barents Sea	0,2		0,006	0,002	33	11	6	1994	Rissanen,1997
Fish	*Pollachius virens*	Saithe	Sayda		FW	Cs-137	Barents Sea	0,4		0,006	0,002	70	23	7	1994	Rissanen,1997
Fish	*Anarhichas lupus*	Wolffish	Zubatka		FW	Cs-137	Barents Sea	0,4		0,006	0,002	70	23	3	1993	Rissanen,1997
Fish	*Sebastes marinus*	Redfish	Morskoy okun'		FW	Cs-137	Barents Sea	0,4		0,006	0,002	70	23	8	1994	Rissanen,1997
Fish	*Pleuronectes platessa*	Plaice	Kambala		FW	Cs-137	Barents Sea	0,6		0,006	0,002	100	33	12	1993	Rissanen,1997
Fish	*Pleuronectes platessa*	Plaice	Kambala		FW	Cs-137	Barents Sea	0,4		0,006	0,002	70	23	8	1994	Rissanen,1997
Fish	*Hippoglossus hippoglossus*	Halibut	Paltus		FW	Cs-137	Barents Sea	0,5		0,006	0,002	83	30	9	1994	Rissanen,1997
Fish	*Raja radiata*	Ray	Scat		FW	Cs-137	Barents Sea	0,8		0,006	0,002	130	40	10	1993	Rissanen,1997
Fish	*Raja radiata*	Ray	Scat		FW	Cs-137	Barents Sea	0,6		0,006	0,002	100	33	3	1994	Rissanen,1997
Fish	*Cottus sp.*	Sculpin	Bychok		FW	Cs-137	Barents Sea	0,3		0,006	0,002	50	17	2	1993	Rissanen,1997
Fish	*Gadus morhua*	Cod	Treska	Bone	FW	Pu-239,240	Barents Sea	0,043		0,000009	3E-06	4800	1600		1993-1994	Rissanen,1997
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Liver	FW	Pu-239,240	Barents Sea	0,017		0,000009	3E-06	1900	640		1993-1994	Rissanen,1997
Fish	*Raja radiata*	Ray	Scat	Muscle	FW	Pu-239,240	Barents Sea	0,0079		0,000009	3E-06	900	300		1993-1994	Rissanen,1997
Fish	*Raja radiata*	Ray	Scat	Bone	FW	Pu-239,240	Barents Sea	0,0049		0,000009	3E-06	540	180		1993-1994	Rissanen,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Barents Sea	0,8		0,006	0,002	130	45		1993-1996	Rissanen,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	Petshora Sea	1,5		0,007	0,002	214	60		1993-1996	Rissanen,1997
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Cs-137	White Sea	3,7		0,0126	0,02	294	50		1993-1996	Rissanen,1997
Fish	*Sprattus sprattus*	Sprat	Sprat		FW	Cs-137	Barents Sea	0,55		0,006	0,002	92	32		1993-1996	Rissanen,1997
Fish	*Cottus sp.*	Sculpin	Bychok		FW	Cs-137	Petshora Sea	0,3		0,007	0,002	43	13		1993-1996	Rissanen,1997
Fish	*Sprattus sprattus*	Sprat	Sprat		FW	Cs-137	White Sea	2,3		0,0126	0,02	183	30		1993-1996	Rissanen,1997
Bird	*Somateria mollissima*	Eider	Gaga		FW	Cs-137	Barents Sea	0,3		0,006	0,002	50	17	4	1996,Feb	Rissanen,1997
Bird	*Cepphus grylle*	Black quillemot	Atlanticheskij chistik		FW	Cs-137	Barents Sea	0,4		0,006	0,002	70	25	1	1996,Feb	Rissanen,1997
Bird	*Larus sp. (L.marinus,L.canus)*	Gull	Chaika		FW	Cs-137	Barents Sea	3,5		0,006	0,002	580	200	3	1995,Aug	Rissanen,1997
Bird	*Stercorarius skua*	Great skua	Pomornic		FW	Cs-137	Barents Sea	21		0,006	0,002	3500	1200	2	1995,Aug	Rissanen,1997
Bird	*Tringa erythropus*	Spotted redshank	Krasnokozhka		FW	Cs-137	Barents Sea	4,3		0,006	0,002	720	250	1	1995,Aug	Rissanen,1997
Bird	*Calidris sp.(C.minuta,C.maritima)*	Sandpiper	Pesochnik		FW	Cs-137	Barents Sea	0,9		0,006	0,002	150	50	10	1995-1996	Rissanen,1997
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Soft parts	DM	Cs-137	Barents Sea	1,2		0,006	0,002	200	70		1993-1996	Rissanen,1997
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Whole	DM	Cs-137	Barents Sea	0,4		0,006	0,002	70	23		1993-1996	Rissanen,1997
Mollusc	*Modiolus modiolus, bivalvia*	Horse mussel		Whole	DM	Cs-137	Barents Sea	0,4		0,006	0,002	70	23		1993-1996	Rissanen,1997
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Soft parts	DM	Cs-137	White Sea	1,4		0,0126	0,02	110	20		1993-1996	Rissanen,1997
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Whole	DM	Cs-137	White Sea	1,4		0,0126	0,02	110	20		1993-1996	Rissanen,1997
Mollusc	*Muculus riger, bivalvia*			Whole	DM	Cs-137	White Sea	3,2		0,0126	0,02	250	40		1993-1996	Rissanen,1997
Mollusc	*Yoldia hyperborea, bivalvia*			Whole	DM	Cs-137	Barents Sea	1,5		0,006	0,002	250	90		1993-1996	Rissanen,1997
Mollusc	*Yoldia hyperborea, bivalvia*			Whole	DM	Cs-137	Petshora Sea	0,7		0,007	0,002	100	30		1993-1996	Rissanen,1997
Mollusc	*Chlamus islandica, bivalvia*	Scallop	Islamdski grebeshok	Soft parts	DM	Cs-137	Barents Sea	0,8		0,006	0,002	130	47		1993-1996	Rissanen,1997
Mollusc	*Chlamus islandica, bivalvia*	Scallop	Islamdski grebeshok	Whole	DM	Cs-137	Petshora Sea	0,3		0,007	0,002	43	12		1993-1996	Rissanen,1997
Mollusc	*Arctica islandica, bivalvia*	Icelandic cyprine		Soft parts	DM	Cs-137	White Sea	1,6		0,0126	0,02	130	20		1993-1996	Rissanen,1997
Mollusc	*Ciliatocardium ciliatum, bivalvia*			Soft parts	DM	Cs-137	Barents Sea	1,6		0,006	0,002	270	90		1993-1996	Rissanen,1997
Mollusc	*Ciliatocardium ciliatum, bivalvia*			Soft parts	DM	Cs-137	Petshora Sea	1,6		0,007	0,002	230	70		1993-1996	Rissanen,1997

Mollusc	*Serripes groenlandicus, bivalvia*			Soft parts	DM	Cs-137	Kara Sea	1,5		0,007	0,002	210	60		1993-1996	Rissanen,1997
Mollusc	*Tridonta borealis, bivalvia*			Soft parts	DM	Cs-137	Petshora Sea	0,8		0,007	0,002	110	30		1993-1996	Rissanen,1997
Mollusc	*Tridonta borealis, bivalvia*			Whole	DM	Cs-137	Petshora Sea	0,4		0,007	0,002	60	16		1993-1996	Rissanen,1997
Mollusc	*Macoma calcarea, bivalvia*			Whole	DM	Cs-137	Petshora Sea	0,8		0,007	0,002	110	30		1993-1996	Rissanen,1997
Mollusc	*Buccinum, gastropoda*			Soft parts	DM	Cs-137	Petshora Sea	0,65		0,007	0,002	90	27		1993-1996	Rissanen,1997
Mollusc	*Cryptonatica, gastropoda*			Whole	DM	Cs-137	Petshora Sea	0,45		0,007	0,002	64	18		1993-1996	Rissanen,1997
Invertebrate	*Asterias rubens, echinodermata*	Sea star	Morskaya zvezda		DM	Cs-137	Petshora Sea	0,4		0,007	0,002	60	17		1993-1996	Rissanen,1997
Invertebrate	*Asterias rubens, echinodermata*	Sea star	Morskaya zvezda		DM	Cs-137	Kara Sea	1,1		0,007	0,002	160	45		1993-1996	Rissanen,1997
Invertebrate	*Stegofiura nodosa, echinodermata*	Brittle star			DM	Cs-137	Petshora Sea	0,4		0,007	0,002	60	17		1993-1996	Rissanen,1997
Invertebrate	*Strongylocentrothus, echinodermata*	Sea urchin	Morskoy ezh		DM	Cs-137	Barents Sea	0,85		0,006	0,002	140	50		1993-1996	Rissanen,1997
Invertebrate	*Cucumaria frondoza, echinodermata*	Sea cucumber	Goloturiya		DM	Cs-137	Barents Sea	1,1		0,006	0,002	180	60		1993-1996	Rissanen,1997
Invertebrate	*Cucumaria frondoza, echinodermata*	Sea cucumber	Goloturiya		DM	Cs-137	Petshora Sea	0,9		0,007	0,002	130	40		1993-1996	Rissanen,1997
Crustacea	*Pagurus pubescens,decapoda*	Heremit crab	Crab		DM	Cs-137	Petshora Sea	0,55		0,007	0,002	80	20		1993-1996	Rissanen,1997
Crustacea	*Hyas aroneus,decapoda*	Crab	Crab		DM	Cs-137	Petshora Sea	0,5		0,007	0,002	70	20		1993-1996	Rissanen,1997
Crustacea	*Balanus Crenatus,decapoda*	Acorn barnacle	Balanus		DM	Cs-137	Barents Sea	0,35		0,006	0,002	60	20		1993-1996	Rissanen,1997
Crustacea	*Gammarus, amphipoda*	Gammarus	Bokoplav		DM	Cs-137	Barents Sea	2,2		0,006	0,002	370	130		1993-1996	Rissanen,1997
Invertebrate	*Alcyonidium disciformi, ectoprocta*				DM	Cs-137	Petshora Sea	1,8		0,007	0,002	260	70		1993-1996	Rissanen,1997
Invertebrate	*Corgonzoa, anthozoa*				DM	Cs-137	Kara Sea	1,8		0,007	0,002	260	70		1993-1996	Rissanen,1997
Invertebrate	*Mesiodothea entomon*				DM	Cs-137	Kara Sea	3,1		0,007	0,002	440	130		1993-1996	Rissanen,1997
Invertebrate	*Myriotrochus rinkii*				DM	Cs-137	Kara Sea	9,5		0,007	0,002	1360	400		1993-1996	Rissanen,1997
Invertebrate	*Sipunculidae goldfingia, annelida*		Kolchatye chervi		DM	Cs-137	Barents Sea	6,2		0,006	0,002	1030	360		1993-1996	Rissanen,1997
Invertebrate	*Polychaetes, annelida*	Polychaetes	Polixeta	Without tubes	DM	Cs-137	Barents Sea	1,2		0,006	0,002	200	70		1993-1996	Rissanen,1997
Invertebrate	*Sipunculidae goldfingia, annelida*		Kolchatye chervi		DM	Cs-137	Petshora Sea	4,7		0,007	0,002	670	190		1993-1996	Rissanen,1997
Invertebrate	*Sipunculidae goldfingia, annelida*		Kolchatye chervi		DM	Cs-137	Kara Sea	5,9		0,007	0,002	840	240		1993-1996	Rissanen,1997
Invertebrate	*Polychaetes, annelida*	Polychaetes	Polixeta		DM	Cs-137	Kara Sea	3,5	1,3	0,007	0,002	500	230		1993-1996	Rissanen,1997
Invertebrate	*Polychaetes, annelida*	Polychaetes	Polixeta	Tubes	DM	Cs-137	Barents Sea	9	3	0,006	0,002	1500	700		1993-1996	Rissanen,1997
Invertebrate	*Polychaetes, annelida*	Polychaetes	Polixeta	Tubes	DM	Cs-137	Kara Sea	17		0,007	0,002	2400	700		1993-1996	Rissanen,1997
Invertebrate	*Pectinaria, annelida*		Kolchatye chervi	Tubes	DM	Cs-137	Barents Sea	1,7		0,006	0,002	280	100		1993-1996	Rissanen,1997
Invertebrate	*Pectinaria, annelida*		Kolchatye chervi	Tubes	DM	Cs-137	Kara Sea	12		0,007	0,002	1700	500		1993-1996	Rissanen,1997
Invertebrate	*Nephus, annelida*		Kolchatye chervi	Tubes	DM	Cs-137	Kara Sea	20		0,007	0,002	2860	820		1993-1996	Rissanen,1997
Invertebrate	*Spiochaetoprerus, annelida*		Kolchatye chervi	Tubes	DM	Cs-137	Kara Sea	6		0,007	0,002	860	240		1993-1996	Rissanen,1997
Algae	*Ptilota plumusa*				DM	Pu-239,240	Barents Sea	0,28	0,02	0,000009	3E-06	31000	11000		1994	Rissanen et al 1995
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	Barents Sea	0,057	0,006	0,000009	3E-06	6300	2200		1994	Rissanen et al 1995
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	Barents Sea	0,029	0,004	0,000009	3E-06	3200	1100		1994	Rissanen et al 1995
Algae	*Laminaria sp.*		Laminariya		DM	Pu-239,240	White Sea	0,039	0,01	0,000009	3E-06	4300	1500		1994	Rissanen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,076	0,008	0,000009	3E-06	8400	3000		1993	Rissanen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,11	0,01	0,000009	3E-06	12000	4300		1993	Rissanen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	White Sea	0,035	0,008	0,000009	3E-06	3900	1400		1994	Rissanen et al 1995
Algae	*Fucus vesiculosus*	Bladder wrack	Fukus		DM	Pu-239,240	Barents Sea	0,23	0,02	0,000009	3E-06	26000	9000		1994	Rissanen et al 1995
Algae	*Fucus sp.*		Fukus		DM	Pu-239,240	Petshora Sea	0,041	0,01	0,000009	3E-06	4600	1600		1993	Rissanen et al 1995
Algae	*Fucus sp.*		Fukus		DM	Pu-239,240	Petshora Sea	0,12	0,01	0,000009	3E-06	13000	5000		1993	Rissanen et al 1995
Algae	*Chorda filum*				DM	Pu-239,240	Barents Sea	0,02	0,005	0,000009	3E-06	2200	800		1994	Rissanen et al 1995
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Shell	DM	Pu-239,240	Barents Sea	0,09		0,000009	3E-06	10000	3500		1993-1996	Rissanen,2000
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Shell	DM	Pu-239,240	Barents Sea	0,014		0,000009	3E-06	1600	600		1993-1996	Rissanen,2000
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Soft parts	DM	Pu-239,240	Barents Sea	0,004		0,000009	3E-06	400	140		1993-1996	Rissanen,2000
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya		DM	Pu-239,240	Barents Sea	0,011		0,000009	3E-06	1200	500		1993-1996	Rissanen,2000
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya		DM	Pu-239,240	Barents Sea	0,005		0,000009	3E-06	600	200		1993-1996	Rissanen,2000
Mollusc	*Mytilus edulis, bivalvia*	Common muscle	Midiya	Soft parts	DM	Pu-239,240	White Sea	0,001		0,000009	3E-06	110	40		1993-1996	Rissanen,2000
Mollusc	*Littorina saxatilis, gastropoda*	Rough periwinkle			DM	Pu-239,240	Barents Sea	0,011		0,000009	3E-06	1200	500		1993-1996	Rissanen,2000
Mollusc	*Modiolus modiolus, bivalvia*	Horse mussel		Shell	DM	Pu-239,240	Petshora Sea	0,032		0,000009	3E-06	3600	1200		1993-1996	Rissanen,2000
Mollusc	*Modiolus modiolus, bivalvia*	Horse mussel		Soft parts	DM	Pu-239,240	Petshora Sea	0,005		0,000009	3E-06	500	200		1993-1996	Rissanen,2000
Mollusc	*Tridonta borealis, bivalvia*			Soft parts	DM	Pu-239,240	Petshora Sea	0,012		0,000009	3E-06	1300	500		1993-1996	Rissanen,2000
Crustacea	*Pagurus pubescens,decapoda*	Heremit crab	Crab		DM	Pu-239,240	Petshora Sea	0,018		0,000009	3E-06	2000	700		1993-1996	Rissanen,2000
Invertebrate	*Cucumaria frondoza, echinodermata*	Sea cucumber	Goloturiya		DM	Pu-239,240	Petshora Sea	0,009		0,000009	3E-06	1000	300		1993-1996	Rissanen,2000
Invertebrate	*Strongylocentrothus, echinodermata*	Sea urchin	Morskoy ezh		DM	Pu-239,240	Petshora Sea	0,041		0,000009	3E-06	4500	1500		1993-1996	Rissanen,2000
Crustacea	*Gammarus, amphipoda*	Gammarus	Bokoplav		DM	Pu-239,240	Barents Sea	0,008		0,000009	3E-06	840	300		1993-1996	Rissanen,2000
Crustacea	*Gammarus, amphipoda*	Gammarus	Bokoplav		DM	Pu-239,240	White Sea	0,004		0,000009	3E-06	430	150		1993-1996	Rissanen,2000
Invertebrate	*Stegofiura nodosa, echinodermata*	Brittle star			DM	Pu-239,240	Petshora Sea	0,025		0,000009	3E-06	2800	1000		1993-1996	Rissanen,2000
Invertebrate	*Asterias rubens, echinodermata*	Sea star	Morskaya zvezda		DM	Pu-239,240	White Sea	0,005		0,000009	3E-06	500	200		1993-1996	Rissanen,2000
Fish	*Boreogadus saida*	Arctic cod	Saika		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Boreogadus saida*	Arctic cod	Saika	Bone		Pu-239,240	Barents Sea	<0.003		0,000009	3E-06	<300			1993-1996	Rissanen,2000
Fish	*Boreogadus saida*	Arctic cod	Saika	Bone		Pu-239,240	Barents Sea	<0.001		0,000009	3E-06	<100			1993-1996	Rissanen,2000
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Pollachius virens*	Saithe	Sayda		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Anarhichas lupus*	Wolffish	Zubatka		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Pleuronectes platessa*	Plaice	Kambala		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Hippoglossus hippoglossus*	Halibut	Paltus		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000

Fish	*Sebastes marinus*	Redfish	Morskoy okun'		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Fish	*Salmo salar*	Atlantic Salmon	Losos'		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1993-1996	Rissanen,2000
Bird	*Somateria mollissima*	Eider	Gaga		FW	Pu-239,240	Barents Sea	<0.001		0,000009	3E-06	<100			1995-1996	Rissanen,2000
Bird	*Somateria mollissima*	Eider	Gaga		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1995-1996	Rissanen,2000
Bird	*Mergus merganser*	Merganser			FW	Pu-239,240	Barents Sea	<0.001		0,000009	3E-06	<100			1995-1996	Rissanen,2000
Bird	*Mergus merganser*	Merganser			FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1995-1996	Rissanen,2000
Bird	*Cepphus grylle*	Black quillemot	Atlanticheskij chistik		FW	Pu-239,240	Barents Sea	<0.001		0,000009	3E-06	<100			1995-1996	Rissanen,2000
Bird	*Cepphus grylle*	Black quillemot	Atlanticheskij chistik		FW	Pu-239,240	Barents Sea	<0.002		0,000009	3E-06	<200			1995-1996	Rissanen,2000
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	pups	FW	Pu-239,240	White Sea	<0.001		0,000009	3E-06	<100			1995-1996	Rissanen,2000
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'	pups	FW	Pu-239,240	White Sea	<0.034		0,000009	3E-06	<4000			1995-1996	Rissanen,2000
Mammal	*Pagophilus groenlandica*	Greenland seal	Grenlandskiy tulen'		FW	Cs-137	Barents Sea	0,23	0,05	0,0034	0,0004	70	17		1999	ARCTICMAR,2000
Fish	*Coregonus automnalis*	Arctic cisco	Omul	Bone		Cs-137	Petshora Sea	0,9		0,007	0,002	130	40		1994-1995	AMAP,1999
Fish	*Coregonus automnalis*	Arctic cisco	Omul	Bone		Sr-90	Petshora Sea	0,03		0,0035	0,0009	9	2		1994-1995	AMAP,1999
Fish	*Gadus morhua*	Cod	Treska	Muscle		Cs-137	Kara Sea	1		0,007	0,002	140	40		1994-1995	AMAP,1999
Fish	*Gadus morhua*	Cod	Treska	Bone		Cs-137	Kara Sea	0,1		0,007	0,002	14	4		1994-1995	AMAP,1999
Fish	*Gadus morhua*	Cod	Treska	Bone		Sr-90	Kara Sea	0,05		0,035	0,0009	14	4		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Bone		Cs-137	Kara Sea	0,1		0,007	0,002	14	4		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Bone		Sr-90	Kara Sea	0,032		0,0035	0,0009	9,1	2,4		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Muscle		Cs-137	Kara Sea	0,08		0,007	0,002	11	3		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Bone		Cs-137	Kara Sea	0,06		0,007	0,002	9	2		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Muscle		Sr-90	Kara Sea	0,02		0,0035	0,0009	5,7	1,5		1994-1995	AMAP,1999
Fish	*Coreagonus sp.*	Cisco	Omul	Bone		Sr-90	Kara Sea	0,08		0,0035	0,0009	23	6		1994-1995	AMAP,1999
Mollusc	*Bivalve*	Mollusc	Mollusc		DM	Cs-137	Kara Sea	0,9		0,007	0,002	130	40		1994-1995	AMAP,1999
Mollusc	*Bivalve*	Mollusc	Mollusc		DM	Cs-137	Kara Sea	0,8		0,007	0,002	114	33		1994-1995	AMAP,1999
Mollusc	*Bivalve*	Mollusc	Mollusc		DM	Cs-137	Kara Sea	1		0,007	0,002	140	40		1994-1995	AMAP,1999
Invertebrate	*Annelida*				DM	Cs-137	Kara Sea	2		0,007	0,002	285	80		1994-1995	AMAP,1999
Invertebrate	*Annelida*				DM	Cs-137	Kara Sea	1,4		0,007	0,002	200	60		1994-1995	AMAP,1999
Invertebrate	*Echinoderms*				DM	Cs-137	Kara Sea	1,6		0,007	0,002	230	60		1994-1995	AMAP,1999
Crustacea	*Crustaceans*				DM	Cs-137	Kara Sea	1		0,007	0,002	140	40		1994-1995	AMAP,1999
Fish	*Pleuronectes platessa*	Plaice	Kambala		FW	Cs-137	North Atlantic	0,65	0,38	0,0037		180	100		1969-1972	Pertsov,1978
Fish	*Pleuronectes platessa*	Plaice	Kambala	Bone		Sr-90	North Atlantic	0,31	0,17	0,011		30	16		1969-1972	Pertsov,1978
Fish	*Macrourus berglax*		Macrurus	Bone		Sr-90	North Atlantic	0,13	0,06	0,011		12	6		1969-1972	Pertsov,1978
Fish	*Merlangius merlangus*	Whiting	Merlang		FW	Cs-137	North Atlantic	0,23	0,04	0,0037		60	10		1969-1972	Pertsov,1978
Fish	*Sebastes marinus*	Redfish	Morskoy okun'		FW	Cs-137	North Atlantic	0,62	0,09	0,0037		170	24		1969-1972	Pertsov,1978
Fish	*Sebastes marinus*	Redfish	Morskoy okun'	Bone		Sr-90	North Atlantic	0,24		0,011		22			1969-1972	Pertsov,1978
Fish	*Hippoglossus hippoglossus*	Halibut	Paltus		FW	Cs-137	North Atlantic	0,47		0,0037		130			1969-1972	Pertsov,1978
Fish	*Hippoglossus hippoglossus*	Halibut	Paltus	Bone		Sr-90	North Atlantic	1,3	0,5	0,011		120	45		1969-1972	Pertsov,1978
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha		FW	Cs-137	North Atlantic	1,1	0,3	0,0037		300	80		1969-1972	Pertsov,1978
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Bone		Sr-90	North Atlantic	0,85	0,4	0,011		80	36		1969-1972	Pertsov,1978
Fish	*Clupea harengus*	Herring	Seld		FW	Cs-137	North Atlantic	0,72	0,12	0,0037		195	30		1969-1972	Pertsov,1978
Fish	*Clupea harengus*	Herring	Seld	Bone		Sr-90	North Atlantic	1,6	1	0,011		145	90		1969-1972	Pertsov,1978
Fish	*Gadus morhua*	Cod	Treska		FW	Cs-137	North Atlantic	0,51	0,07	0,0037		140	20		1969-1972	Pertsov,1978
Fish	*Gadus morhua*	Cod	Treska	Bone		Sr-90	North Atlantic	1,1	0,7	0,011		100	60		1969-1972	Pertsov,1978
Fish	*Merluccius merluccius*	Hake	Hek	Bone		Sr-90	North Atlantic	0,27		0,011		25			1969-1972	Pertsov,1978
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	3		0,006	0,003	500	250		1998	ARCTICMAR,2000
Algae	*Laminaria sacharina*		Laminariya		DM	Cs-137	Barents Sea	260		0,006	0,003	43000	22000		1998	ARCTICMAR,2000
Algae	*Laminaria sacharina*		Laminariya		DM	Tc-99	Barents Sea	3,2	0,4	0,0007	0,0003	4600	2000		1998	ARCTICMAR,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	32		0,0007	0,0003	46000	20000		1998	ARCTICMAR,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,6		0,0058	0,0015	100	30		1995	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,8		0,0058	0,0015	140	40		1995	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,6		0,0058	0,0015	100	30		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,4		0,0058	0,0015	70	20		1996	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,8		0,0058	0,0015	140	40		1996	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,6		0,0058	0,0015	100	30		1996	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,6		0,004	0,001	150	40		1997	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,95		0,004	0,001	240	60		1997	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	1,05		0,004	0,001	260	70		1998	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,9		0,004	0,001	220	60		1998	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,75		0,004	0,001	190	50		1998	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,4		0,0034	0,0004	120	14		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,85		0,0034	0,0004	250	30		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Cs-137	Barents Sea	0,7		0,0034	0,0004	210	30		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	30		0,00015	0,00003	200000	40000		1995	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	25		0,00015	0,00003	170000	30000		1995	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	20		0,00015	0,00003	130000	30000		1995	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	30		0,00015	0,00003	200000	40000		1996	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	30		0,00015	0,00003	200000	40000		1996	NRPA,2000

Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	10		0,00015	0,00003	70000	20000		1996	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	230		0,0007	0,0003	330000	140000		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	340		0,0007	0,0003	490000	200000		1999	NRPA,2000
Algae	*Fucus sp.*		Fukus		DM	Tc-99	Barents Sea	120		0,0007	0,0003	170000	70000		1999	NRPA,2000
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Sr-90	Barents Sea	0,0094	0,001	0,0017	0,0001	5,5	0,7		1999	NRPA,2000
Fish	*Gadus morhua*	Cod	Treska	Bone		Sr-90	Barents Sea	0,089	0,005	0,0017	0,0001	52	4		1999	NRPA,2000
Fish	*Mallotus villosus*	Capelin	Moiva	Muscle	FW	Cs-137	Barents Sea	0,14	0,045	0,0034	0,0004	41	14	3	1999	NRPA,2000
Fish	*Mallotus villosus*	Capelin	Moiva	Muscle	FW	Sr-90	Barents Sea	0,0055	0,0005	0,0017	0,0001	3,2	0,3		1999	NRPA,2000
Fish	*Boreogadus saida*	Arctic cod	Saika	Muscle	FW	Cs-137	Barents Sea	0,14	0,02	0,0034	0,0004	41	8	3	1999	NRPA,2000
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Cs-137	Barents Sea	0,27	0,11	0,0034	0,0004	80	34	9	1999	NRPA,2000
Fish	*Gadus morhua*	Cod	Treska	Muscle	FW	Sr-90	Barents Sea	0,025	0,002	0,0017	0,0001	15	2		1999	NRPA,2000
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Cs-137	Barents Sea	0,33	0,04	0,0034	0,0004	100	14	2	1999	NRPA,2000
Fish	*Pleuronectes platessa*	Plaice	Kambala	Muscle	FW	Sr-90	Barents Sea	0,023	0,001	0,0017	0,0001	14	2		1999	NRPA,2000
Fish	*Pleuronectes flesus*	Flounder	Kambala	Muscle	FW	Cs-137	Barents Sea	0,33	0,04	0,0034	0,0004	100	40		1999	NRPA,2000
Fish	*Pleuronectes flesus*	Flounder	Kambala	Muscle	FW	Sr-90	Barents Sea	0,015	0,006	0,0017	0,0001	9	4		1999	NRPA,2000
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Cs-137	Barents Sea	0,18	0,06	0,0034	0,0004	53	18	5	1999	NRPA,2000
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Sr-90	Barents Sea	<0.007		0,0017	0,0001	<4	18		1999	NRPA,2000
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Tc-99	Barents Sea	<0.3		0,0007	0,0003	<400			1999	NRPA,2000
Fish	*Melanogrammus aeglefinus*	Haddock	Piksha	Muscle	FW	Sr-90	Barents Sea	0,015	0,001	0,0017	0,0001	9	1		1999	NRPA,2000
Crustacea	*Paralithodes camtschaticus*	Kamchatka crab	Crab	Meat	FW	Cs-137	Barents Sea	<0.33		0,0034	0,0004	<100			1999	NRPA,2000
Crustacea	*Paralithodes camtschaticus*	Kamchatka crab	Crab	Meat	FW	Tc-99	Barents Sea	<0.3		0,0007	0,0003	<400			1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Tc-99	Barents Sea	<0.3	0,022	0,0007	0,0003	<400			1999	NRPA,2000
Invertebrate	*Asteroidea*	Sea star	Morskaya zvezda		FW	Cs-137	Barents Sea	<0.016		0,0034	0,0004	<5			1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Barents Sea	0,18	0,045	0,0034	0,0004	53	15		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Barents Sea	0,08	0,028	0,0034	0,0004	24	9		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Sr-90	Barents Sea	0,018	0,001	0,0017	0,0001	11	1		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Shell	FW	Sr-90	Barents Sea	0,045	0,003	0,0017	0,001	26	2		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka		FW	Cs-137	Barents Sea	0,08	0,022	0,0034	0,0004	24	9		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Meat	FW	Sr-90	Barents Sea	0,032	0,002	0,0017	0,0001	19	2		1999	NRPA,2000
Crustacea	*Pandalus borealis*	Northern Pink Shrimp	Krevetka	Shell	FW	Sr-90	Barents Sea	0,05	0,003	0,0017	0,001	29	2		1999	NRPA,2000