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Application of biokinetic parameters for some representative accident cases based on state of the art modeling

[1] Mikhail Iosjpe
[2]Mats Isaksson
[3]Hans Pauli Joensen
[4]Gísli Jónsson
[5]Vesa Suolanen

[1]Norwegian Radiation and Nuclear Safety Authority (DSA)
[2]Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgenska Academy, University of Gothenburg, Sweden
[3]Fróðskaparsetur Føroya
[4]Icelandic Radiation Safety Authority
[5]VTT Technical Research Centre of Finland Ltd

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Abstract

The release scenario corresponding to a potential accident with a modern operating Russian nuclear submarine reactors in the Southwest part of the Barents Sea has been assessed. The evaluation of the kinetic parameters for bioaccumulation process for a wide set of radionuclides and biota has been provided. Evaluation of the kinetic parameters has been provided based on literature review, the extraction from existing databases and mathematical experiments including the successive simulations of bioaccumulation processes during increasing trophic levels. The importance of implementing the kinetic bioaccumulation model for consequences from short-lived radionuclides has been provided. The sub-model with the modified kinetic parameters for bioaccumulation process has been used based on simulations from the compartmental model, which uses the non-instantaneous dispersion of radioactivity in the marine environment. Concentrations of radionuclides in biota, doses to humans and dose rates to the marine organisms have been evaluated. The results of the present study can be used to improve the ability to evaluate the consequences to humans and biota after a radioactive release into marine environment.

Key words

Bioaccumulation of radionuclides, kinetic modelling, dose assessment to humans and biota

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Application of biokinetic parameters for some representative accident cases based on state of the art modelling (BIOAPP)

Mikhail Iosjpe[1], Mats Isaksson[2], Hans Pauli Joensen[3], Gísli Jónsson[4], Vesa Suolanen[5]

[1]Norwegian Radiation and Nuclear Safety Authority (DSA), [2]Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden, [3]University of the Faroe Islands, [4]Icelandic Radiation Safety Authority, [5]VTT Technical Research Centre of Finland Ltd

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1. Introduction

The present work is logical continuation of the NKS project BIORAD: Evaluation of the bioaccumulation processes for a wide set of radionuclides under accidental releases by biota (Iosjpe at al., 2022).

Kinetic modelling of the bioaccumulation processes has been shown to provide more realistic results when compared to an approach based on concentration ratio (CR). It was also demonstrated successful validation of kinetic modelling approach for Cs-137 for fish (Iosjpe et al., 2016). The main purpose of the BIORAD project was to consider possibilities to determinate kinetic parameters for actual radionuclides and biota through selection from articles and reports, use of allometric expressions and mathematical experiments.

In course of the BIORAD project it was shown that it is impossible to use two approaches for the bioaccumulation process at the same time: (i) bioaccumulation based on the concentration ratio approach and (ii) kinetic modelling of the bioaccumulation process. Simultaneous use of these two approaches provides a wrong description of the bioaccumulation process and concentration of radionuclides in biota, especially during the first period of exposure. In this connection, the following methodology for the evaluation of the kinetic parameters for bioaccumulation process for a wide set of radionuclides and biota has been proposed: (i) preliminary evaluation of the kinetic parameters has been provided based on literature review and the extraction from existing databases and then (ii) the selected kinetic parameters have been further improved based on mathematical experiments, including the simulations of bioaccumulation processes during increasing trophic levels.

It is necessary to note the following important point regarding the selection of kinetic parameters for the bioaccumulation sub-model for the BIORAD project. Due to lack of information (or uncertain information), the kinetic parameters were chosen to provide as close as possible values corresponding to published values for concentrations for all organisms and radionuclides under equilibrium conditions (one example for Cs-137 for fish adopted from the BIORAD project is shown in Figure 1).

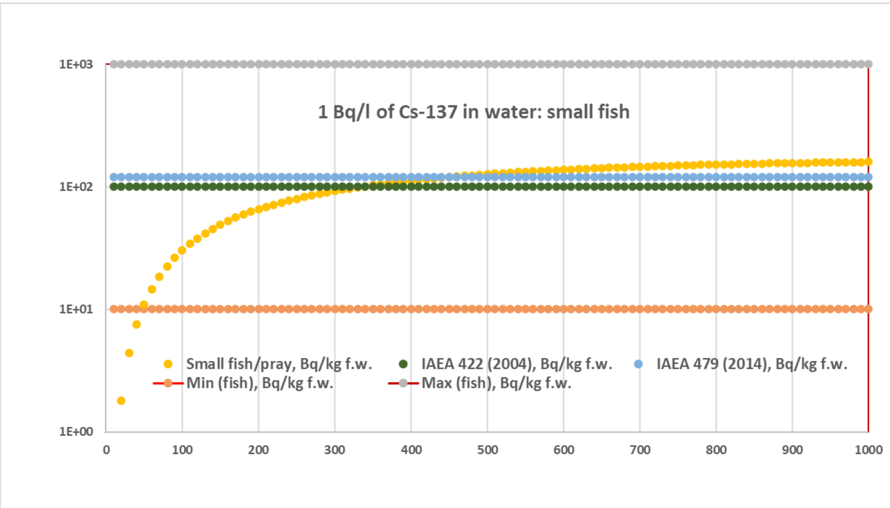


Figure 1. Kinetic modelling vs. Concentration ratio approach under quasi-equilibrium conditions for 1000 days.

The same reasonable approach for selection of the kinetic rates is used in the present report.

The objective of the present study (BIOAPP) is implementation of the bioaccumulation kinetic modelling for some representative accident cases with analyzing of the consequences for human and biota for a wide set of radionuclides due to the potential release scenarios into marine environment for actual marine regions, which includes coastal waters for the Nordic countries.

2. Release scenario

2.1. Release scenario of the potential accident

In this report, the hypothetical accidental release scenario involving a modern operating Russian submarine (third-generation reactors) with a maximum credible stockpile of radionuclides and maximum release has been chosen, based on results from Reistad (2008).

The hypothetical scenario underlying this report corresponds to a core melt/loss of coolant accident that should have occurred in conjunction with another type of accident, such as an explosion.

The release scenario includes two phases: (i) an immediate release of release fractions of radionuclides after a core meltdown and (ii) a constant release of fuel corrosion products.

The immediate release of release fractions for different radionuclides varies greatly. For example, the immediate release fraction for iodine, cesium and tellurium is 0.8, for rubidium, strontium and barium it is 0.1, and for americium, plutonium and curium it is 0.01.

The second component of the release fraction is fuel degradation and corrosion. The calculations of the present report correspond to the conservative scenario of the release of radionuclides by corrosion products with constant corrosion rate: 1% of fuel material per year (Yefimov, 1994).

Examples of individual releases in comparison with the total release of the radionuclides that had the most significant effect on the release rates during the initial and later time are presented in Figure 2. The maximum release occurs during the initial period after the accident (the instant release fraction) with maximum values of $1.6 \cdot 10^{18}$ Bq. Figure 2 shows that short-lived radionuclides of iodine and barium are most significant during the initial phase of release, while Sr-90, Pu-241 and Cs-137 dominate after ten years of release.

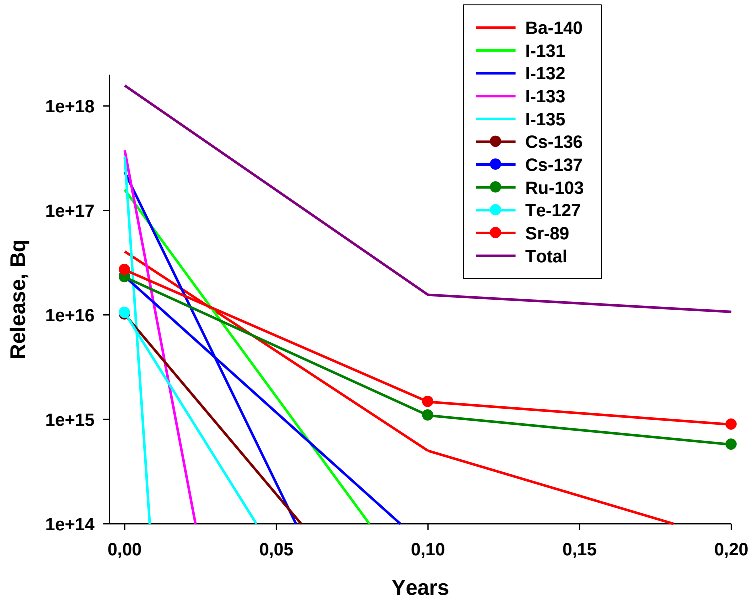


Figure 2. The release scenario for the initial time of 0-0.2 year (top) and for the time 0.1-10 years (bottom).

2.2. Location of the potential accident.

The location chosen for the accident was based on an evaluation of the radiological sensitivity of marine areas relevant to the study. Radiological sensitivity analysis of Arctic marine regions shows that the North Norwegian coastline and the Barents Sea can be considered as the most vulnerable areas in the Arctic region, in terms of the effects of possible radioactive contamination (Iosjpe et al., 2003; Iosjpe and Liland, 2012).

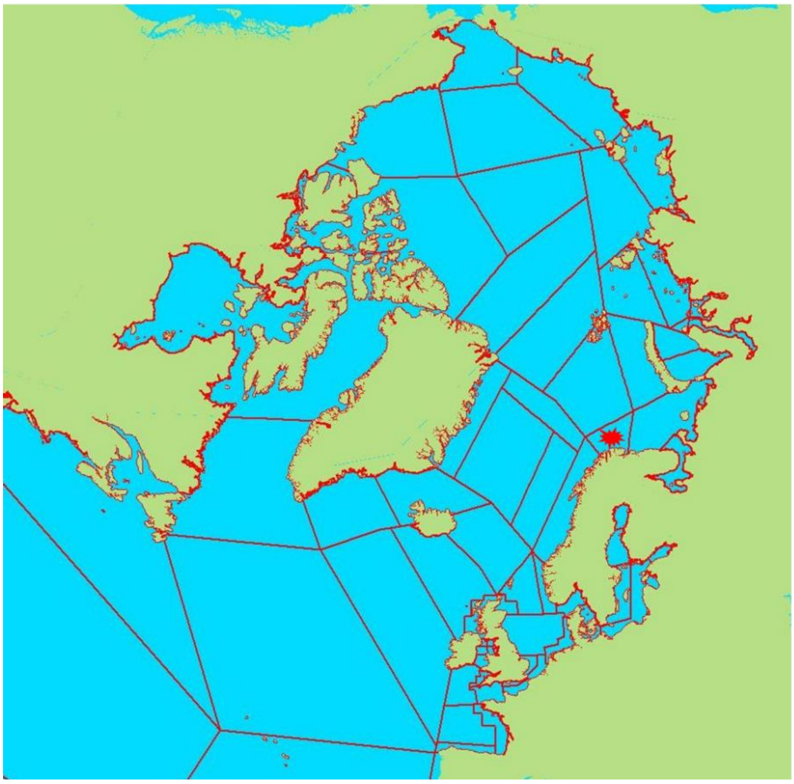


Figure 3. The location of the potential accident (the red “explosion” mark) is shown with the structure of the ARCTICMAR compartment model.

3. Methoddology for radioecologisk assessment

3.1. Main equations for the dispersion of radionuclides in the oceanic space of the ARCTICMAR model

The present model uses a modified approach for compartmental modelling (Iosjpe et al., 2002, 2009; Iosjpe, 2006), which allows the study of dispersion of radionuclides over time (non-instantaneous mixing in the oceanic space). The box structures for surface, mid-depth and deep-water layers have been developed based on the description of polar, Atlantic and deep waters in the Arctic Ocean and the Northern Seas and site-specific information for the boxes generated from the 3D hydrodynamic model NAOSIM (Karcher and Harms, 2000). The model contains 345 water and sediment compartments. The surface structure of the model is presented in Figure 3.

The box model includes the processes of advection of radioactivity between compartments, sedimentation, diffusion of radioactivity through pore water in sediments, particle mixing, pore water mixing and a burial process of radioactivity in deep sediment layers. Radioactive decay is calculated for all compartments. Accumulation of contamination by biota is further calculated from radionuclide concentrations in filtered seawater in different water regions. Doses to humans are calculated on the basis of given seafood consumptions, based on available data for seafood catches and assumptions about human diet in the respective areas. Dose rates to biota are derived on the basis of calculated radionuclide concentrations in marine organisms, water and sediment, using dose conversion factors.

The equations of the transfer of radionuclides between the boxes are of the form:

$$\frac{dA_i}{dt} = \sum_{j=1}^{n} k_{ji} A_j \gamma[t \geq (T_j + w_{ji})] - \sum_{j=1}^{n} k_{ij} A_i \gamma[t \geq (T_i + w_{ij})] - k_i A_i \gamma(t \geq T_i) + Q_i,\ t \geq T_i \qquad (1)$$

$$A_i = 0, t < T_i$$

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 ($Bq\ y^{-1}$); n is the number of boxes in the system, T_i is the time of availability for box i (the first times when box i is open for dispersion of radionuclides) and γ is an unit function:

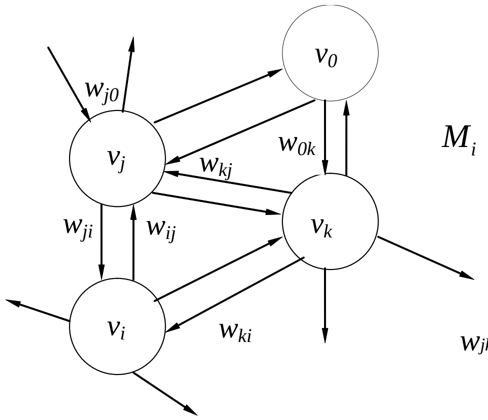
$$\gamma(t \geq T_i) = \begin{cases} 1, t \geq T_i \\ 0, t < T_i \end{cases}.$$

The times of availability T_i

$$T_i = \min_{\mu_m(v_0, v_i) \in M_i} \sum_{j,k} w_{jk} \qquad (2)$$

are calculated as a minimized sum of the weights for all paths μ_m $(v_0,...,v_i)$ 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 (graph elements as well as available paths are illustrated by Figure 4). 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). Weight, w_{jk}, is considered as a discrete function F of the water fluxes f_{jk}, f_{kj} between boxes j and k, geographical information g_{jk} and expert evaluation X_{jk}. M_i is a set of feasible paths from the initial box (v_0) to the box i (v_i).

The traditional box modelling is a particular case of the present approach when all times of availability in (1) are zero: $\{T_i\} = 0, i = 1, \ldots, n.$



$$M_i = \begin{cases} \mu_1(v_0, v_j, v_i) \\ \mu_2(v_0, v_k, v_i) \\ \mu_3(v_0, v_j, v_k, v_i) \\ \mu_4(v_0, v_k, v_j, v_i) \end{cases}$$

$$w_{jk} = F(f_{jk}, f_{kj}, g_{jk}, X_{jk})$$

Figure 4. Graph elements.

Expressions for the transfer rates of radioactivity between the bottom water and sediment compartments (Iosjpe, 2011) will be useful in the present analysis (the transfer rates are shown in Figure 5):

$$k_{WS} = \frac{SR \cdot k_d}{d \cdot (1 + k_d \cdot SSL)} + \frac{D}{d \cdot h_S (1 + k_d \cdot SSL)} + \frac{R_T \cdot \omega \cdot h_S}{d \cdot (1 + k_d \cdot SSL)} + \frac{R_W \cdot \rho \cdot k_d \cdot (1 - \omega)}{d \cdot (1 + k_d \cdot SSL)}$$

$$k_{SW} = \frac{D}{h_S^2 \cdot [\omega + k_d \cdot \rho \cdot (1 - \omega)]} + \frac{R_T \cdot \omega}{\omega + k_d \cdot \rho \cdot (1 - \omega)} + \frac{R_W \cdot \rho \cdot k_d \cdot (1 - \omega)}{h_S \cdot [\omega + k_d \cdot \rho \cdot (1 - \omega)]}$$

$$k_{SM} = \frac{D \cdot \omega}{h_S^2 \cdot [\omega + k_d \cdot \rho \cdot (1 - \omega)]} + \frac{k_d \cdot SR}{h_S \cdot [\omega + k_d \cdot \rho \cdot (1 - \omega)]} \qquad (3)$$

$$k_{MS} = \frac{D \cdot \omega}{h_S \cdot h_{SM} \cdot [\omega + k_d \cdot \rho \cdot (1 - \omega)]}$$

$$k_{MD} = \frac{k_d \cdot SR}{h_{SM} \cdot [\omega + k_d \cdot \rho \cdot (1-\omega)]}.$$

Here k_{WS} is composed of expressions describing the transfer of activity by sedimentation, molecular diffusion, pore water mixing and particle mixing, respectively. Similarly, k_{SW} is composed of expressions describing the transfer of radioactivity by molecular diffusion, pore water mixing and particle mixing. k_{SM} is composed of expressions describing the transfer of radioactivity by sedimentation and molecular diffusion. k_{MS} corresponds to the transfer by molecular diffusion. Finally, k_{MD} corresponds to the transfer of radioactivity by sedimentation. R_W (m y^{-1}) is the sediment reworking rate; R_T (y^{-1}) is the pore-water turnover rate; k_d (m^3 t^{-1}) is the sediment distribution coefficient; *SSL* (t m^{-3}) is the suspended sediment load in the water column; *SR* (t m^{-2} y^{-1}) is the sedimentation rate; *D* (m^2 y^{-1}) is the molecular diffusion coefficient, h_S (m) and h_{SM} (m) are the surface and middle sediment thickness respectively; ω is the porosity of the bottom sediment; ρ (t m^{-3}) is the density of the sediment material and *d* is the depth of the water column.

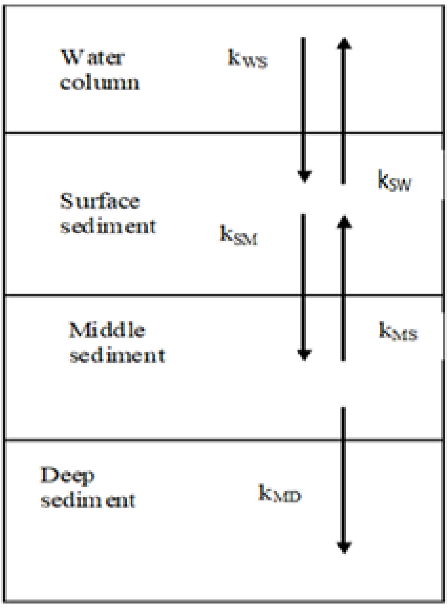


Figure 5. Generic vertical structure of the water-sediment compartments.

The ARCTICMAR model has previously been employed successfully in a number of applications. Results of simulations have been compared with experimental data, where data have been available (Iosjpe et al., 2009; Iosjpe, 2011; Iosjpe and Liland, 2012; Periánez et al., 2016).

Concentrations of the radionuclides in marine organisms can be calculated from radionuclide concentrations in filtered seawater and the concentrations ratios as well as by the kinetic modelling of the bioaccumulation processes in biota.

3.2. Dose assessment for humans.

The internal dose D_{CR} and D_B can be determined using the following expressions for the concentration ratio approach and for the kinetic modelling of the bioaccumulation processes in biota, correspondently:

$$D_{CR} = \sum_{j=1}^{m} DCF_j \sum_{l=1}^{k} \phi_l \cdot CF_{lj} \sum_{i=1}^{n} A_{il} \int_0^T C_{ij}\,(t)dt$$
$$D_B = \sum_{j=1}^{m} DCF_j \sum_{l=1}^{k} \phi_l \cdot \sum_{i=1}^{n} A_{il} \int_0^T C_{ij}^{(l)}\,(t)dt \qquad (4)$$

where [0, T] is the time interval for dose assessment; DCF_j is the dose conversion factor for radionuclide j (j = 1,2,…, m); CF_{lj} is the concentration factor for radionuclide j in seafood of type l (l = 1,2,…, k); A_{il} is consumption of seafood of type l in the model compartment i; (i = 1,2,…,n) for the doses to critical group and catch of seafood for collective doses, if necessary; C_{ij} and $C_{ij}^{(l)}$ are the concentration of radionuclide j in filtered seawater and in seafood of type l in model compartment i, correspondently; and φ_l is equal 1 for the doses to the critical group and φ_l is the edible fraction for seafood of type i (50% for fish, 35% for crustaceans and 15% for mollusks (CEC, 1990; EC, 2000; IASAP, 2003) for the collective doses, if necessary.

The individual dose rate for the external exposure can be estimated with the following expression (Iosjpe et al., 2009). Methodology is similar to EC (1994):

$$DR_{ext} = F_W^{(O)} \cdot \sum_i DCF_i^{(ext,w)} \cdot \bar{C}_i^{(bulk,w)} + F_S^{(O)} \cdot f_S \cdot \sum_i DCF_i^{(ext,s)} \cdot \bar{C}_i^{(bulk,s)}\,, \qquad (5)$$

where $\bar{C}_i^{(bulk,w)}$ is the average bulk concentration of radionuclide i in the water column with regards to both water and sediment phases; $\bar{C}_i^{(bulk,s)}$ is the average bulk concentration of the sediment phase in the actual sea area; $DCF_i^{(ext,w)}$ and $DCF_i^{(ext,s)}$ are the dose conversion factors for external exposure of radionuclide i, for water immersion and contaminated ground surface, respectively; $F_W^{(O)}$ and $F_S^{(O)}$ are the occupancy factors for “swimming” and the “beach sediment” pathways (it is assumed that both factors are of 0.5); f_S is a part of the sediment concentration, which is considered as beach concentration (following (IASAP, 2003), it is assumed that f_S is of 0.1).

In the present study, the doses to man are calculated only for ingestion because the comparison of the contribution to human doses from this pathway against external exposure indicates a clear domination of the former (EC, 1994; IASAP, 2003, Iosjpe et al., 2009).

3.3. Dose assessment for biota

The ARCTICMAR model uses the following expressions for internal and external dose rates for biota (Brown and Hosseini, 2019; Hosseini et al., 2016, 2017, Iosjpe et al., 2009).

The total absorbed dose-rate is the sum of internal ($\dot{D}_{int}$) and external ($\dot{D}_{ext}$) absorbed dose-rates (in units of µGy h-1), through the application of dose conversion coefficients (DCCs).

$$\dot{D}^{b}_{int} = \sum_{i} C^{b}_{i} * DCC^{b}_{int,\,i} \tag{6}$$

where:

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

$DCC^{b}_{int,\,i}$ is the radionuclide-specific dose conversion coefficient (DCC) for internal exposure defined as the ratio between the average activity concentration of radionuclide *i* in the organism *j* and the dose rate to the organism b (µGy h^{-1} per Bq kg^{-1} fresh weight).

$$\dot{D}^{b}_{ext} = \sum_{z} v_{z} \sum_{i} C^{ref}_{zi} * DCC^{b}_{ext,zi} \tag{7}$$

where v_z is the occupancy factor, i.e. fraction of the time that the organism *b* spends at a specified position *z* in its habitat, C_{zi}^{ref} is the average concentration of radionuclide *i* in the reference media of a given location *z* (Bq kg^{-1} fresh weight (water) or dry weight (sediment) or Bq l^{-1} (water)), $DCC^{j}_{ext,zi}$ is the dose conversion coefficient for external exposure defined as the ratio between the average activity concentration of radionuclide *i* in the reference media corresponding to the location *z* and the dose rate to organism *b* (µGy h^{-1} per Bq kg^{-1} fresh weight or Bq l^{-1}).

Weighted total dose rates (in µGy h^{-1}) are derived through the application of weighting factors (dimensionless) for alpha, low beta and high beta-gamma radiation.

$$DCC_{int} = wf_{low\beta} \cdot DCC_{int,\,low\beta} + wf_{\beta+\gamma} \cdot DCC_{int,\,\beta+\gamma} + wf_{\alpha} \cdot DCC_{int,\,\alpha}$$

$$DCC_{ext} = wf_{low\beta} \cdot DCC_{ext,low\beta} + wf_{\beta+\gamma} \cdot DCC_{ext,\beta+\gamma} \tag{8}$$

Here “wf“ are weighting factors for various components of radiation (low β, β + γ and α), DCC are dose conversion coefficients in µGy h^{-1} per Bq l^{-1} or Bq kg^{-1}. Default radiation weighting factors of 10 for alpha radiation, 1 for low energy beta and 1 for (high energy) beta and gamma radiation are applied in this assessment in line with those applied in UNSCEAR (2008).

3.4. Kinetic approach for bioaccumulation of radionuclides in marine organisms

3.4.1. Food chain

Figure 6 shows the schematic of the food chain for the biokinetic models, which was selected as a basis for the present study (Hosseini et al., 2016, 2017; IAEA 1998; Iosjpe et al., 2016; de With et al., 2021).

3.4.2. The system of equations for the bioaccumulation process

The system of equations for the biokinetic model can be described by the following expression, which was chosen after analysing the existing models (Thomann, 1981; Heling et al., 2002; Brown et al., 2004; Vives i Batlle et al., 2008; Maderich et al., 2013; de With et al., 2021):

$$\frac{dC_i^{(tl)}}{dt} = AE_i \cdot IR_i \cdot C_{i-1}^{(tl)} + k_{u,i} \cdot C_w - C_i^{(tl)} \cdot k_{e,i} \qquad (9)$$

Here $C^{(tl)}_i$ and $C^{(tl)}_{i-1}$ – concentrations of radionuclide in trophic levels ”*i*” and ”*i-1*”; C_W – concentration of radionuclide in water column; AE_i – the assimilation efficiency for trophic level “*i*”, IR_i – ingestion per unit mass for trophic level “*i*”; $k_{u,i}$ – rate of the direct uptake of activity from water column for trophic level “i”; $k_{e,i}$ – the excretion rate for trophic level “i”. Where the consumption for species in trophic levels ”*i*” includes “*m”* different species in trophic levels ”*i-1*”, parameter $C^{(tl)}_{i-1}$ can be described as

$$C_{i-1}^{(tl)} = \sum_{j=1}^{m} w_j \cdot C_{i-1,j}^{(tl)} \qquad (10)$$

Here the consumption for species in trophic level ”*i*” includes *m* species in trophic levels

”*i-1*” with concentration of radionuclide in species *j* (*j=1,…,m*) of $C^{(tl)}_{i-1,j}$; w_j is a fraction of species *j* of all m species, where

$$\sum_{j=1}^{m} w_j = 1$$

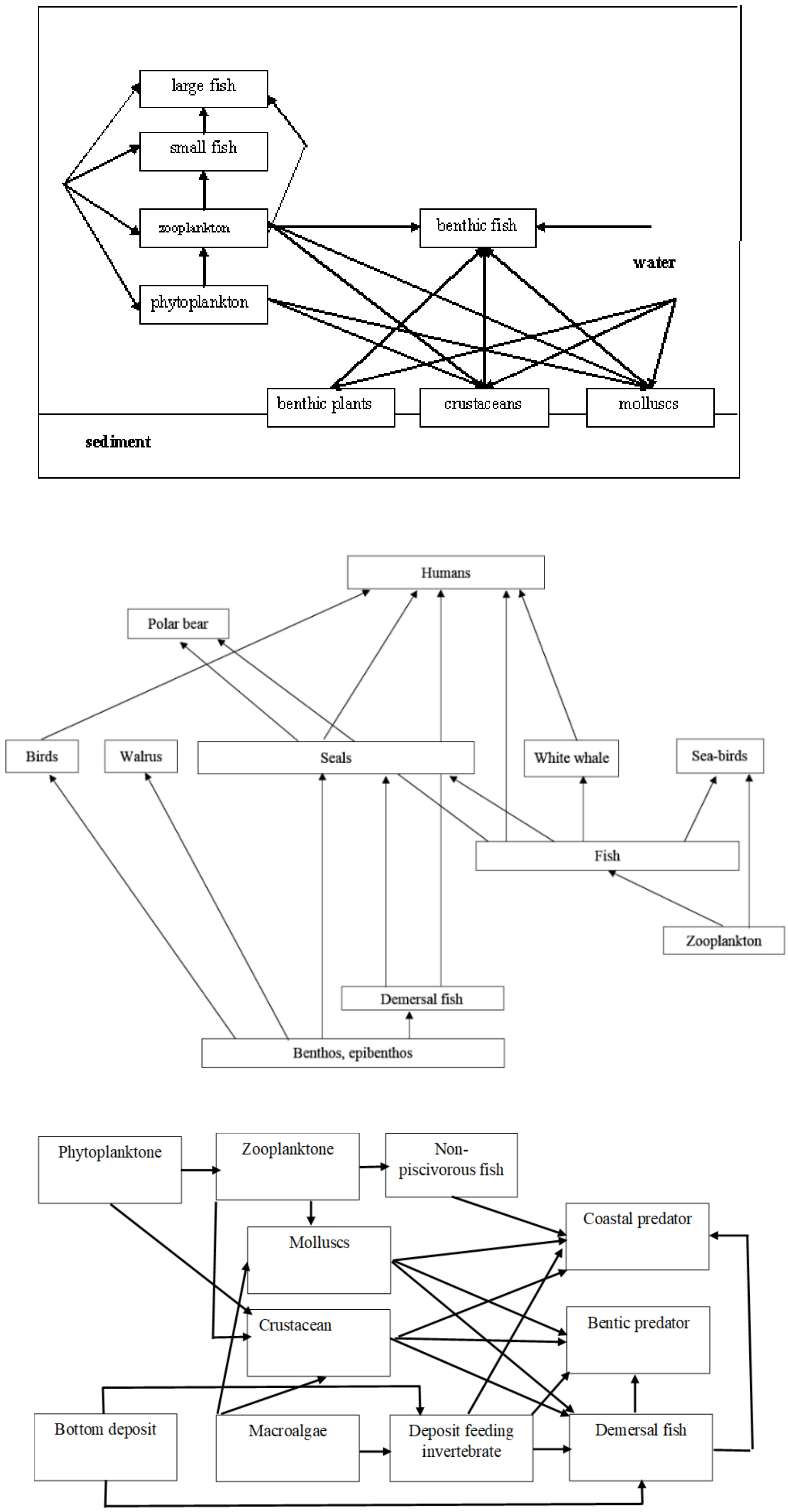


Figure 6. Schematic of the biokinetic models. Arrows correspond to the radionuclide transfer between marine organisms.

4. Estimation of significance of radionuclides by concentration ratio approach.

According to (Reistad, 2008), the following radionuclides can be considered in a release scenario: Ag-110m, Ag-111, Am-241, Am-242, Am-244, Ba-140, Ce-141, Ce-143, Ce-144, Cm-242, Cm-244, Cs-134, Cs-135, Cs-136, Cs-137, Eu-154, Eu-155, Eu-156, I-129, I-131, I-132, I-133, I-135, Nb-95, Nb-97, Np-237, Np-238, Np-239, Np-240, Pa-233, Pm-147, Pm-148, Pm-148m, Pm-149, Pm-151, Pu-238, Pu-239, Pu-240, Pu-241, Pu-243, Ru-103, Ru-105, Ru-106, Sb-125, Sb-126, Sb-127, Se-79, Sm-151, Sm-153, Sn-126, Sr-89, Sr90, Tb-160, Tc-99, Tc-99m, Te-125m, Te-127, Te-129, Te-129m, Te-132, Th-228, Th-234, U-232, U-234, U-235, U-236, U-237, U-238, U-239, Y-90, Y-91, Zr-93, Zr-95, Zr-97.

In Section 1, it is noted that the kinetic parameters must be chosen to give values as close as possible to published values of concentrations for all organisms and radionuclides under equilibrium conditions. This approach makes it possible to reduce a large set of radionuclides for the current release scenario. The following two phases for the determination of the bioaccumulation process will be used: (i) definition of the most significant and insignificant radionuclides for a bioaccumulation process through the concentration ratio approach and (ii) definition of parameters for kinetic sub-models for radionuclides selected in phase (i).

According to recommendations of the "Food and Agriculture Organization of the United Nations and World Health Organization (FAO)" (CAC, 2006), radionuclides can be divided into groups, mainly depending on their potential to be dangerous to humans. Each group of radionuclides has its own guideline level for the maximum concentration of radionuclides in food.

Examples of some typical radionuclides for each group according to FAO/WHO (CAC, 2006) are presented in Table 1.

Table 1. Examples of FAO/WHO international guideline levels for radionuclides in food.

Example radionuclides		Levels (Bq/kg)	
		Infant foods	Other foods
Group 1	^{238}Pu, ^{239}Pu, ^{241}Am	1	10
Group 2	^{90}Sr, ^{106}Ru, ^{129}I	100	100
Group 3	^{60}Co, ^{134}Cs, ^{137}Cs	1000	1000
Group 4	^{3}H, ^{14}C, ^{99}Tc	1000	10 000

Concentration of radionuclides in biota ($C^{(B)}$) can be defined by expression (11):

$$C^{(B)} = \frac{CR \cdot C_w}{1 + k_d \cdot SSL} \qquad (11)$$

Here, CR is a concentration ratio for the relevant radionuclide, C_w is a concentration of this radionuclide in unfiltered water, k_d is a sediment distribution coefficient and SSL is a suspended sediment load (see expression (3) in Section 3.1).

Table A1 of the Appendix includes information about equilibrium/quasi-equilibrium concentration ratios (CR) for considered biota and radionuclides.

It is necessary to note some important points concerning the sediment distribution coefficients. The definition of the sediment distribution coefficients (k_d) is based on assumptions about the equilibrium balance between dissolved and particulate phases (IAEA, 2004). This assumption is not generally supported by the real conditions in marine environments (Periáñez et al., 2018). Therefore, terms "site-specific" and "apparent" k_d are used in some investigations (Iosjpe, 2011; Periáñez et al., 2018). Kinetic sub-models for the exchange of radionuclides between water and sediment phases require k_d to be under equilibrium conditions in order to define the system of kinetic coefficients (Periáñez, 2003). Additionally, the kinetic sub-models can construct "apparent" k_d during numerical simulations. In particular, it was shown, that (i) "apparent" k_d value near the source of contamination can be 2-3 times less than the equilibrium value and (ii) "apparent" k_d value in the sediment near the source of contamination can be 10-1000 times less than the equilibrium value (Periáñez et al., 2018). In this report, a conservative approach will be used with "apparent" k_d 3 times less than the equilibrium value near the source of contamination in the water column.

Concentrations for Groups 1-4 in following sections will be presented in Bq/kg f.w. as function of time (in years).

Considering that concentration ratio approach is a preliminary stage of the present investigation and contains significant uncertainties, the following criterion will be used to reduce the radionuclide sets: the combined impact to the concentration of the selected radionuclides in each group must be less than 0.05% of the total concentration in that group of radionuclides.

4.1. The concentration ratio approach: the Group 1 of radionuclides.

Figures 7 – 9 show concentration in the typical seafood/biota for Group 1 of radionuclides. The calculations, presented in Figures 7-9, correspond to the compartment of the initial release of radionuclides described in section 2.2. Figures 7-9 demonstrate that Pu-238 dominates concentration of radionuclides in Group 1 (89-95% of the combined impact) while impact of Np-237 and U-232 is negligible (the joint influence of Np-237 and U-232 is less than 0.002% of the Group 1 total concentration) while other radionuclides

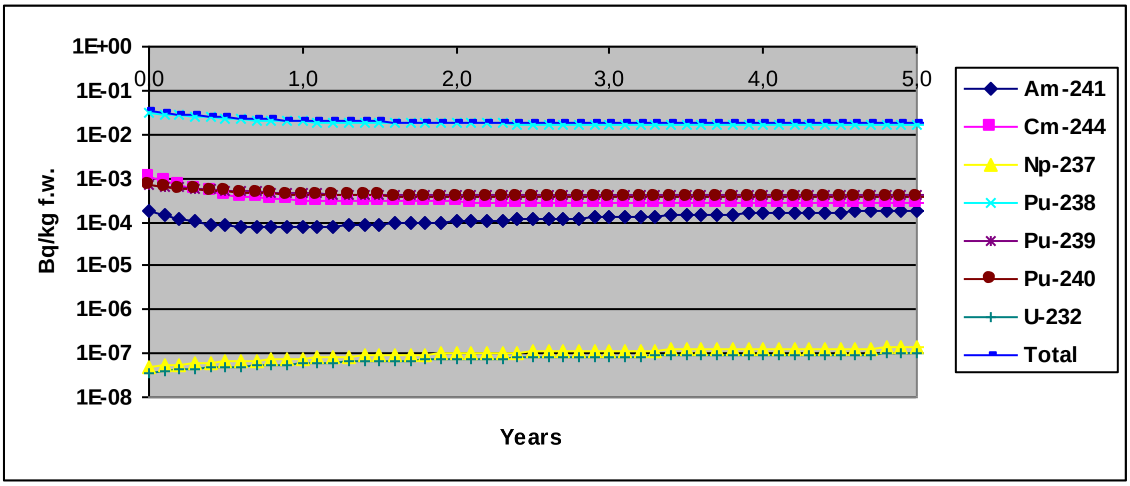


Figure 7. Concentration of radionuclides in fish for Group 1.

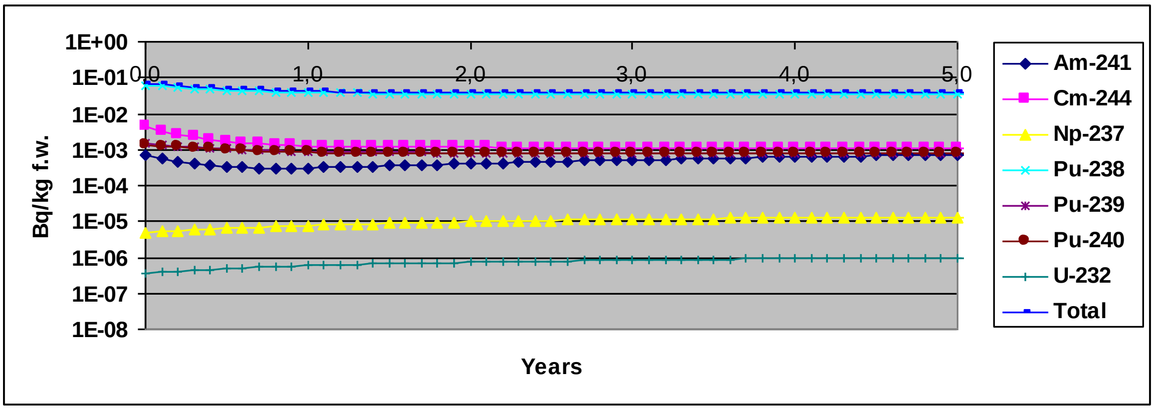


Figure 8. Concentration of radionuclides in crustaceans for Group 1.

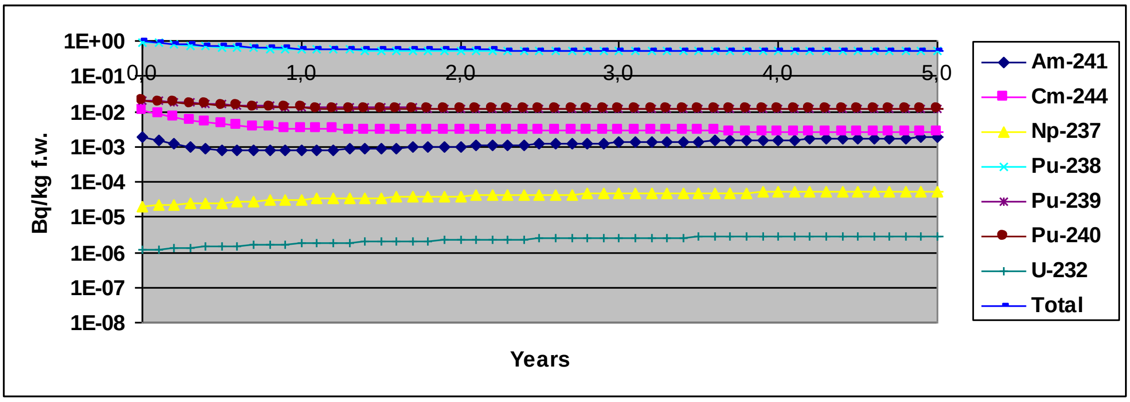


Figure 9. Concentration of radionuclides in molluscs for Group 1.

4.2.The concentration ratio approach: the Group 2 of radionuclides.

Figures 10–12 show concentration in seafood/biota for group 2 of radionuclides. Figures demonstrate that the effect of radionuclides on the group 2 concentration varies with time. At the initial time of releases of radionuclides, I-131 dominates the concentration of radionuclides in fish (up to 98% of the total concentration for Group 2) and the concentration in crustaceans and mollusks is dominated by two radionuclides: I-131 and Ru-106 (up to 95% of the total concentration for Group 2). After an initial time, the concentration in fish is dominated by Sr-90 and Pu-241 (up to 99% of the total concentration for Group 2); concentration in crustaceans is dominated by Pu-241, Sr-90 and Ru-106 (up to almost the total concentration for Group 2) and concentration in mollusks is dominated by Pu-241 (up to 78% of the total concentration for Group 2). The influence of I-129, Th-228, U-234, U-235, U-236 and U-238 to the concentration of radionuclides in Group 2 is negligible (the combined influence of these radionuclides is less than 0.003% of the Group 2 total concentration).

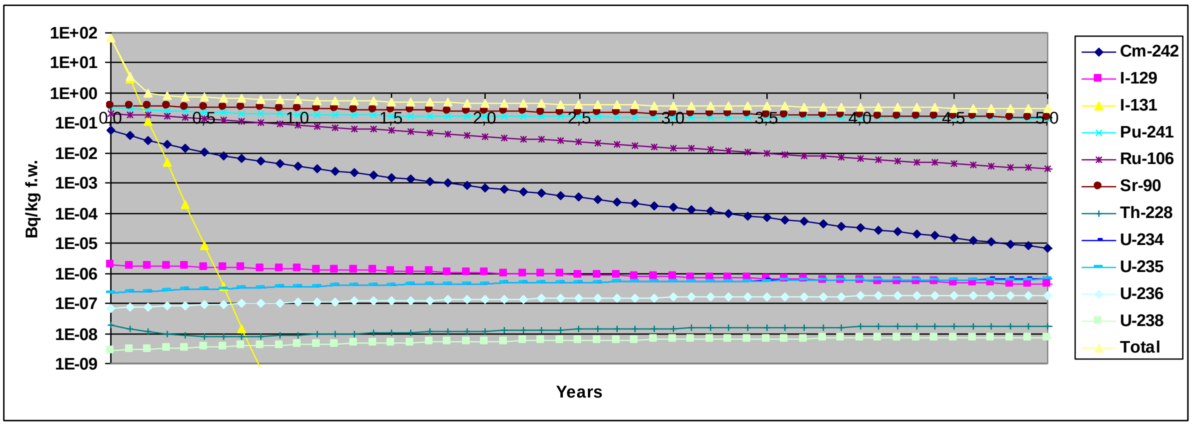


Figure 10. Concentration of radionuclides in fish for Group 2.

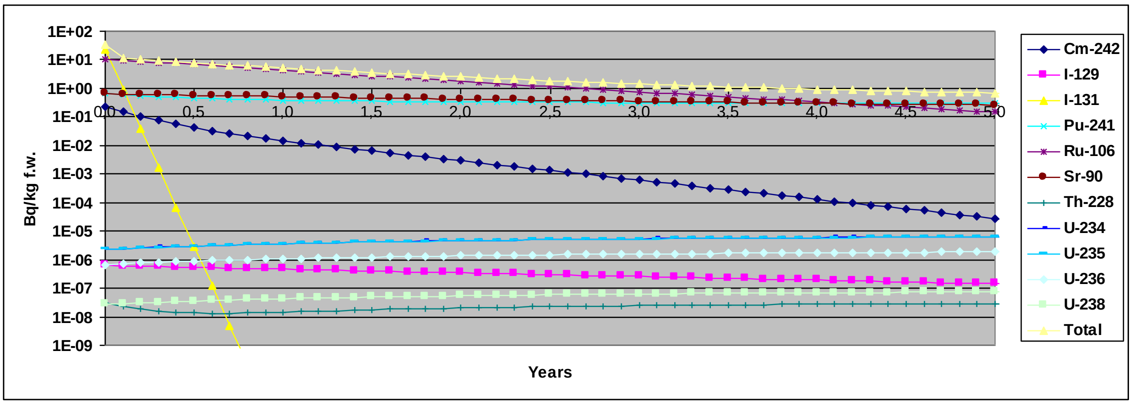


Figure 11. Concentration of radionuclides in crustaceans for Group 2.

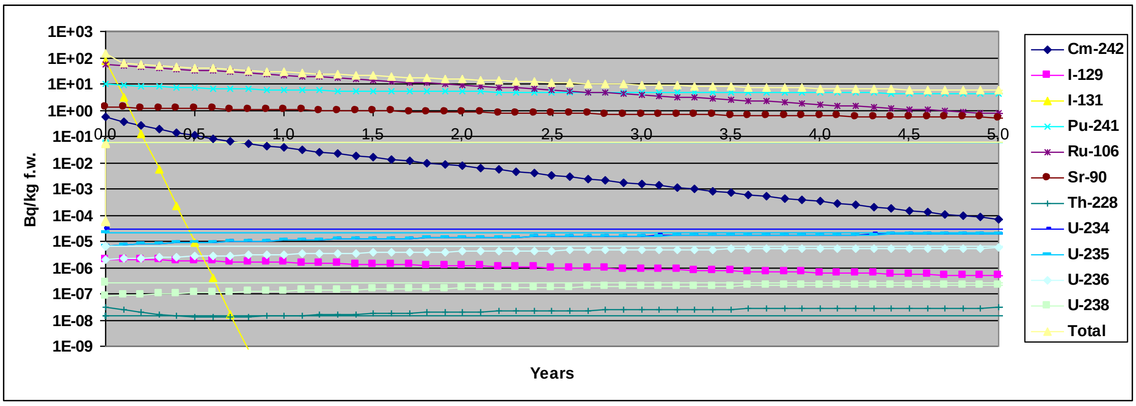


Figure 12. Concentration of radionuclides in molluscs for Group 2.

4.3. The concentration ratio approach: the Group 3 of radionuclides.

Figures 13–15 show concentration in seafood/biota for group 3 of radionuclides. Figures demonstrate that the effect of radionuclides on the group 3 concentration varies with time similar to dynamic of concentrations in groupe 2. At the initial time of releases of radionuclides, Te-132 dominates the concentration of radionuclides in fish (up to 94% of the total concentration for Group 3) while the concentration in crustaceans and mollusks is dominated by two radionuclides: Te-132 and Eu-156 (up to 99% and 95% of the total concentration for Group 3, correspondently). After an initial time, the concentration in biota is dominated by Cs-137, Sn-126 and Cs-135 (95-100% of the total concentration for Group 3). The influence of Cs-135, Th-234, Tb-160, Se-79, and Sb-126 to the concentration of radionuclides in Group 3 for all marine organisms concederes assessed as insignificant (the combined influence of these radionuclides is less than 0.03% of the Group 3 total concentration).

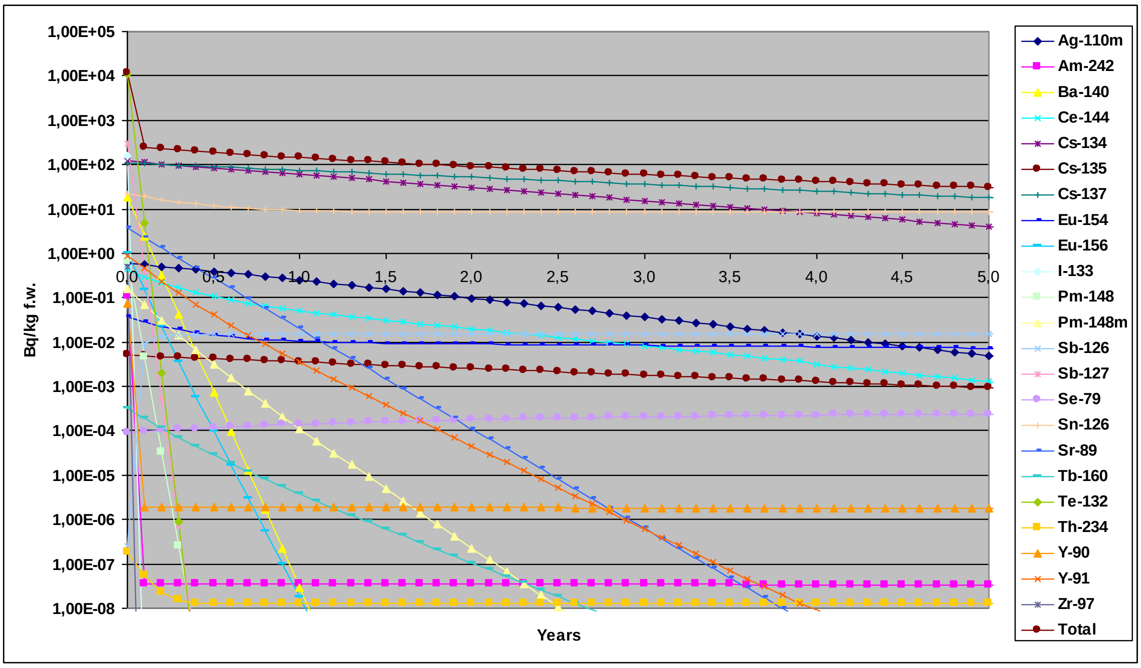


Figure 13. Concentration of radionuclides in Fish for Group 3.

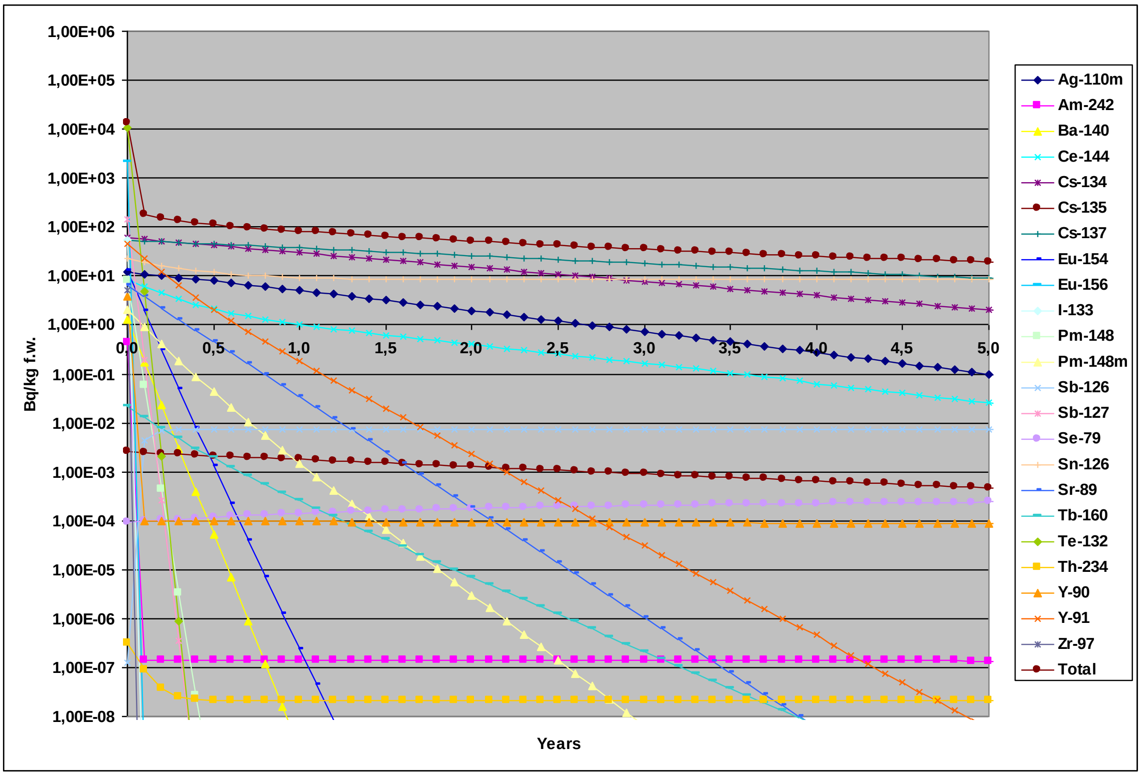


Figure 14. Concentration of radionuclides in crustaceans for Group 3.

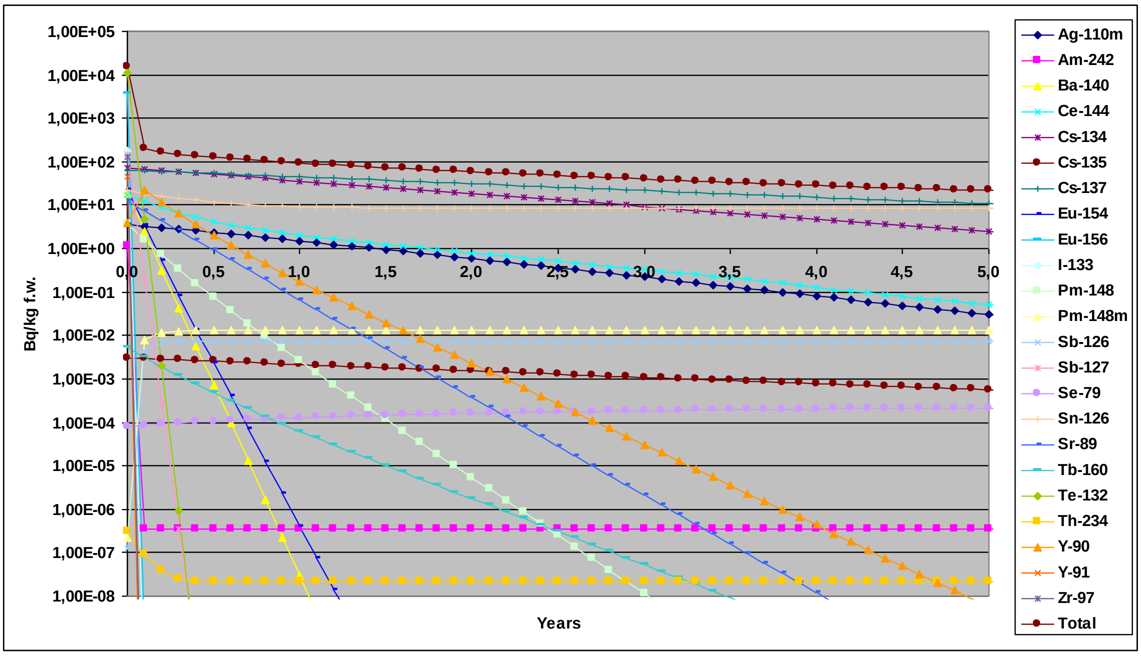


Figure 15. Concentration of radionuclides in mollusks for Group 3.

4.4. The concentration ratio approach: the Group 4 of radionuclides.

The Grope 4 contains the largest number of radionuclides for the present release scenario, and a significant part of radionuclides from Group 4 has short halv-lifes. An exsampel of the concentration dynamic of Group 4 of radionuclides in fish is shown in Figure16.

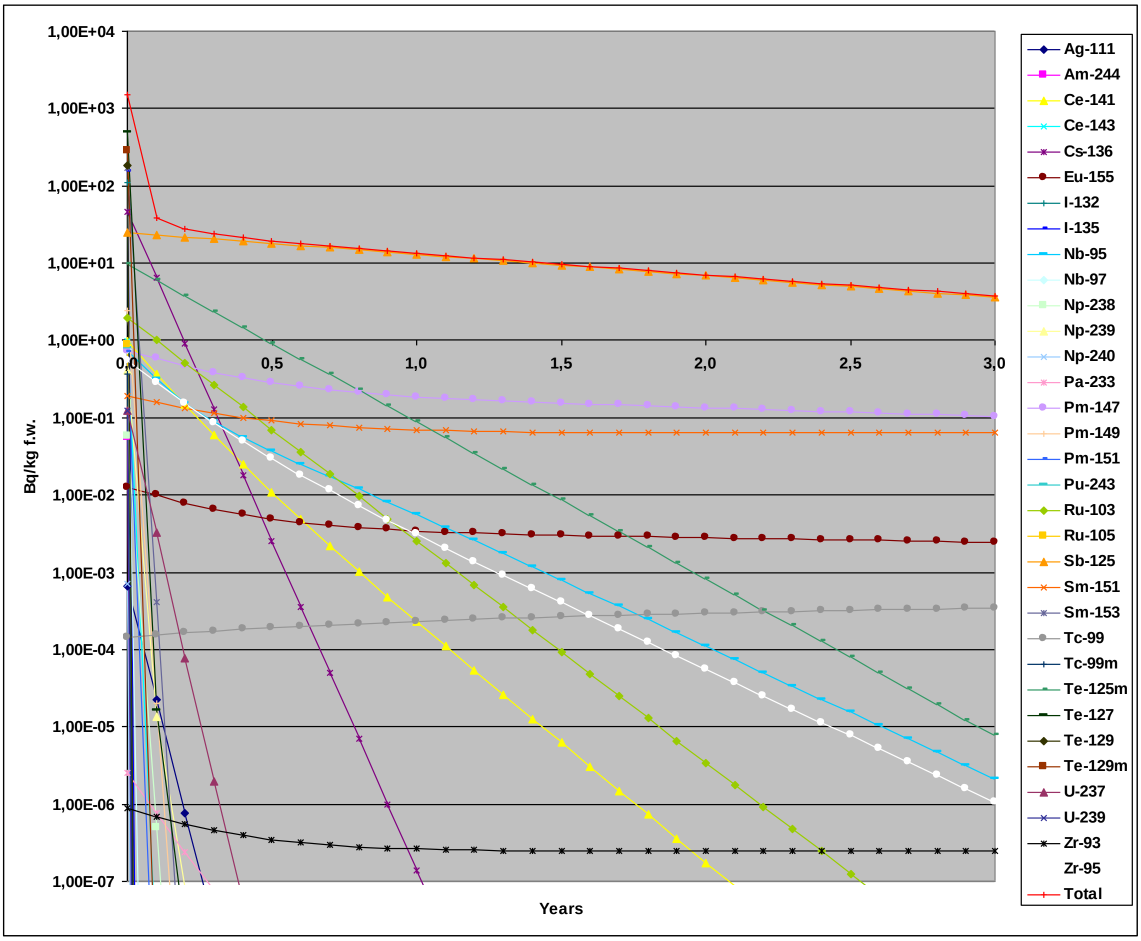


Figure 16. Concentration of radionuclides in fish for Group 4.

Figure 17 shows that at the initial time of releases of radionuclides an isotope of samarium (Sm-153), isotopes of telluriem (Te-127, Te-129, Te- 129m), iodine (I-132, I-135) and Ruthenium (Ru-103, Ru-105) dominate the concentration of radionuclides in biota (up to 94% of the total concentration for Group 4).

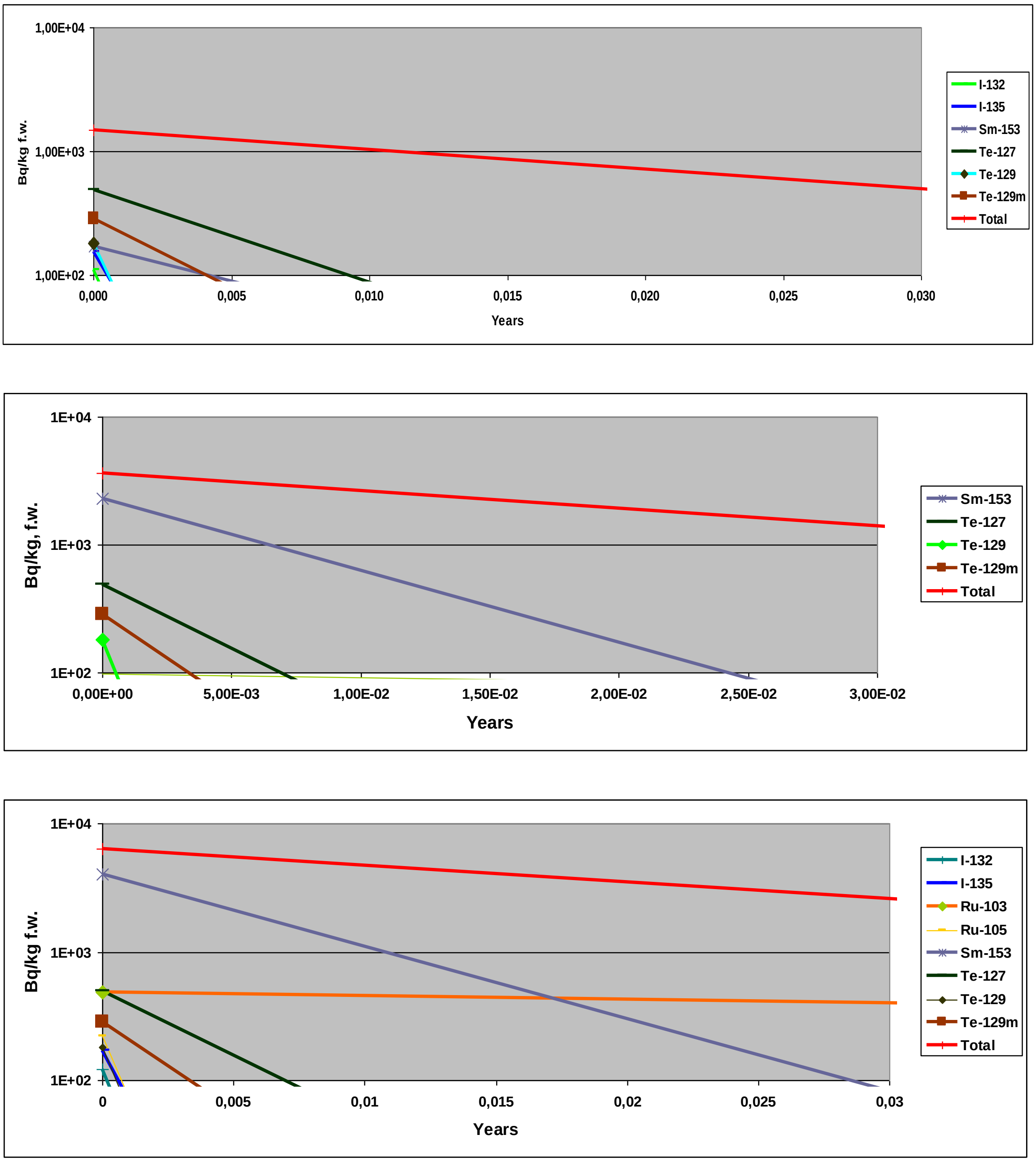


Figure 17. Concentration of radionuclides in biota at the initial time of release of radionuclides (fish - top, crustaceans - middle, molluscs - bottom).

After an initial time, the concentration in biota in Group 4 is dominated by Sb-125 for fish and Sb-125 and Sm-151 for crustaceans and mollusks as shown in Figure 18 (95-98% of the total concentration for Group 4). The influence of the relatively large set of radionuclides, namely Ag-111, Am-244, Eu-155, Np-238, Np-240, Pm-147, Pm-149, Pm-151, Tc-99, Tc-99m, U-232, U-239, Zr-93, Zr-95, Zr-97 to the concentration of Group 4 radionuclides for all marine organisms assessed as insignificant (the combined influence of these radionuclides is less than 0.03% of the Group 4 total concentration).

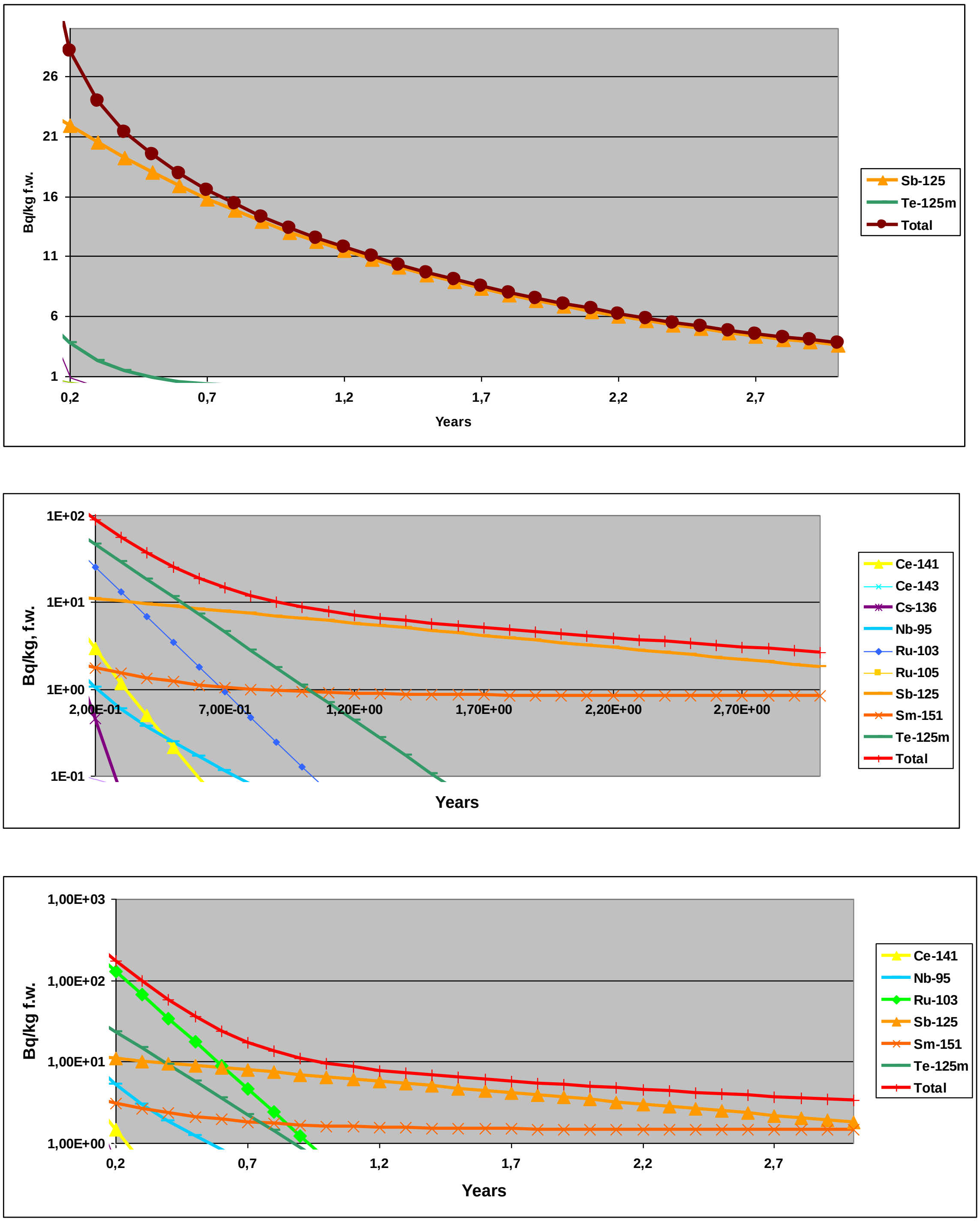


Figure 18. Concentration of radionuclides in biota after the initial time of release of radionuclides (fish - top, crustaceans - middle, molluscs - bottom).

5. **Choosing of the kinetic parameters for the model for bioaccumulation of radionuclides**

A significant/crucial lack of information about the kinetic parameters described in equations (9) – (10) has been demonstrated during implementation of the NKS project BIORAD (Iosjpe et al., 2022). In the course of the BIORAD project some possibilities for potential reduction the uncertainty for evaluation of the kinetic parameters has been suggested and tested for limited number of radionuclides: use of (i) allometric approach, (ii) simulating of the different excretion rates for the isotopes of the same radioactive element, (iii) potential simplification of the modelling approach, (iv) the similarity of the distribution of radionuclides in biota and (v) the successive simulations of bioaccumulation processes during increasing trophic levels. Approaches (i)-(v) were discussed in detail in the NKS BIORAD report (Iosjpe et al., 2022).

Similar to the Iosjpe et al. (2022), kinetic coefficients have been evaluated for following marine organisms: (1) phytoplankton, (2) zooplankton, (3) macroalgae, (4) different kind of non-piscivorous and piscivorous fish (different kind of fish are caused by different consumption and food preferences for species), (5) deposit-feeding invertebrate, (6) mollusks, (7) crustaceans, (8) seals/sea mammals and (9) sea birds/sea bird eggs.

Mathematical experiments to estimate the kinetic parameters were carried out in the present project based on the methodology (i)-(v) described above in this section. The results of simulations are presented in Tables A2–A6 of the Appendix. Kinetic parameter values based on a literature review, existing databases, and the results of the BIORAD project are also included in Tables A2-A6. Ingestion per unit mass of biota (ingestion rate IR) is presented in Table A2. Consumption for species with food preferences, described as a fraction of w from expression (10), is shown in Table A3. The assimilation efficiency for food consumptions (AE) for marine organisms is presented in Table A4. The rate of the direct uptake of activity from water column (k_u) for marine organisms is presented in Table A5. The excretion rate (k_e) for selected radionuclides and marine organisms and biological half-life of radionuclides in organisms ($T_{1/2}$) are presented in Table A6. The symbol "*" in tables A2-A6 corresponds to the parameters obtained in this study or selected from existing databases. The expression "General approach" described by PREPARE (2015) and de Wids et al. (2021) applies to all radionuclides unless they are presented in Tables A2-A6.

Figures 19-46 show examples of simulations for different radionuclides from all groups 1-4 for sea water with constant concentrations of radionuclides of 1 Bq per 1 liter. These conditions lead to the equilibrium/quasi-equilibrium conditions for bioaccumulation of radionuclides in biota. Therefore, results of simulations are compared with the concentration ratio approach.
For some radionuclides and biota there is information about arithmetical and geometrical mean values (AM and GM, correspondently) and the range for potential values (Min and Max, correspondently) of concentration ratios. This information is also presented in figures.

Figures 19-46 demonstrate that there are different possibilities of describing the kinetic parameters to fit different values of the concentration ratios and corresponding to additional uncertainty for definition of parameters.

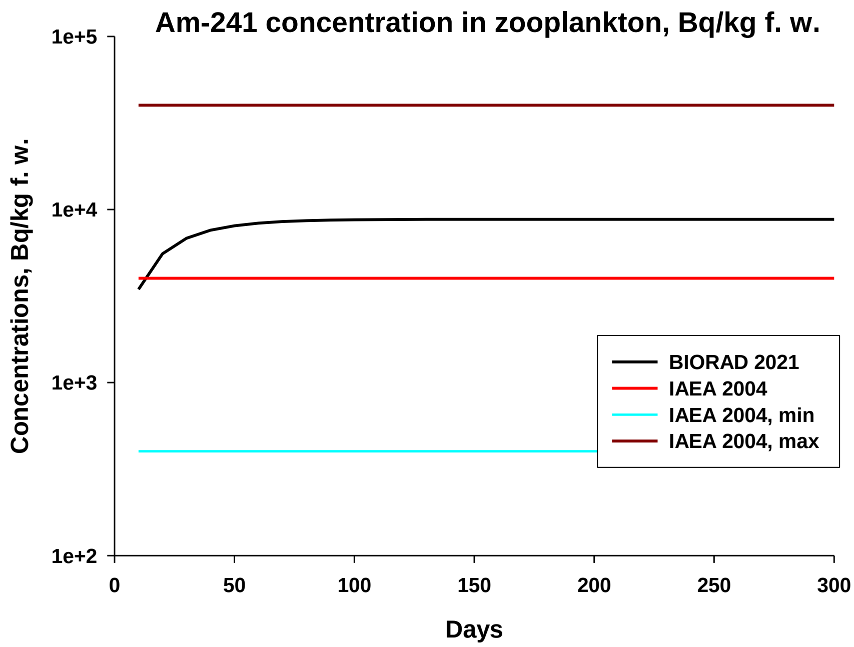


Figure 19. Kinetic model vs concentration ratio approach for Am-241 bioaccumulation in zooplankton.

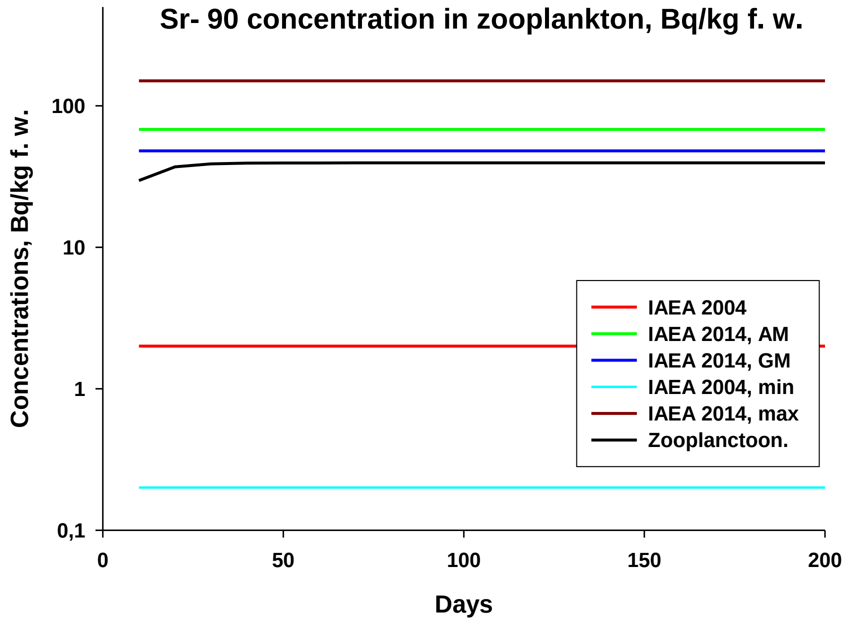


Figure 20. Kinetic model vs concentration ratio approach for Sr-90 bioaccumulation in zooplankton.

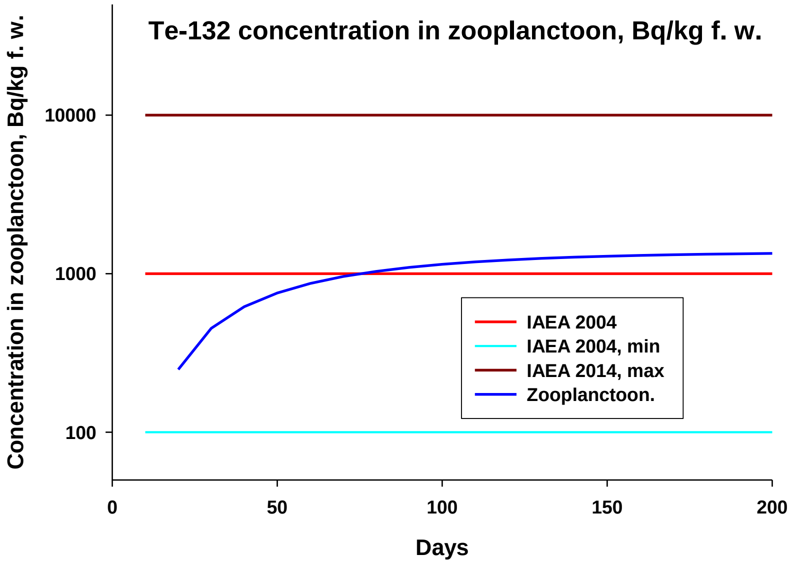


Figure 21. Kinetic model vs concentration ratio approach for Te-132 bioaccumulation in zooplankton.

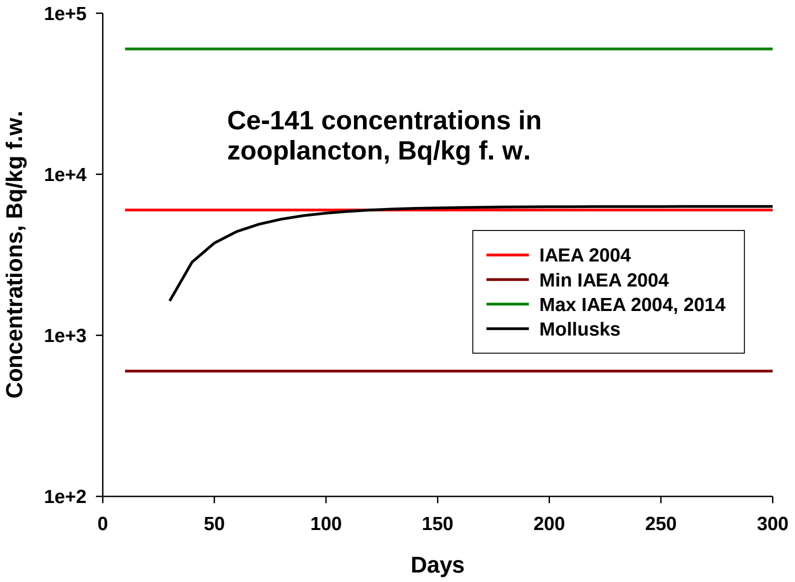


Figure 22. Kinetic model vs concentration ratio approach for Ce-141 bioaccumulation in zooplankton.

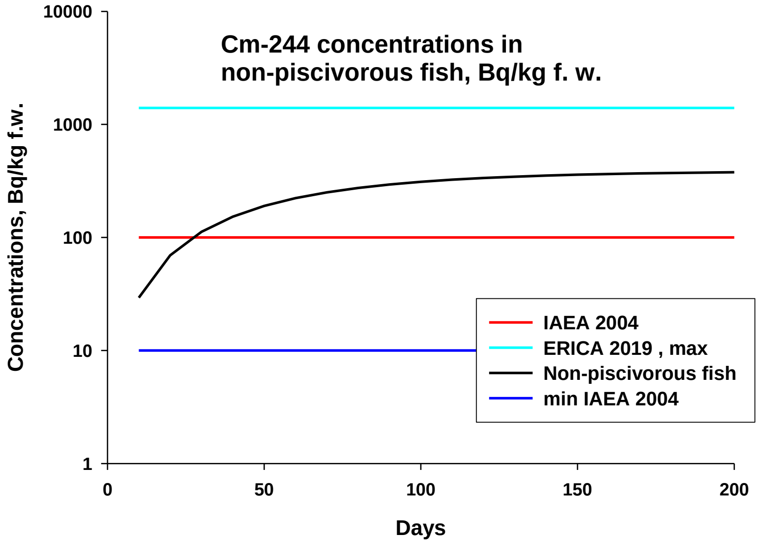


Figure 23. Kinetic model vs concentration ratio approach for Cm-244 bioaccumulation in non-piscivorous fish.

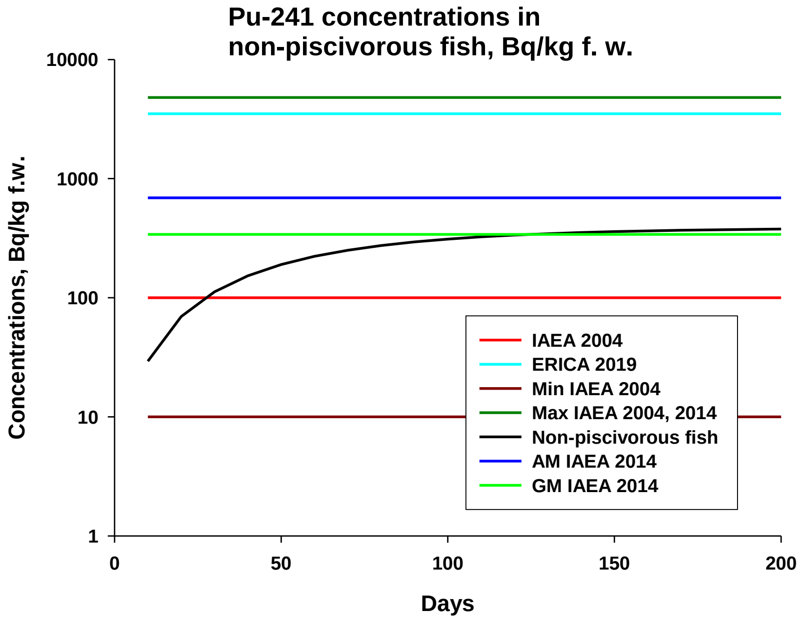


Figure 24. Kinetic model vs concentration ratio approach for Pu-241 bioaccumulation in non-piscivorous fish.

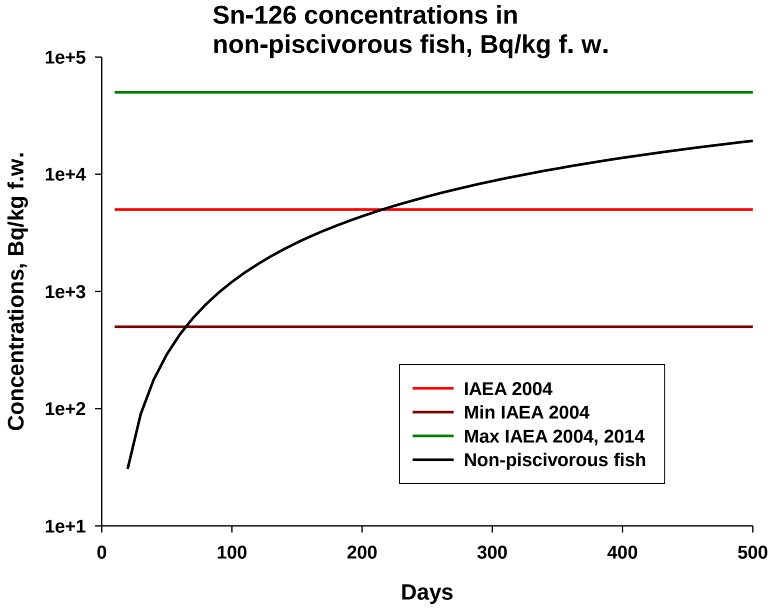


Figure 25. Kinetic model vs concentration ratio approach for Sn-126 bioaccumulation in non-piscivorous fish.

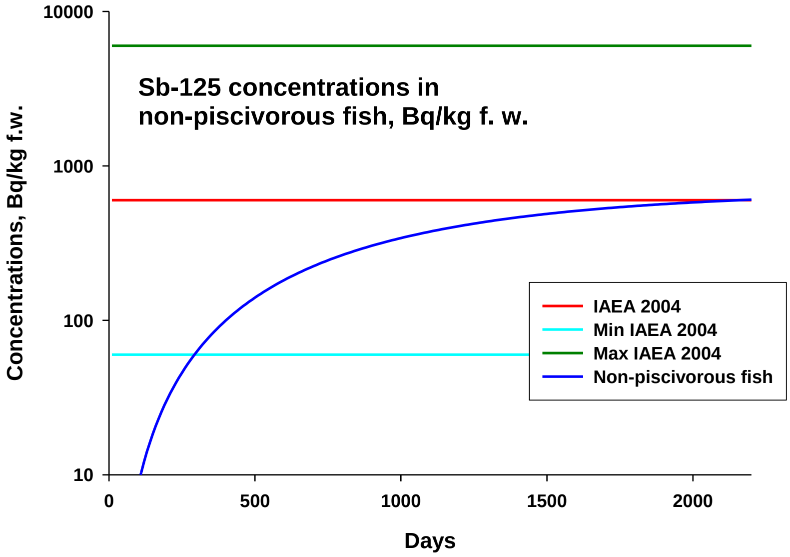


Figure 26. Kinetic model vs concentration ratio approach for Sb-125 bioaccumulation in non-piscivorous fish.

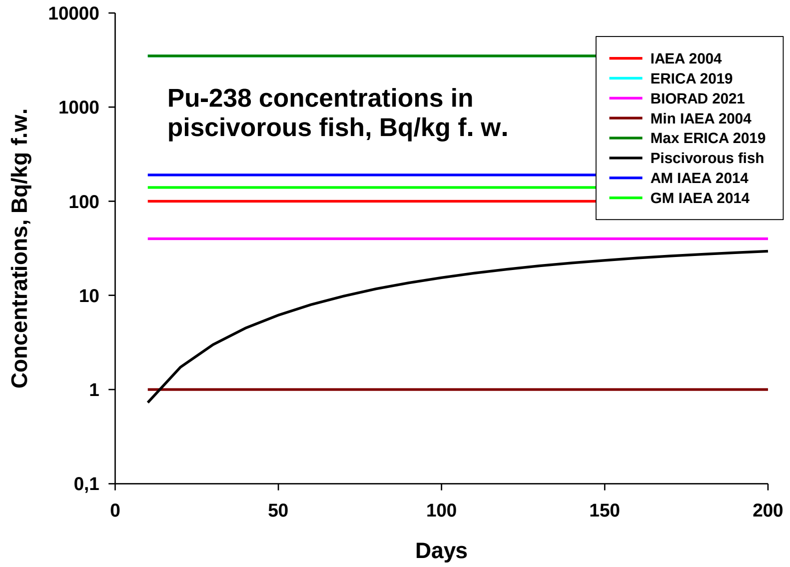


Figure 27. Kinetic model vs concentration ratio approach for Pu-238 bioaccumulation in piscivorous fish.

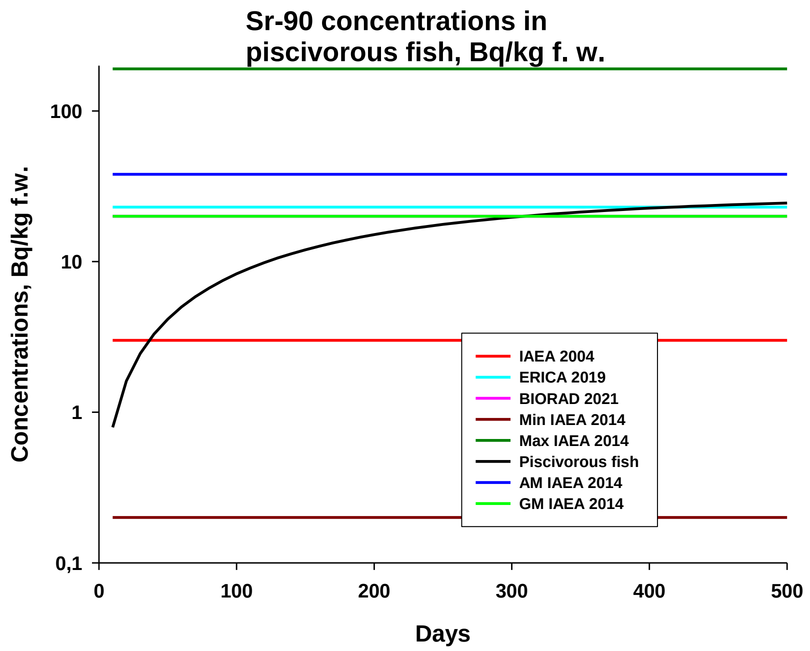


Figure 28. Kinetic model vs concentration ratio approach Sr-90 bioaccumulation in piscivorous fish.

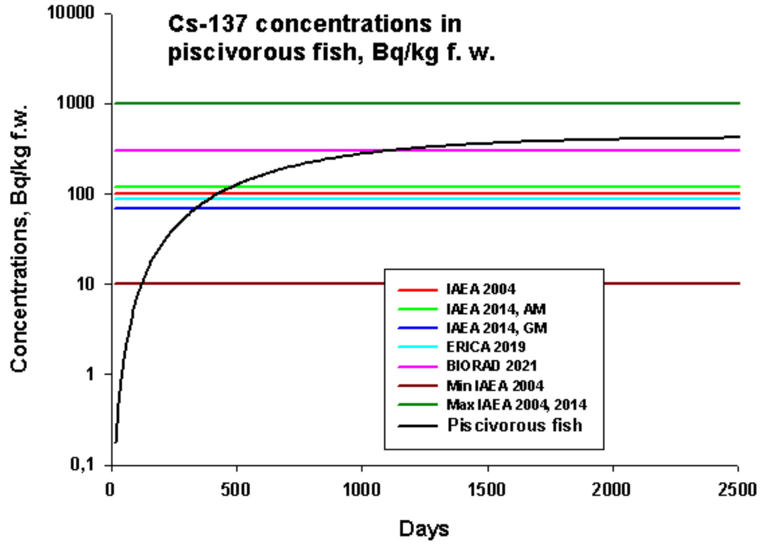


Figure 29. Kinetic model vs concentration ratio approach Cs-137 bioaccumulation in piscivorous fish.

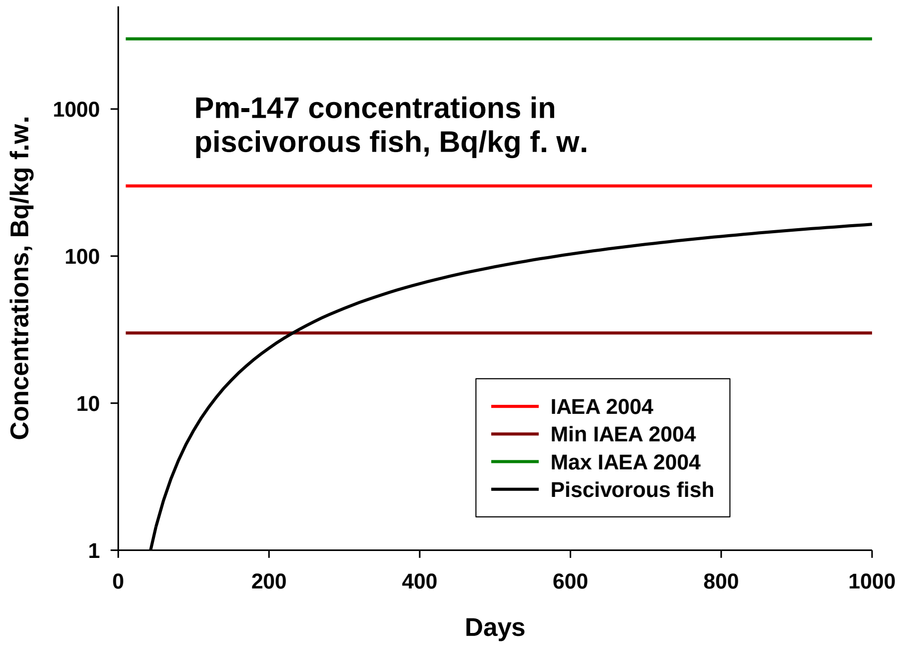


Figure 30. Kinetic model vs concentration ratio approach Pm-147 bioaccumulation in piscivorous fish.

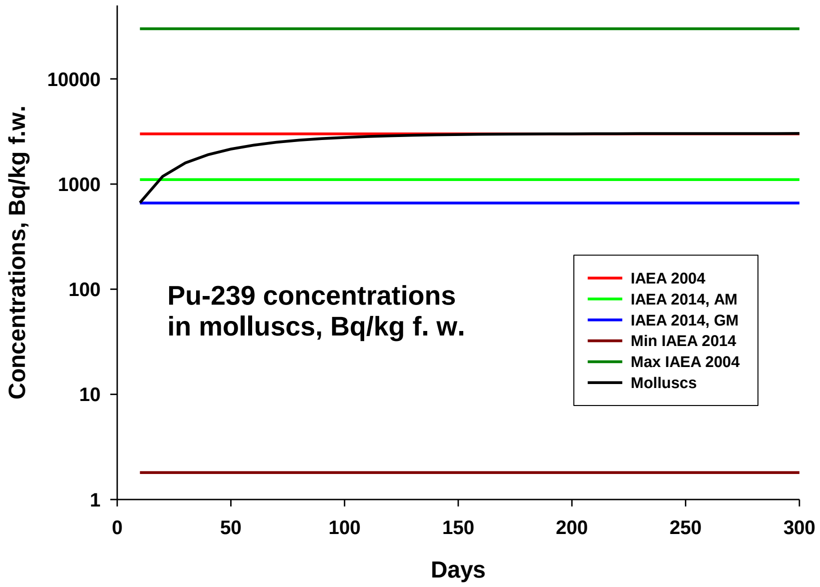


Figure 31. Kinetic model vs concentration ratio approach Pu-239 bioaccumulation in mollusks.

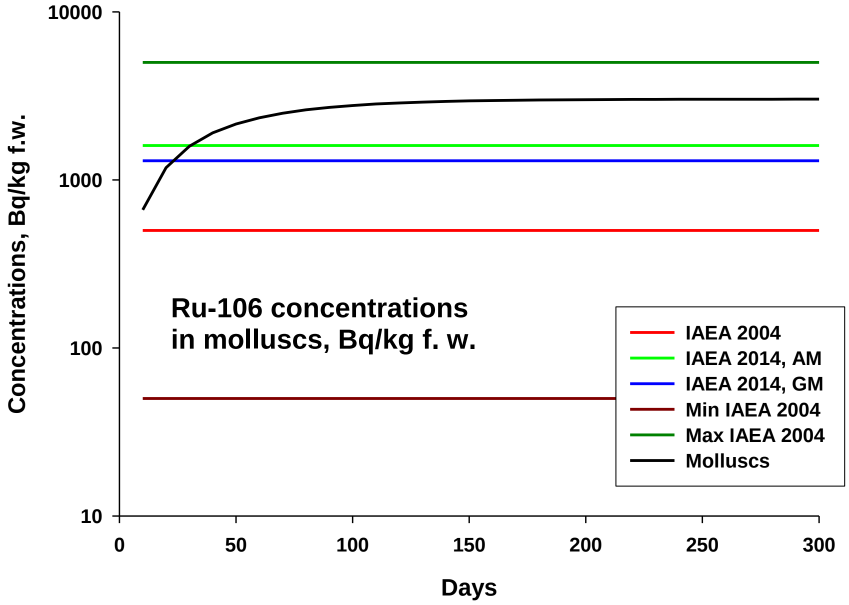


Figure 32. Kinetic model vs concentration ratio approach Ru-106 bioaccumulation in mollusks.

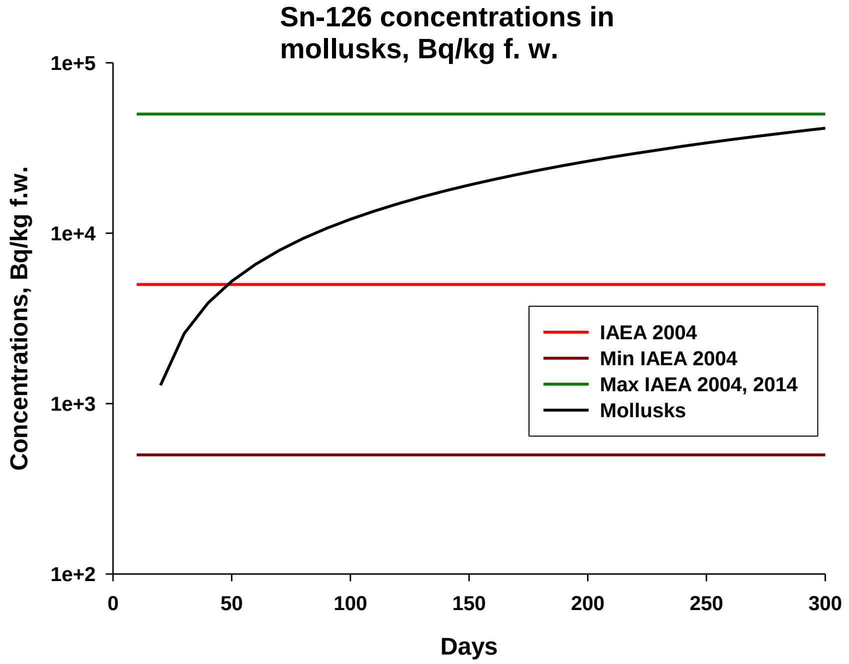


Figure 33. Kinetic model vs concentration ratio approach Sn-126 bioaccumulation in mollusks.

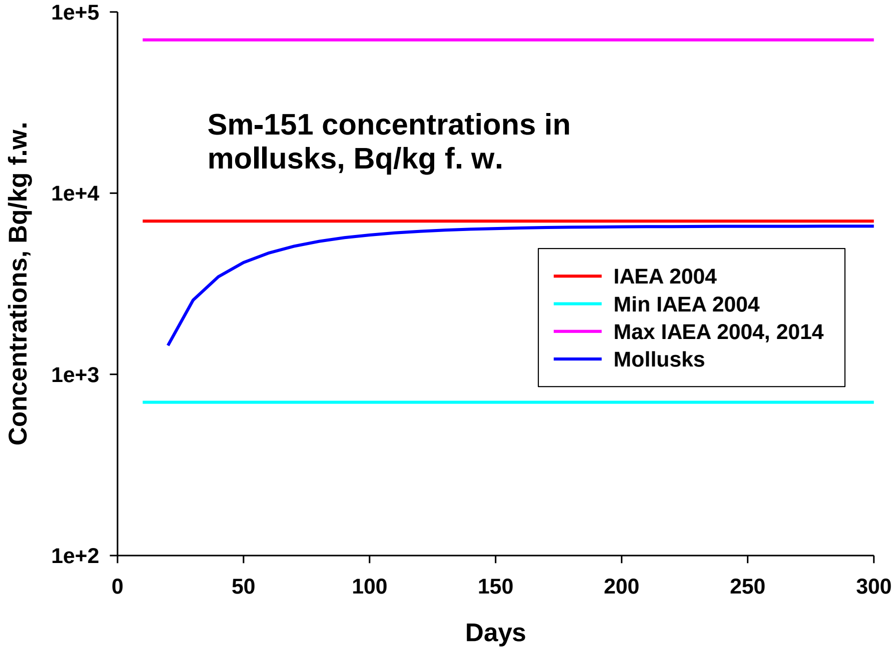


Figure 34. Kinetic model vs concentration ratio approach Sm-151 bioaccumulation in mollusks.

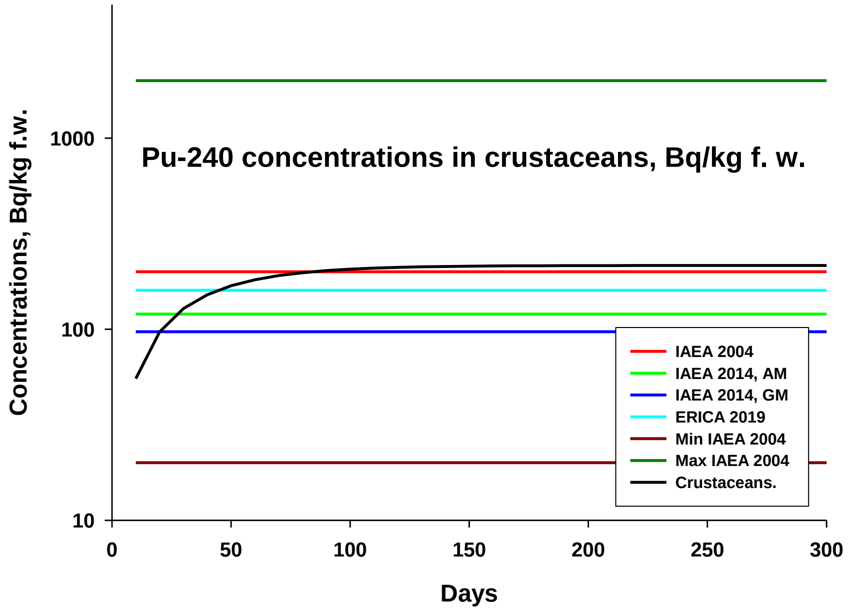


Figure 35. Kinetic model vs concentration ratio approach Pu-240 bioaccumulation in crustaceans.

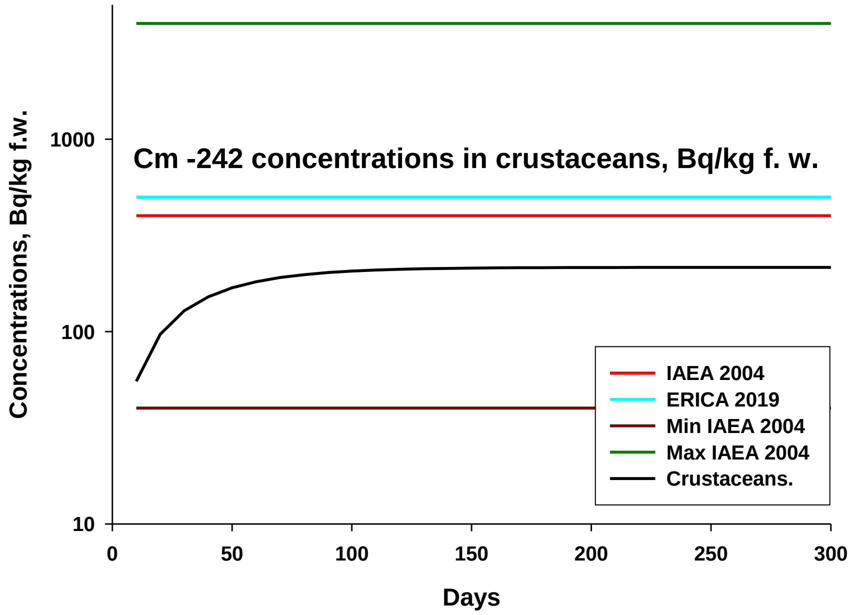


Figure 36. Kinetic model vs concentration ratio approach Cm-242 bioaccumulation in crustaceans.

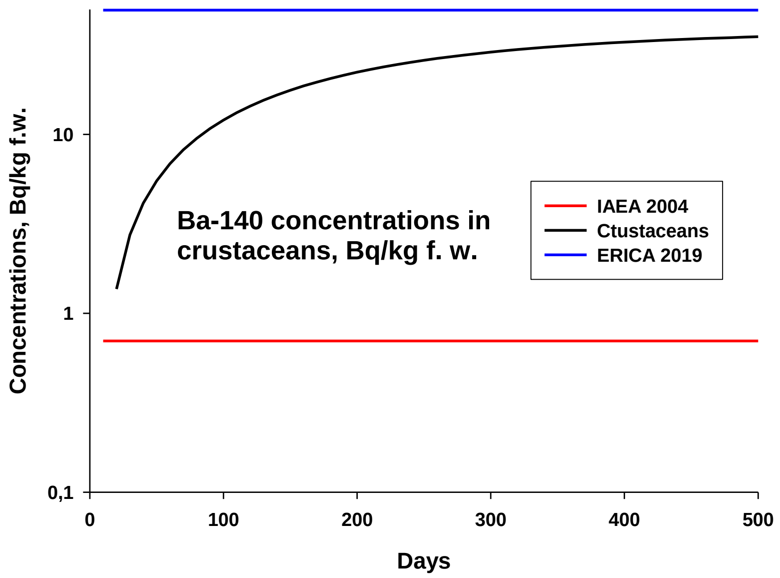


Figure 37. Kinetic model vs concentration ratio approach Ba-140 bioaccumulation in crustaceans.

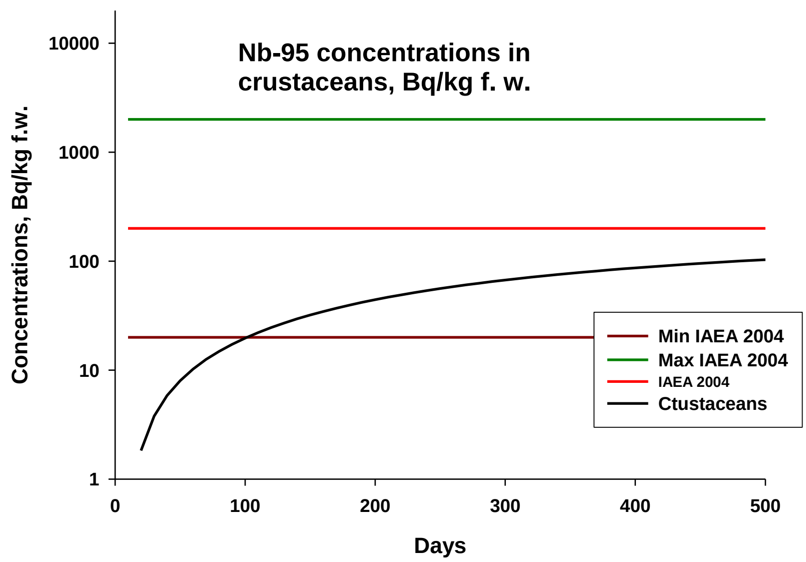


Figure 38. Kinetic model vs concentration ratio approach Nb-95 bioaccumulation in crustaceans.

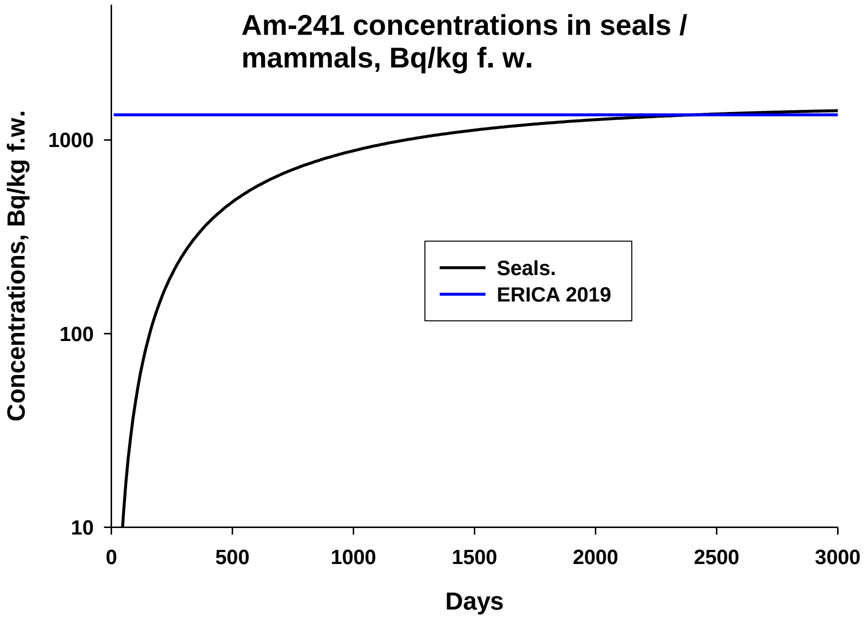


Figure 39. Kinetic model vs concentration ratio approach Am-241 bioaccumulation in seals/sea mammals.

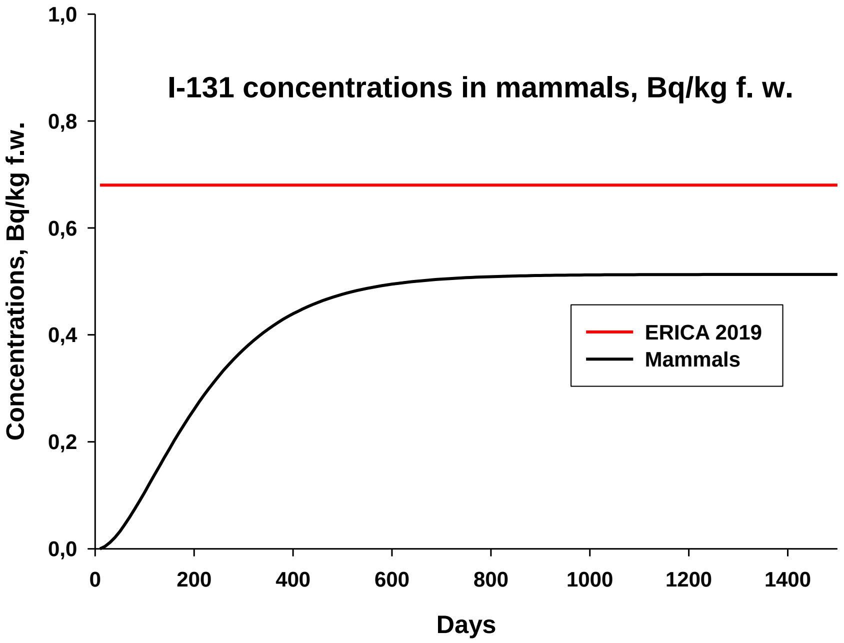


Figure 40. Kinetic model vs concentration ratio approach I-131 bioaccumulation in seals/sea mammals.

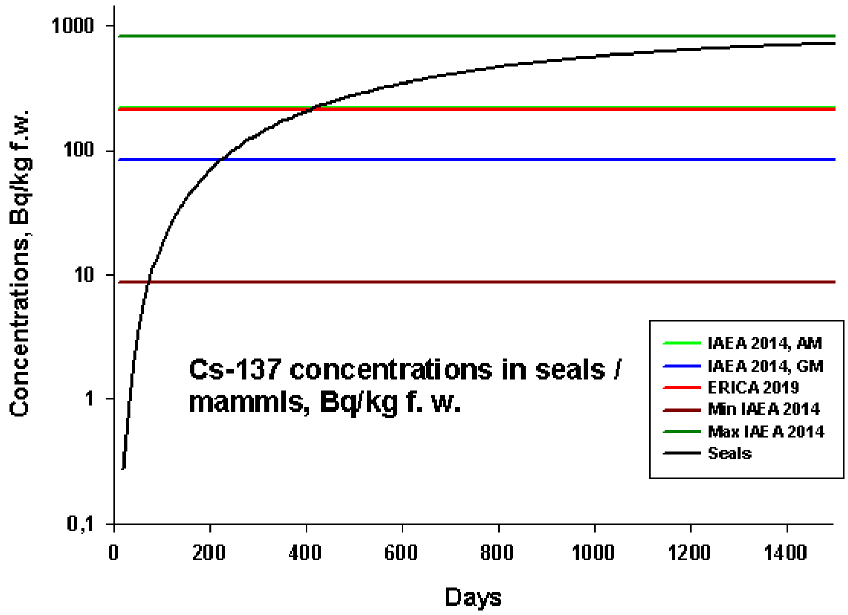


Figure 41. Kinetic model vs concentration ratio approach Cs-137 bioaccumulation in seals/sea mammals.

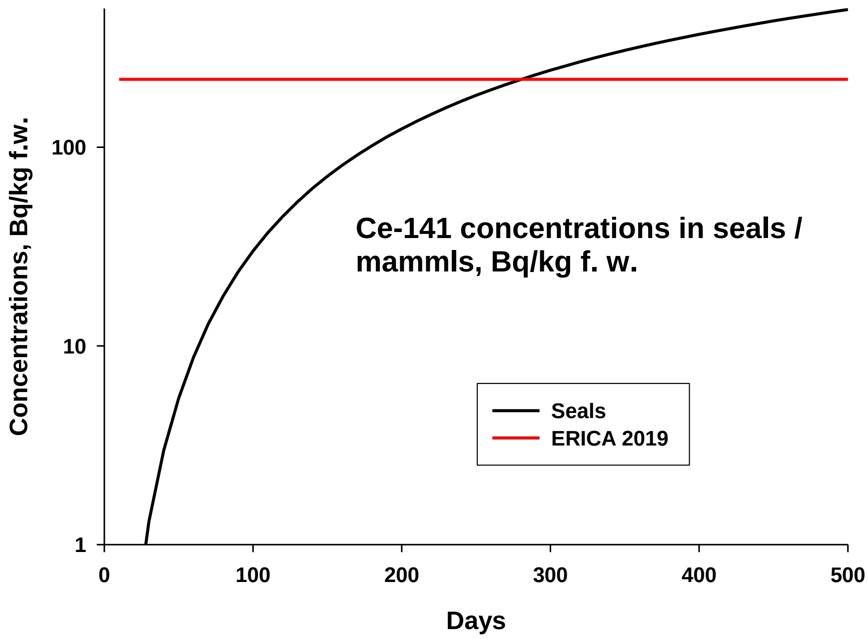


Figure 42. Kinetic model vs concentration ratio approach Ce-141 bioaccumulation in seals/sea mammals.

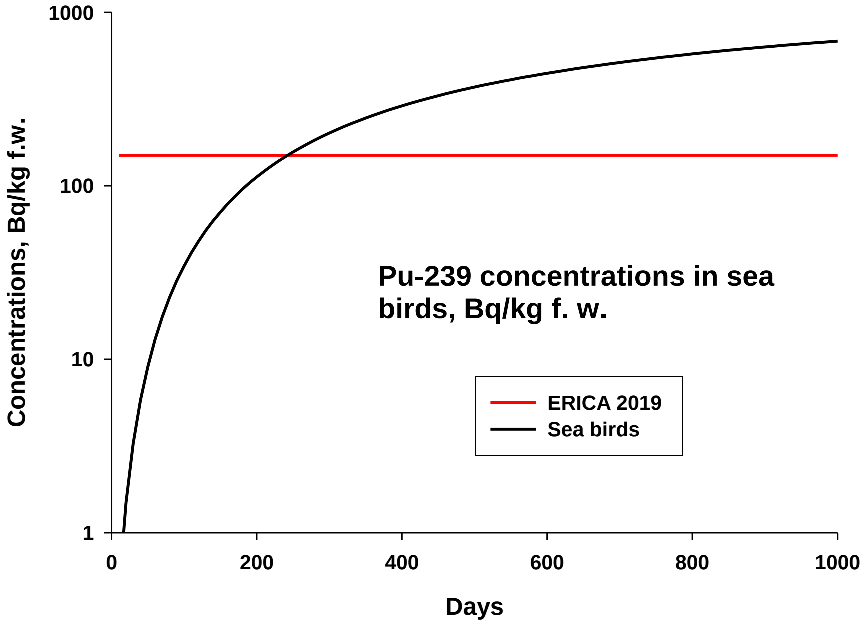


Figure 43. Kinetic model vs concentration ratio approach Pu-239 bioaccumulation in seals/sea mammals.

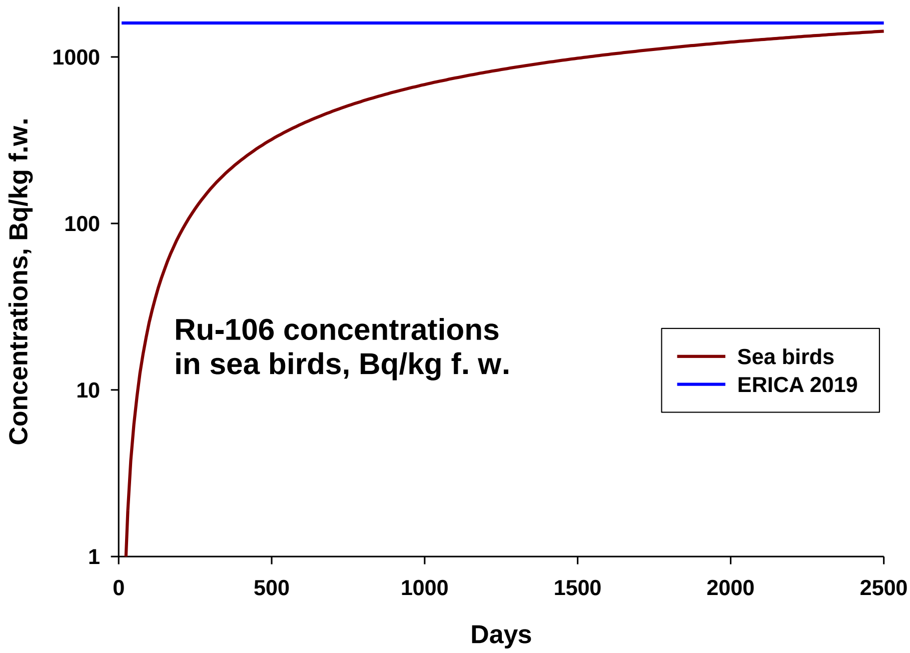


Figure 44. Kinetic model vs concentration ratio approach Ru-106 bioaccumulation in seals/sea mammals.

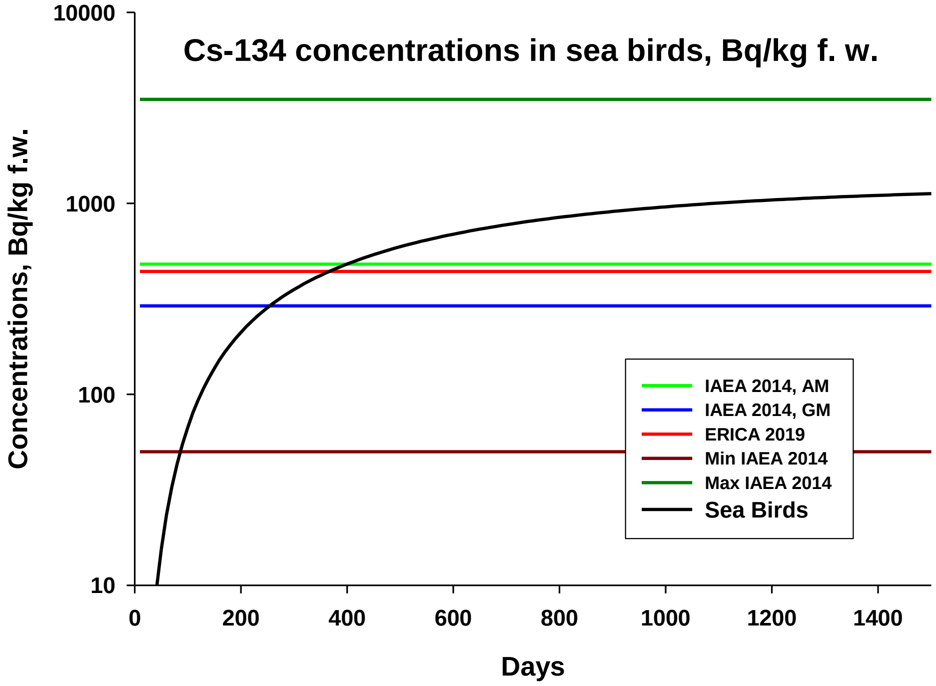


Figure 45. Kinetic model vs concentration ratio approach Cs-134 bioaccumulation in seals/sea mammals.

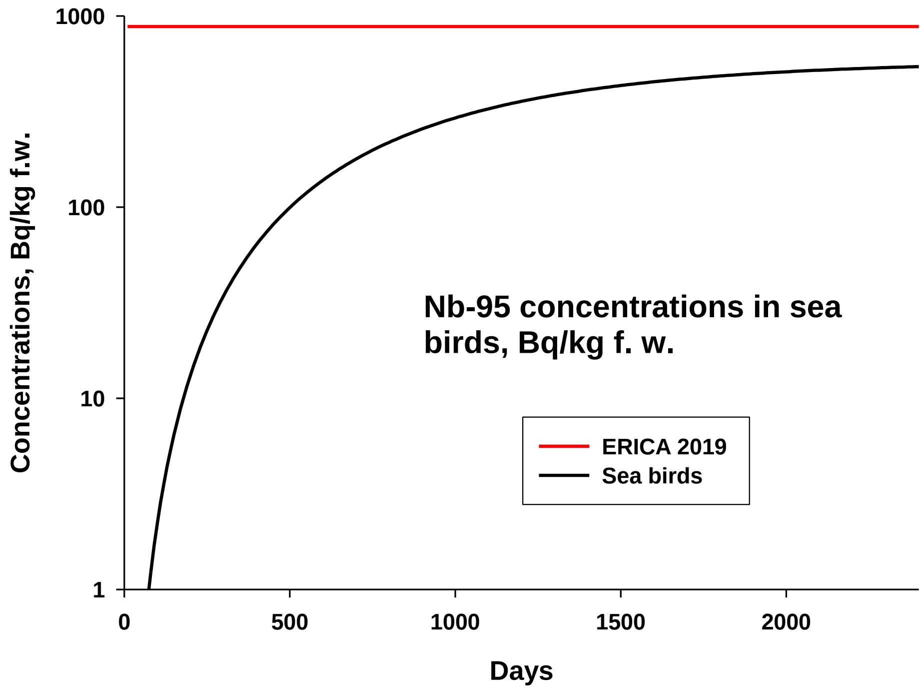


Figure 46. Kinetic model vs concentration ratio approach Nb-95 bioaccumulation in seals/sea mammals.

It is necessary to emphasize the following points with regard to the results in Figures 19-46: (i) the values of the kinetic coefficients selected due performed mathematical experiments can provide suitable comparison with concentration ratio approach related to equilibrium and (ii) such methodology allow to find suitable set of kinetic parameters, but it is impossible to proof that this set of parameters is best (Iosjpe, 2014). Point (ii) means that it is necessary to justify the correctness of the parameters with site-specific information from assessed marine regions, where this is possible.

6. The importance of implementing the kinetic bioaccumulation model for consequences from short-lived radionuclides

The excretion rate for organism of trophic level "*i*" ($k_{e,i}$) is calculated by following expression:

$$k_{e,i} = \frac{ln2}{T_{1/2,i}}, \qquad (12)$$

where $T_{1/2,i}$ is the effective half-life of radionuclide in this organism.

$T_{1/2,i}$ can be defined from equation

$$\frac{1}{T_{1/2,i}} = \frac{1}{T_{1/2,i}^{(B)}} + \frac{1}{T_{1/2,i}^{(R)}}, \qquad (13)$$

where $T_{1/2,i}^{(B)}$ and $T_{1/2,i}^{(R)}$ are biological and radioactive/physical half-life, respectively.

It is easy to derive following statements for short-life radionuclides from expressions (12) and (13):

If $T_{1/2,i}^{(B)} >> T_{1/2,i}^{(R)}$ then $T_{1/2,i} \approx T_{1/2,i}^{(R)}$ and $k_{e,i} \approx \frac{ln2}{T_{1/2,i}^{(R)}}$ (14)

Expression (14) demonstrate that the removal of radionuclides from the biota can be strongly dominated by the physical half-life of radionuclide for short-life radionuclides.

Figures 47 - 48 show the results of a kinetic simulation of the Pu-243 bioaccumulation process, similar to the simulations in section 5. The results correspond to zooplankton and molluscs compared to similar results for Pu-239. Simulations adopt a reasonable assumption that the assimilation efficiency (AEi), the ingestion per unit mass (IRi) and rate of the direct uptake of activity from the water column (ku,i) are the same for each isotope of the same radioactive element. Figures show that the concentration of Pu-243 in biota under equilibrium conditions is less than the Pu-243 concentration (up to orders of magnitude). These results can be explained by extremely rapid removal of the Pu-243 isotope from the biota (half-life of Pu-243 is about 5 hours).

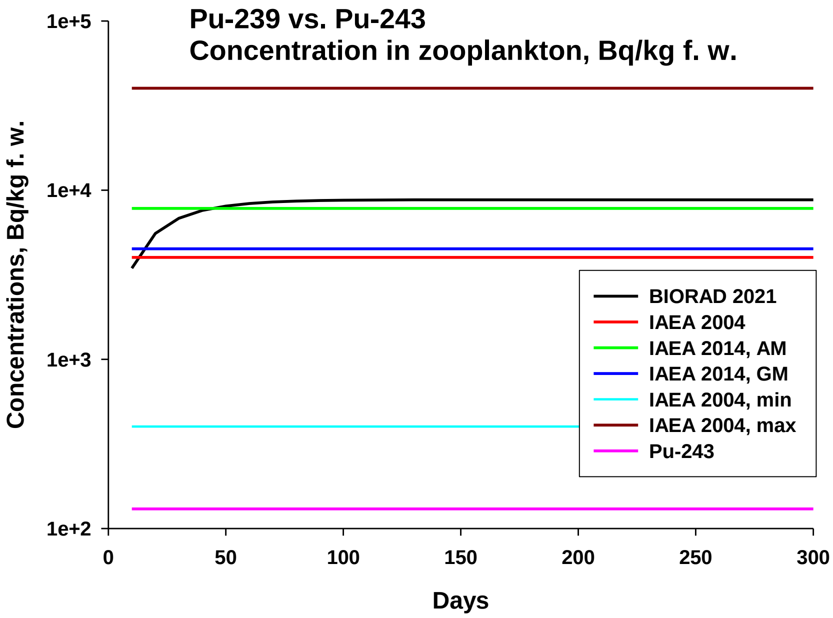


Figure 47. Concentrations of Pu-243 and Pu-239 in zooplankton under equilibrium conditions.

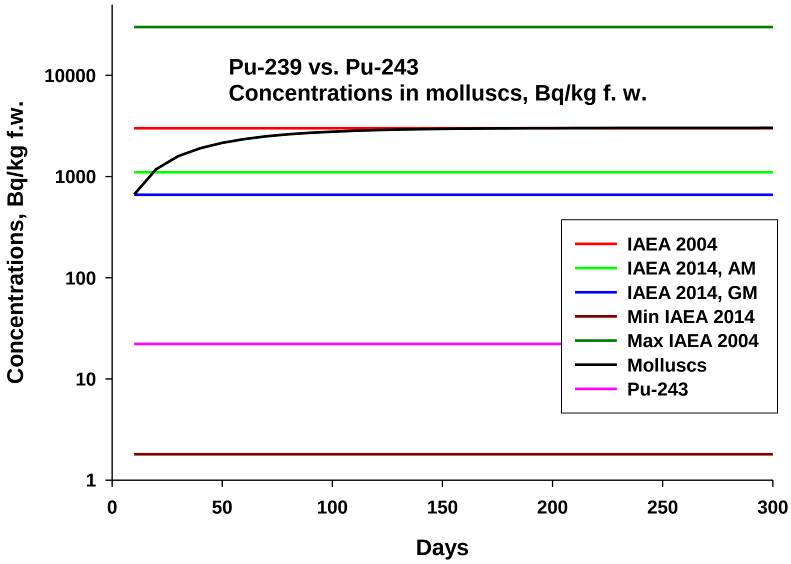


Figure 48. Concentrations of Pu-243 and Pu-239 in mollusks under equilibrium conditions.

Figure 49 shows results of simulations for Pu-243 according to release scenario described in section 2.1 of the present report for (i) the concentration ratio approach and (ii) kinetic modelling of the bioaccumulation process.

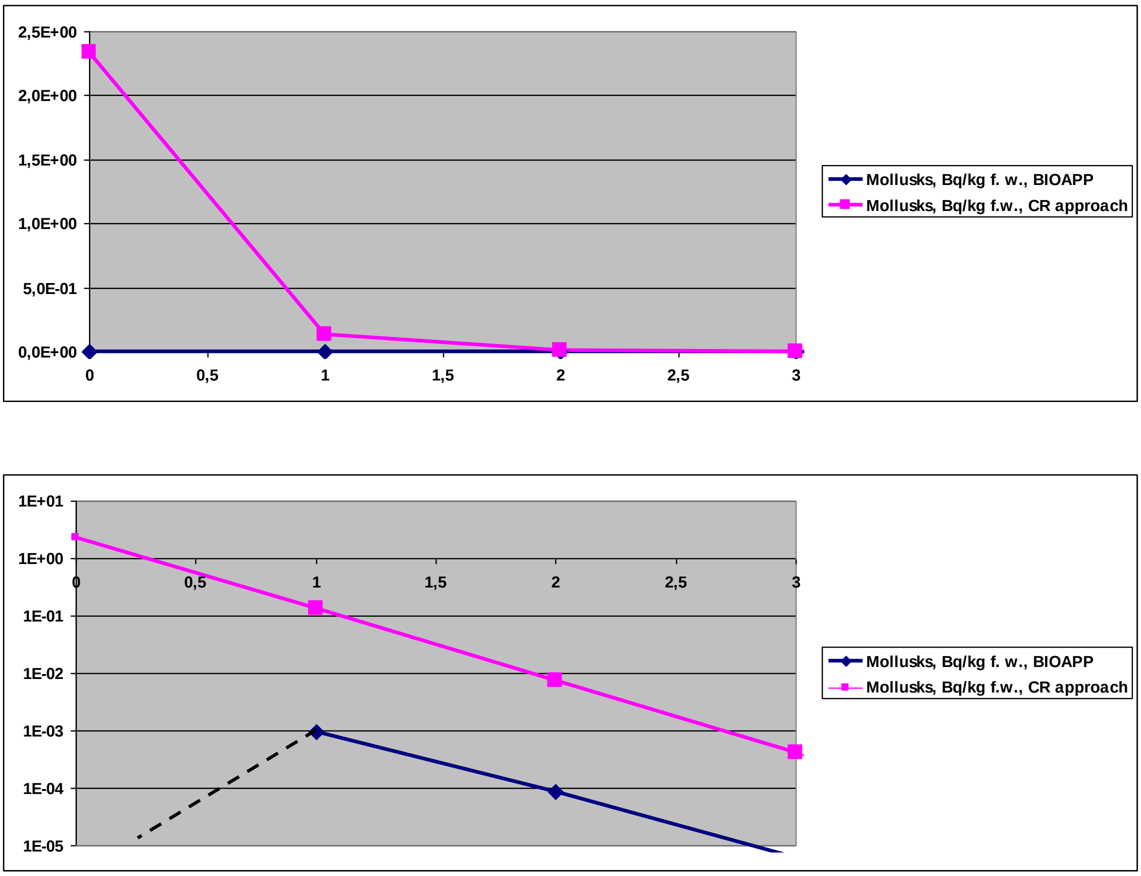


Figure 49. Pu-243 concentration in mollusks according to the concentration ratio approach and kinetic modelling of the bioaccumulation process with the linear (top) and logarithmic (bottom) scales. Simulations correspond to time interval [0, 3] days.

The most important differences are observed at the beginning of discharge. The concentration ratio approach gives results proportional to the concentration of radionuclide in water, while the starting value for kinetic modeling is zero at the beginning of the release. This statement is typical for all radionuclides, but for short-lived radionuclides this difference (low values for radionuclide concentration up to orders of magnitude) will be permanent in time (see Figures 47-48). Therefore, short-lived radionuclides have minor or negligible influence on the radioecological consequences even under significant concentration in water at the beginning of the release.

7. Implementation of the kinetic modelling for bioaccumulation of radionuclides in biota: consequences after potential nuclear accident.

7.1. Concentrations of radionuclides in marine biota/sea food

Figures 50-58 show the typical results of the model simulations for the radionuclide concentrations in marine organisms/seafood for each of four groups of radionuclides presented in Table 1 (CAC, 2006) (see chapter 4 of the present report). Figures 50-58 demonstrate also concentrations of radionuclides with most significant impact to the total concentration of the marine organisms for each of four groups.

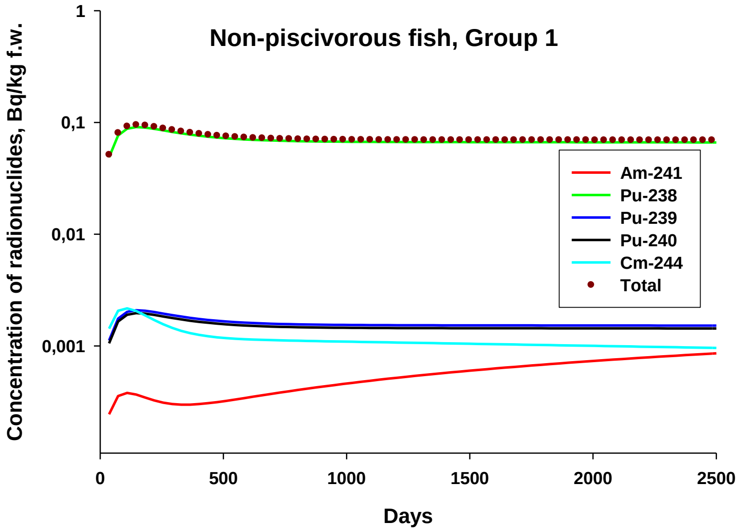


Figure 50. Concentration of radionuclides in non-piscivorous fish for Group 1.

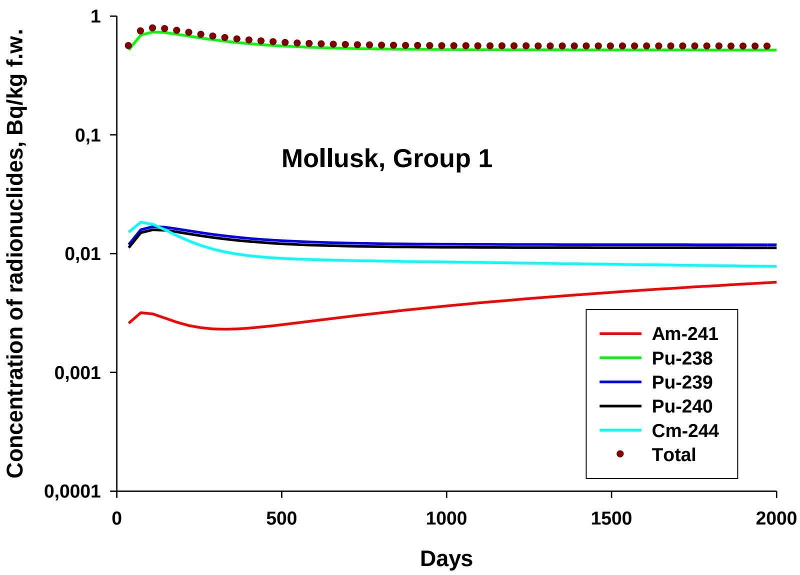


Figure 51. Concentration of radionuclides in mollusks for Group 1.

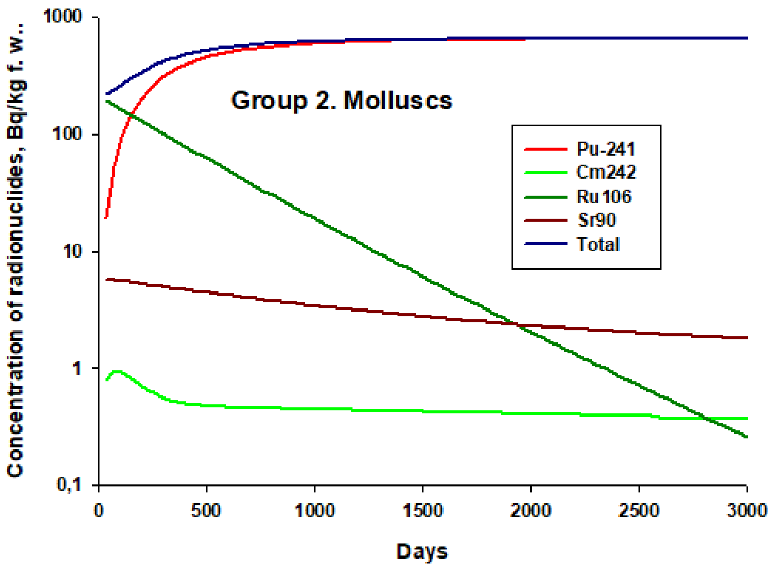


Figure 52. Concentration of radionuclides in mollusks for Group 2.

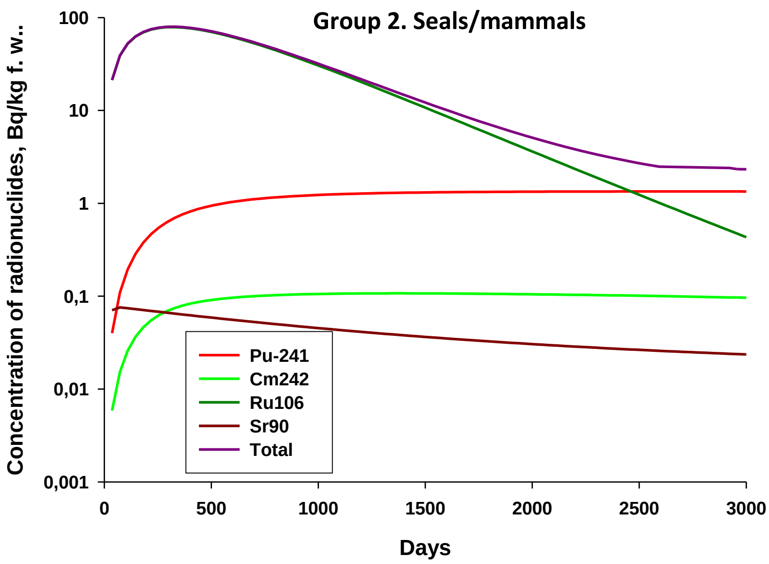


Figure 53. Concentration of radionuclides in sea mammals for Group 2.

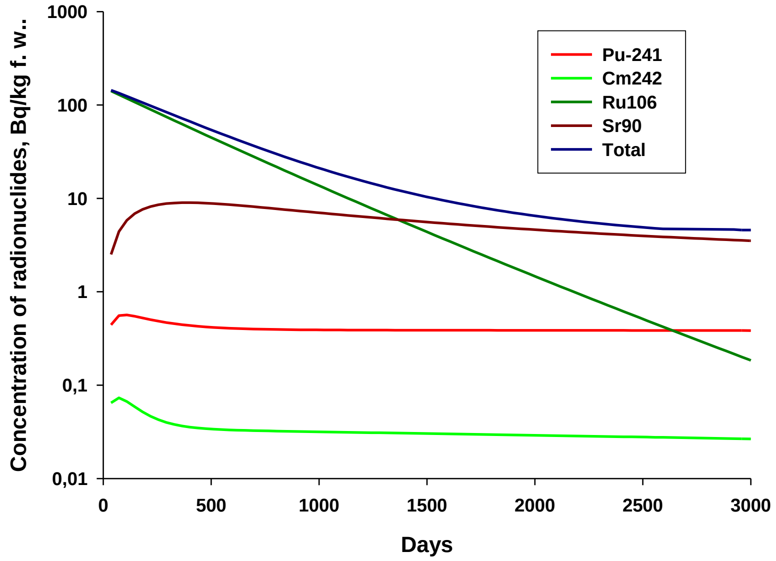


Figure 54. Concentration of radionuclides in crustaceans for Group 2.

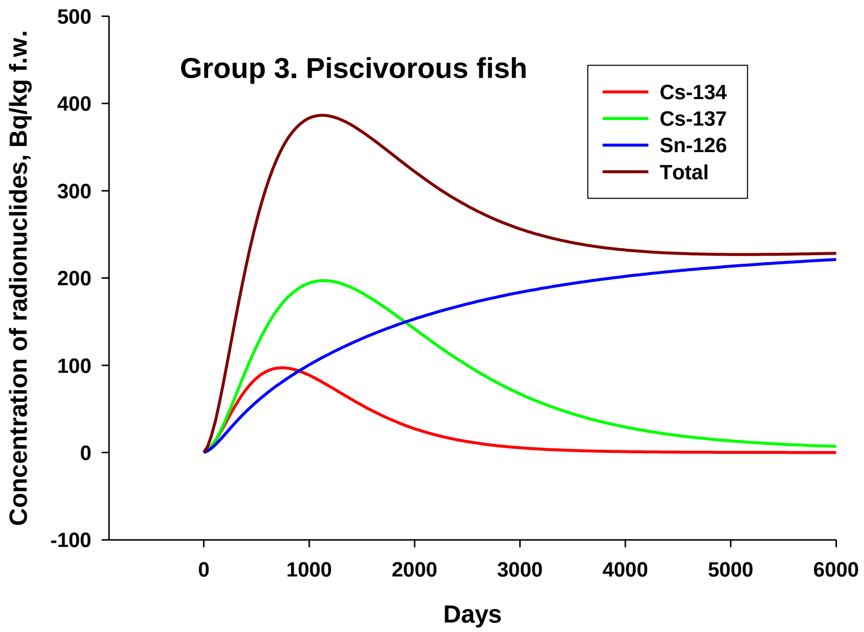


Figure 55. Concentration of radionuclides in piscivorous fish for Group 3.

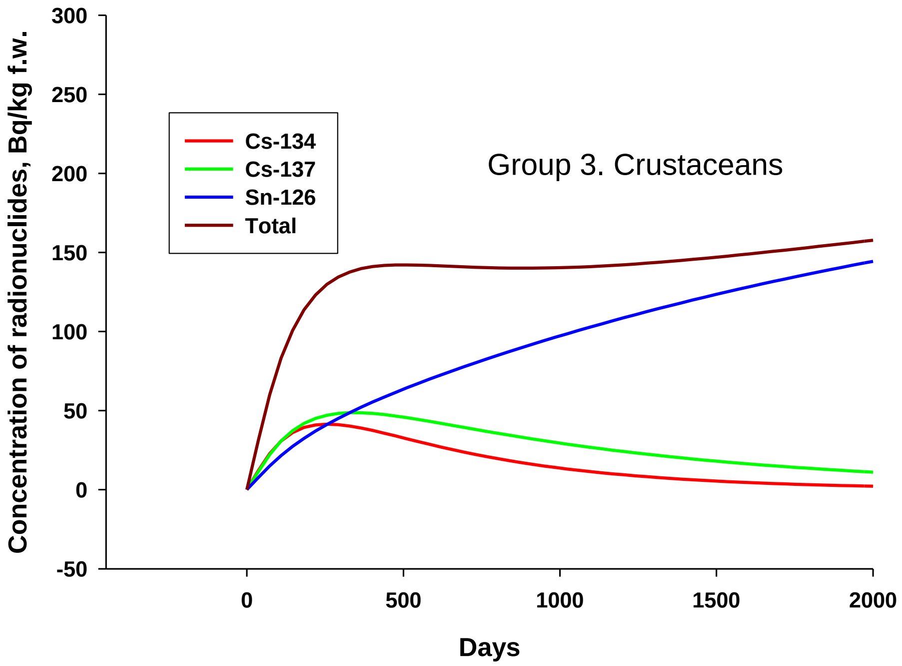


Figure 56. Concentration of radionuclides in crustaceans for Group 3.

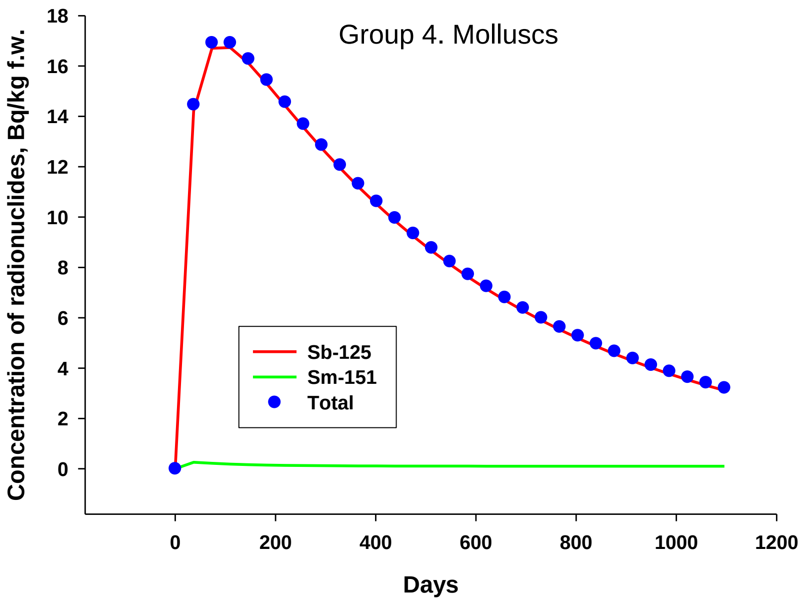


Figure 57. Concentration of radionuclides in mollusks for Group 4.

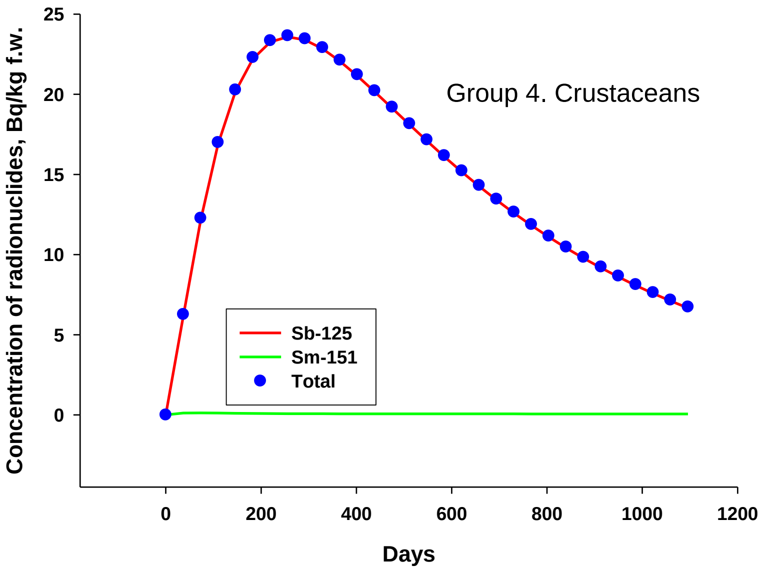


Figure 58. Concentration of radionuclides in crustaceans for Group 4.

Figures 50 – 58 show that concentration of radionuclide in the marine organisms/seafood vary with time significantly for all groups of radionuclides. It is necessary to note that the calculations, presented in Figures 50 - 58, correspond to the compartment described in section 2.2, where the potential accident occurs.

All biota from groups 1, 3 and 4, have no restrictions as seafood (Figures 50-51 and 55-58). Radionuclide concentrations from Group 2 exceed the Guidance levels values for mollusks during the entire period of simulations (ten years) and for crustaceans during six months, approximately (Figures 52 and 54), and, therefore, cannot be recommended as seafood without limitations.

7.2. Doses to a human in the critical group

In the present report, the critical group of humans is defined as persons with high consumption of seafood from the local compartment of the Gulf of Finland (Bergsten, 2003; Iosjpe et al., 2009). It is also assumed here that this group will use crustacean and mollusks in spite of recommended restrictions from the section 7.3 with the following dietary data: (i) sea fish, 200 g/d; (ii) crustacean, 40 g/d; (iii) mollusks, 4 g/d (Bergsten, 2003).

Figures 59 shows the dynamic of the total dose for a human in the critical group. Figure 60 demonstrates that the main impact to the maximal dose for a human in the critical group (0.7 mSv, approximately, during the second year after start of radioactivity releases) corresponds to Cs-137 (35.0%), Cs-134 (34.6%) and Sn-126 (11.4%).

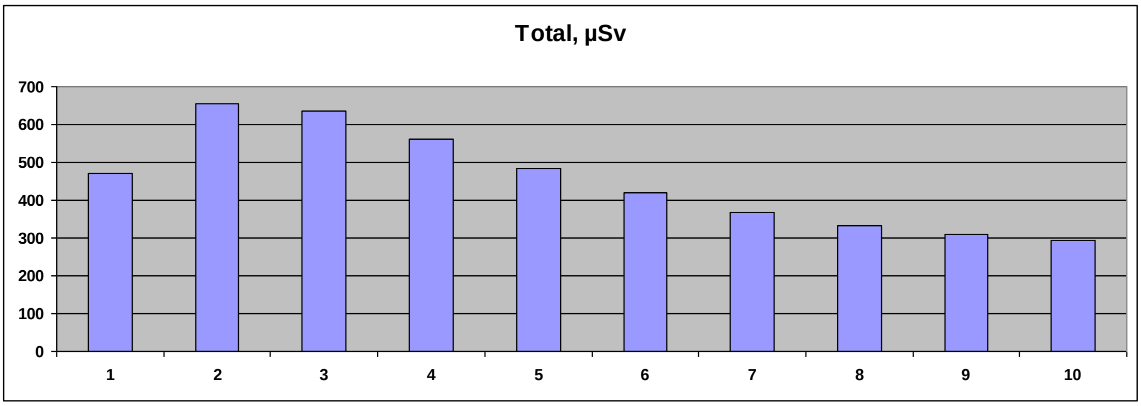


Figure 59. Dynamic of the impact of radionuclides in the effective dose to a human in the critical group. Simulations are presented within time interval [0, 10] years.

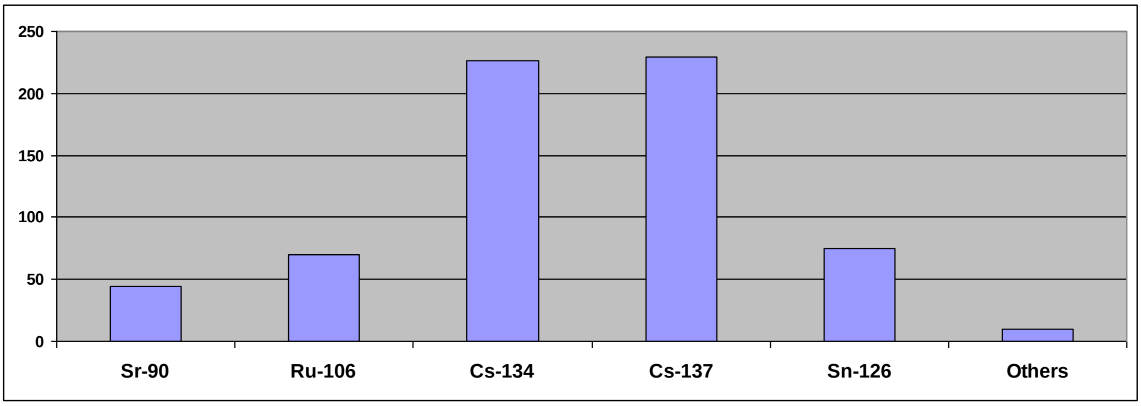


Figure 60. The impact of radionuclides in the effective dose to a human in the critical group, µSv.

It is important to note that the dose of 1 mSv per year does not exceeds the public dose limit recommended by the ICRP (ICRP, 1991).

7.3. Dose rates to marine organisms

The dose rates calculated for marine organisms, which are most significant for radioecological assessment, are calculated in the compartment of the Southwest part of the Barents Sea (the location for the hypothetical release of radionuclides). A conservative approach is used, which assumes that marine organisms do not leave the compartment during the simulation time. Results of simulations are presented in Figures 61-64. Figure 61 shows the total impact of all selected different radionuclides on dose rate (in units of µGy/h) for biota.

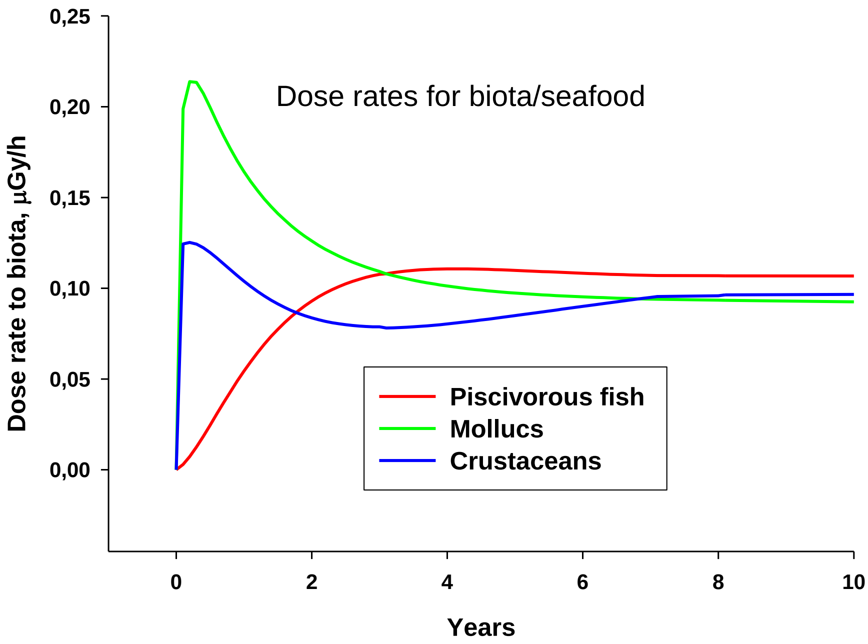


Figure 61**.** The dose-rates dynamic for selected biota, µGy/h. Simulations are presented within time interval [0-10] years.

Figures 62-64 show the most significant impact of radionuclides for the highest values of dose rates of biota. It is important to note that impact of radionuclides to the total dose rates can vary with time in wide limits.

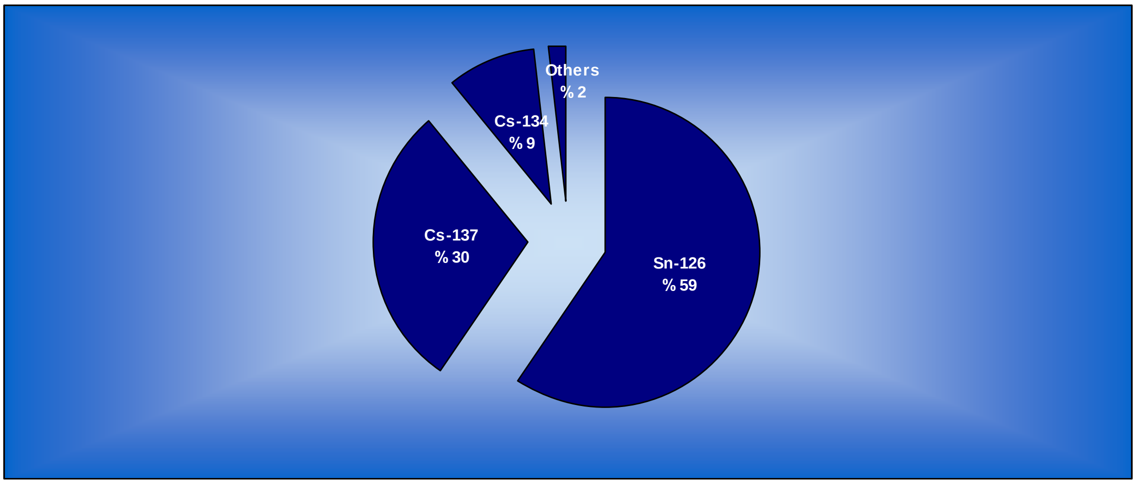


Figure 62. Contribution of various radionuclides to the highest dose rate (1.11E-1 µGy/h) for piscivorous fish after approx. 4 years from the onset of discharge.

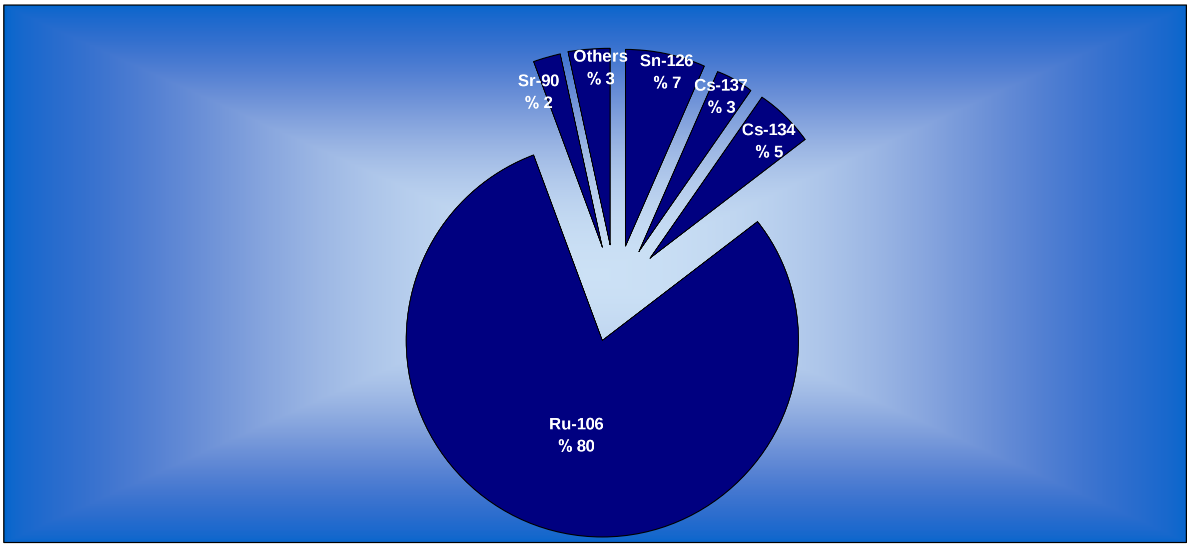


Figure 63. Contribution of various radionuclides to the highest dose rate (1.25E-1 µGy/h) for crustaceans after approx. 2.5 month from the onset of discharge.

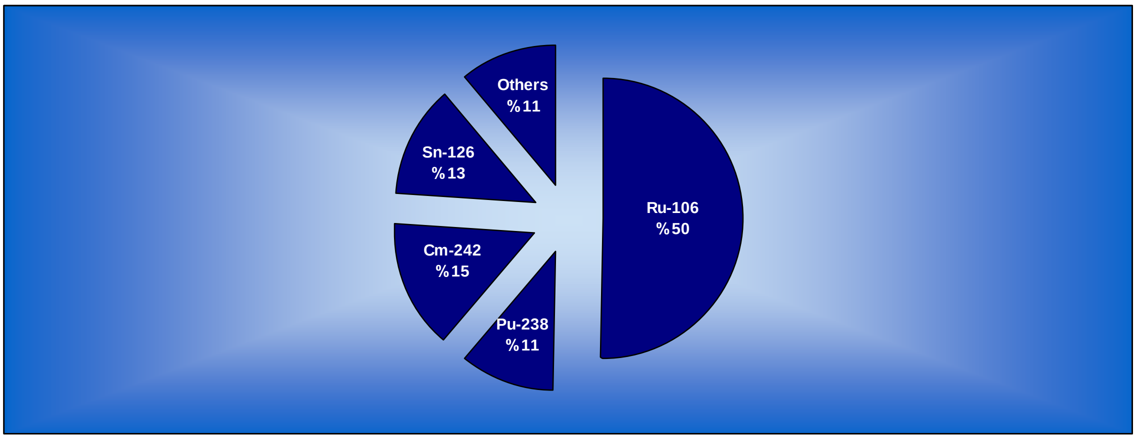


Figure 64. Contribution of various radionuclides to the highest dose rate (2.13E-1 µGy/h) for mollusks after approx. 4 months from the onset of discharge.

It is necessary to note that radionuclide Sn-126 has a rather significant impact on the results of this study. This can be explained by (i) relatively high release to the marine environment according to the release scenario and (ii) Sn-126 has a very high value for the concentration ratio (CR=5.5E5) according to IAEA (2004). This value is many times (up to one-two orders of magnitude) higher than concentration ratios for other radionuclides, which is also quite important for the definition of kinetic parameters during this study (see section 5 of this report).

It is important to note that the results of simulations demonstrate that the dose rate for all marine organisms does not exceed the screening dose (10 µGy/h), which can be considered as a safe level below which the potential for significant impacts on biota would be negligible.

8. Conclusions

The set of radionuclides corresponds to release scenario involving a modern operating Russian submarine (third-generation reactors) have been considered. The evaluation of the kinetic parameters for bioaccumulation process for a wide set of radionuclides and biota has been provided.

Preliminary evaluation of the kinetic parameters has been provided based on literature review, the extraction from existing databases and mathematical experiments including the successive simulations of bioaccumulation processes during increasing trophic levels.

The importance of implementing the kinetic bioaccumulation model for consequences from short-lived radionuclides has been provided.

The sub-model with the modified kinetic parameters for bioaccumulation process has been used based on simulations from the compartmental model, which uses the non-instantaneous dispersion of radioactivity in the marine environment. The selected release scenario corresponds to a potential accident with nuclear submarine reactors in the Southwest part of the Barents Sea.

Concentrations of radionuclides in biota, doses to humans and dose rates to the marine organisms have been evaluated.

The results of the present study can be used to improve the ability to evaluate the consequences to humans and biota after a radioactive release into marine environment. It was shown that the methodology, which was used here allows to find a suitable set of kinetic parameters, but it is impossible to proof that this set of parameters is the best version. Therefore, it is important to justify the correctness of the parameters by site-specific information from considered marine regions.

References.

Beresford, N.A., Beaugelin-Seiller, K., Wells, C., Vives-Lynch, S., Vives i Batlle, J., Wood, M.D., Tagami, K., Real, A., Burgos, J., Fesenko, S., Cujic, M., Kryshev, A., Pachal, N., Su, B.S., Barnett, C.L., Uchida, S., Hinton, T., Mihalík, J., Stark, K., Willrodt, C., Chaplow, J., 2015. A Database of Radionuclide Biological Half-life Values for Wildlife. NERC-Environmental Information Data Centre. http://doi.org/10.5285/b95c2ea7-47d2-4816-b942-68779c59bc4d.

Bergsten, C., 2003. Fish and Game Study, Part B. The Consumption of Foods that may be Important when Assessing the Dietary Intake of Mercury, Cadmium and PCB/ dioxins, with a Focus on Population Groups Living on the Coast and in the Inland of Norway. Norwegian Food Safety Authority, Oslo (in Norwegian).

Brown J.E., Alfonso B., Avila R. et al., 2008: The ERICA tool. Journal of Environmental Radioactivity, 2008, 99(9), 1371-1383.

Brown J., Børretzen P., Dowdall M., Sazykina T., and Kryshev I., 2004. The derivation of transfer parameters in the assessment of radiological impacts on Arctic marine biota. Arctic, 57, No. 3, 279-289.

Brown, J.E. & Hosseini, A., 2019. 'Task 3.3 - Prioritization based on radiological hazards'. Feasibility study INSC/2013/ MC.04/13 Report for Feasibility Study and Preparation for the Implementation of an Action Plan Concerning the Safe and Secure Management/Disposal of Sunken Radioactive Objects in the Arctic Sea; Report to : Directorate General for International Cooperation and Development – Europeaid.

CAC, 2006. Codex Alimentarius Commission: Joint FAO/WHO Food Standards Programme. Appendix XXXI. ftp://ftp.fao.org/codex/Alinorm06/al29_41e.pdf (09.01.07)

CEC, 1990. The Radiological Exposure of the Population of the European Community from Radioactivity in North European Marine Waters. Project 'Marina'. Commission of the European Communities, Bruxelles. EUR 12483.

EC, 2000. The radiological exposure of the population of the European Community to radioactivity in the Baltic Sea, Marina-Balt Project. European Commission, Luxembourg, EUR 19200.

EC, 1994. The Radiological Exposure of the Population of the European Community from Radioactivity in the Mediterranean Sea. Project ''MARINA-Med''. In: Radiation Protection Series 69, EC XI-094/93.

EFMARE, 2015. Effects of dynamic behaviour of Nordic marine environment to radioecological assessments. Halldórssón Ó., Iosjpe M., Isaksson M., Joensen H.P., Jonsson G., Logemann K., Roos P., Suolanen V., Thomas R., Vartti V.-P., NKS-326, ISBN 978-87-7893-407-9, http://www.nks.org/en/nks_reports/view_document.htm?id=111010212673171

ERICA, 2019. ERICA assessment tools, 2019, http://erica-tool.com/erica/

Heling R., Koziy I., Bulgakov V., 2002. On the dynamic uptake model developed for the uptake of radionuclides in marine organisms for the POSEIDON-R model system. Radioprotection 37 (C1), 833-838.

Hosseini, A., Amundsen, I., Brown, J.E., Dowdall, M., Standring W. (2015). Inventory and source term evaluation on the dumped nuclear submarine K-27. StrålevernRapport 2015:06. Østerås: Statens strålevern, 2015.

Hosseini, A., Amundsen, I., Bartnicki, J., Brown, J.E., Dowdall, M., Dyve, J.E., Karcher, M., Kauker, F., Klein, H., Lind, O.C., Salbu, B., Schnur, R., Standring, W., 2016. Environmental Modelling and Radiological Impact Assessment Associated with Hypothetical Accident Scenarios for the Nuclear Submarine K-27. StrålevernRapport 2016:8. Statens strålevern, Østerås, Norway.

Hosseini, A., Amundsen, I., Brown, J.E., Dowdall, M., Dyve, J.E., Klein H., 2017. Radiological impact assessment for hypothetical accident scenarios involving the Russian nuclear submarine K-159. StrålevernRapport 2017:12. Østerås: Statens strålevern.

IAEA, 1998. Radiological conditions of the Western Kara Sea: assessment of the radiological impact of the dumping of radioactive waste ion the Arctic Seas. Radiological assessment reports series 4. Vienna: IAEA, 1998.

IAEA, 2001. Generic models for use in assessing the impact of discharges of radioactive substances to the environment. Safety report series No. 19, IAEA, Vienna, 2001.

IAEA, 2014. Handbook of parameter values for the prediction of radionuclide transfer to wildlife. IAEA technical report series 479. Vienna, IAEA.

IAEA, 2004. Sediment distribution coefficients and concentration factors for the biota in the marine environment. IAEA technical report series 422. Vienna, IAEA.

IASAP, 2003. Modelling of the radiological impact of radioactive waste dumping in the Arctic Seas. IAEA-TECDOC-1330. Vienna: International Atomic Energy Agency, IAEA.

ICRP, 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21 (1-3).

Iosjpe M., 2006. Environmental Modelling: Modified Approach for Compartmental Models. In: Radionuclides in the Environment. Edd. P.P. Povinec, J.A. Sanchez-Cabeza. Radioactivity in the Environment, vol. 8, Series Editor: M.S. Baxter, 2006, 463-476.

Iosjpe M., O. Reistad, I.B. Amundsen, 2009. Radioecological consequences of a potential accident during transport of spent nuclear fuel along an Arctic coastline. Journal of Environmental Radioactivity 100 (2009) 184–191.

Iosjpe M., 2011. A sensitivity analysis of the parameters controlling water-sediment interactions in the coastal zone: Consequences to man and environment, Journal of Marine Systems 88 (2011), 82-89.

Iosjpe M., Brown J. & Strand P., 2002. Modified Approach for Box Modelling of Radiological Consequences from Releases into Marine Environment, Journal of Environmental Radioactivity, Vol. 60, No 1-2, 91-103.

Iosjpe M., Isaksson M., Joensen H.P., Jonsson G., Logemann K., Roos P., Suolanen V., Thomas R., 2016. Effects of dynamic behaviour of Nordic marine environment to radioecological assessments, 15 Febr 2016, ISBN: 978-87-7893-442-0, http://www.nks.org/en/nks_reports/view_document.htm?id=111010213400466

Iosjpe M., Isaksson M., Joensen H. P., Jónsson G., Suolanen V., 2022. Evaluation of the bioaccumulation processes for a wide set of radionuclides under accidental releases by biota (BIORAD). Nordic nuclear safety research, Norwegian Radiation and Nuclear Safety Authority (DSA), https://www.nks.org/en/nks_reports/view_document.htm?id=111010214698001

Iosjpe M. and Liland A., 2012. Evaluation of environmental sensitivity of the marine regions. Journal of Environmental Radioactivity 108 (2012) 2-8.

Iosjpe M., Perianez R, Aldridge J. & Børetzen P. (2003). Radionuclide dispersion models for Arctic, Atlantic and Mediterranean seas. Estimation of radiological sensitivity of marine areas. A deliverable report for REMOTRANS, Project FIGE-CT-2000-00085, December 2003.

Iosjpe M., Suolanen V., Isaksson M., Joensen H. P., Ilkov M, 2021. Preliminary choosing of the kinetic parameters based on available information, Norwegian Radiation and Nuclear Safety Authority (DSA).

Iosjpe M. 2014. Radioecological assessment of marine environment: complexity, sensitivity and uncertainties. International conference on radioecology and environmental radioactivity 7-12 September, Barcelona, Spain. Extended abstracts. Online publication O-026, https://intranet.pacifico-meetings.com/amsysweb/publicacionOnline.jsf?id=146

Karcher M.J. and Harms I.H., 2000. Estimation of water and ice fluxes in the Arctic for an improved box structure of the NRPA box model. In: Iosjpe M. (Ed.): Transport and fate of contaminants in the Northern Seas, NRPA, 2000.

Keum D.-K., Jin L., Kim B.-H., Lim K.-M., Choi Y.-H., 2015. A dynamic model to estimate the activity concentration and whole body dose rate of marine biota as consequences of a nuclear accident. Journal of Environmental Radioactivity, 140, 84-94.

Kull, I., Bergstroöm, A., Lilja, G., Pershagen, G., Wickman, M., 2006. Fish consumption during the first year of life and development of allergic diseases during childhood. Allergy 61 (8), 1009–1015.

Maderch V., Bezhenar R., Heling R., G. de With, Jung K.T., Myoung J.G., Cho Y.-K., Qiao F., Robertson L., 2013. Regional long-term model of radioactivity dispersion and fate in the Fukushima Dai-ichi accident. Journal of Environmental Radioactivity 2013, www.elsevier.com/locate/jenvrad.

Periánez R., Bezhenar R., Brovchenko I., Duffa C., Iosjpe M., Jung K.T., Kobayashi T., Lamego F., Maderich V., Min B.I., Nies H., Osvath I., Outola I., Psaltaki M., Suh K.S., G. de With, 2016. Modelling of marine radionuclide dispersion in IAEA MODARIA program: lessons learnt from the Baltic Sea and Fukushima scenarios. The science of the total environment, vol. 569-570, 594-602.

Periáñez, R., Brovchenko, I., Jung, K., Kim, K., & Maderich, V. (2018). The marine kd and water/sediment interaction problem. Journal of Environmental Radioactivity, 192, 635-647

PREPARE, 2015. Design document for POSEIDON model integration. Deliverable D 5.2, PREPARE(WP5)-(1)-01.

Reistad O., 2008. Analyzing Russian naval nuclear safety and security by measuring and modeling reactor and fuel inventory and accidental releases. Doctoral thesis at NTNU, 2008:14.

Thomann R.V., 1981. Equilibrium model of fate of microcontaminants in diverse aquatic food-chains. Canadian Journal of Fisheries and Aquatic Sciences 38:280-296.

UNSCEAR, 2008. United Nations Scientific Committee on the Effects of Atomic Energy. Sources and Effects of Ionizing Radiation. 2008 Report to the General Assembly, with Scientific Annexes. Volume I. New York: United Nations, 2010. Available from: http://www.unscear.org/docs/reports/2008/09-86753_Report_2008_GA_Report_corr2.pdf

Vives i Batlle J., Wilson R.C., Watts S.J., Jones S.R., McDonald P., Vives-Lynch S., 2008. Dynamic model for assessment of radiological exposure to marine biota. Journal of Environmental Radioactivity 99, 1711-1730.

de With G., R. Bezhenar, V. Maderich, Y. Yevdin, M. Iosjpe, K.T. Jung, F. Qiao, R. Perianez, 2021. Development of a dynamic food chain model for assessment of the radiological impact from radioactive releases to the aquatic environment. Journal of Environmental Radioactivity, Volume 233, 106615.

Yefimov E., 1994. Radionuclides composition, characteristics of shielding barriers and analysis of week points of the dumped reactors of nuclear submarine N 601, Working material of the International Arctic Seas assessment project IASAP, IAEA-IASAP-6, Vienna.

Appendix.

A1. The equilibrium/quasi-equilibrium concentration ratios

The concentration ratio are shown in Table A1, where AM is the arithmetic mean, GM is geometric mean, Min and Max are minimum and maximum values of the parameters**.**

Table A1. The concentration ratios.

Organism	**Radionuclide**	**AM**	**GM**	**Min**	**Max**	**References**
Phytoplanctoon	Ag	6.9E4	4.4E4	1.3E4	2.0E5	IAEA, 2014
		5.0E4				IAEA, 2004
	Am	2.1E5	1.1E5	7.0E3	6.9E5	IAEA, 2014
		2.0E5				IAEA, 2004
	Ba	8.0E2				IAEA, 2004
		1.9E2				Erica, 2019
	Ce	9.0E4				IAEA, 2004
		1.1E4	4.8E3	3.4E2	4.5E4	IAEA, 2014
	Cm	2.0E5				IAEA, 2004
		2.7E5	2.1E5	1.2E5	6.4E5	IAEA, 2014; Erica, 2019
	Co	3.1E3	1.8E3	1.0E2	1.24	IAEA, 2014; Erica, 2019; Brown et al., 2008
		2.0E3				IAEA, 2004
	Cs	8.5E0	3.6E0	1.0E0	7.3E1	IAEA, 2014
		2.0E1				IAEA, 2004
		1.3E2				Erica, 2019; Brown et al., 2008
	Eu	9.0E4				IAEA, 2004; ERICA, 2019; Brown et al., 2008
	I	8.0E2				IAEA, 2004
		9.5E2				IAEA, 2014
	Nb	1E3				IAEA, 2004
	Ni	5.7E2	3.5E2	1.6E2	1.4E3	IAEA, 2014
		3.0E3				IAEA, 2004
		1.4E3				ERICA, 2019; Brown et al., 2008
	Np	1.0E2				IAEA, 2004
		1.4E2	1.3E2	3.0E1	2.4E2	IAEA, 2014; Erica, 2019
	Pm	9.0E4				IAEA, 2004
	Pu	1.3E5	8.3E4	4.0E2	6.3E5	IAEA, 2014
		2.0E5				IAEA, 2004; ERICA, 2019; Brown et al., 2008
	Ru	2.0E5				IAEA, 2004

Table A1. The concentration ratios (continued).

		6.7E3	4,1E3	5.4E1	1.0E4	IAEA, 2014
	Sb	1.0E3				IAEA, 2004
	Sm	9.0E4				IAEA, 2004
	Sn	7.0E4				IAEA, 2004
	Sr	1.9E2	9.6E1	4.0E0	1.6E3	IAEA, 2014
		1.0E0				IAEA, 2004
		2.1E2				ERICA, 2019; Brown et al., 2008
	Te	1.0E3				IAEA, 2004
		1.3E4	8.4E3	1.0E3	4.5E4	IAEA, 2014
	Th	4.0E5				IAEA, 2004
		7.3E5	5.1E5	7.5E3	2.0E6	IAEA, 2014
	U	2.0E1				IAEA, 2004
		2.2E2	1.5E2	1.0E1	6.0E2	IAEA, 2014; Erica, 2019
	Y	1.0E2				IAEA, 2004
	Zr	6.0E4				IAEA, 2004
		3.3E4	1.7E4	1.1E4	5.5E4	IAEA, 2014
Macroalgae	Ag	3.0E3	2.1E3	2.0E2	1.5E4	IAEA, 2014
		5.0E3				IAEA, 2004
	Am	4.3E2	2.1E2	3.9E1	3.8E3	IAEA, 2014
		8.0E3				IAEA, 2004
	Ba	7.0E1				IAEA, 2004
		2.9E1				Erica, 2019
	Ce	5.0E3				IAEA, 2004
		2.1E3	1.2E3	1.4E1	1.1E4	IAEA, 2014
	Cm	5.0E3				IAEA, 2004
		1.2E4	8.2E3	1.3E3	5.2E4	IAEA, 2014; Erica, 2019
	Co	1.7E3	7.8E2	9.0E0	1.4E4	IAEA, 2014
		6.0E3				IAEA, 2004
		2.1E3				ERICA, 2019; Brown et al., 2008
	Cs	9.6E1	2.4E1	3.7E0	4.8E3	IAEA, 2014
		5.0E1				IAEA, 2004; ERICA, 2019; Brown et al., 2008

Table A1. The concentration ratios (continued).

Organism	Radionuclide	AM	GM	Min	Max	References
Macroalgae	Eu	1.4E3	1.1E3	3.0E2	2.6E3	IAEA, 2014 ERICA, 2019; Brown et al., 2008;
		3.0E3				IAEA, 2004
	I	4.2E3	1.4E3	1.6E2	8.5E4	IAEA,2014
		1.0E4				IAEA, 2004
	Nb	3.0E3				IAEA, 2004
		5.6E2	3.2E2	2.0E1	1.7E3	IAEA, 2014
	Ni	9.5E2	6.9E2	2.5E2	2.8E3	IAEA, 2014
		2.0E3				IAEA, 2004
		7.9E2				ERICA, 2019; Brown et al., 2008
	Np	5.0E1				IAEA, 2004
		5.2E1	4.8E1	1.5E1	6.6E1	IAEA, 2014; Erica, 2019
	Pm	3.0E3				IAEA, 2004
	Pu	4.1E3	1.7E3	8.5E1	4.9E4	IAEA, 2014; ERICA, 2019; Brown et al., 2008
		4.0E3				IAEA, 2004
	Ru	2.0E3				IAEA, 2004
		1.2E3	8.8E2	1.5E2	3.9E3	IAEA, 2014
	Sb	2.1E1				IAEA, 2004
		2.2E2	9.4E1	5.0E1	3.0E3	IAEA, 2014
	Sm	3.0E3				IAEA, 2004
	Sn	2.0E5				IAEA, 2004
	Sr	2.9E1	1.4E1	2.0E-1	3.3E2	IAEA, 2014
		1.0E1				IAEA, 2004
		4.2E1				ERICA, 2019; Brown et al., 2008
	Te	1.0E4				IAEA, 2004
		4.25E2				ERICA, 2019
	Th	2.0E2				IAEA, 2004
		4.6E3	2.4E3	2.3E2	2.0E4	IAEA, 2014
	U	1.0E2				
		8.3E1	5.4E1	2.1E1	5.1E2	IAEA, 2014; Erica, 2019
	Y	1.0E3				IAEA, 2004
	Zr	3.0E3				IAEA, 2004
		1.7E3	9.3E2	2.3E1	1.0E4	IAEA, 2014
Zooplanctoon	Ag	6.0E3	3.2E3	4.7E2	1.7E4	IAEA, 2014
		2.0E4				IAEA, 2004
	Am	4.0E3				IAEA, 2004

Table A1. The concentration ratios (continued).						
	Ba	8.0E1				IAEA, 2004
		6.8E1				Erica, 2019
	Ce	6.0E3				IAEA, 2004
	Cm	4.0E3				IAEA, 2004
		6.3E3				Erica, 2019
	Co	4.8E3	2.9E3	2.0E2	2.6E4	IAEA, 2014; ERICA, 2019; Brown et al., 2008
		7.0E3				IAEA, 2004
	Cs	1.3E2	6.7E1	2.9E0	9.9E2	IAEA, 2014
		4.0E1				IAEA, 2004
		1.1E2				ERICA, 2019; Brown et al., 2008
	Eu	4.0E3				IAEA, 2004; ERICA, 2019; Brown et al., 2008
	I	3.1E3				IAEA, 2004, IAEA, 2014
	Nb	2.0E4				IAEA, 2004
	Ni	5.0E2				IAEA, 2014
		1.0E3				IAEA, 2004; ERICA, 2019; Brown et al., 2008
	Np	4.0E2				IAEA, 2004
		1.7E1				IAEA, 2014; Erica, 2019
	Pm	4.0E3				IAEA, 2004
	Pu	7.8E3	4.5E3	2.0E3	2.8E4	IAEA, 2014; ERICA, 2019; Brown et al., 2008
		4.0E3				IAEA, 2004
	Ru	2.0E3				IAEA, 2004
	Sb	8.0E1				IAEA, 2004
		1.3E3	6.1E2	1.3E1	8.7E3	IAEA, 2014
	Sm	4.0E3				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	6.8E1	4.8E1	1.1E1	1.5E2	IAEA, 2014
		2.0E0				IAEA, 2004
		4.6E0				ERICA, 2019; Brown et al., 2008
	Te	1.0E3				IAEA, 2004
	Th	1.0E4				IAEA, 2004
	U	7.2E3 3.0E1	5.0E3	2.0E2	1.5E4	IAEA, 2014 IAEA, 2004

Table A1. The concentration ratios (continued).

		3.7	2.3	1.7E-1	5.5	IAEA, 2014; Erica, 2019
	Y	1.0E2				IAEA, 2004
	Zr	2.0E4				IAEA, 2004
		2.2E4	1.4E4	2.0E4	2.5E4	IAEA, 2014
		1.1E4	8.1E3	7.2E2	2.4E4	IAEA, 2014
		1.0E4				IAEA, 2004
	Am	4.0E1				Iosjpe et al., 2022
		1.0E2				IAEA, 2004
	Ba	1.0E1				IAEA, 2004
		2.5E1				ERICA, 2019
	Ce	5.0E1				IAEA, 2004
		3.9E2	2.1E2	2.1E1	1.1E3	IAEA, 2014
	Cm	1.0E2				IAEA, 2004
		1.4E3				Erica, 2019
	Co	1.1E3	3.8E2	3.5E1	1.0E4	IAEA, 2014
		7.0E2				IAEA. 2004
		3.0E2				Iosjpe et al., 2022
		5.6E3				ERICA, 2019; Brown et al., 2008
	Cs	1.2E2	6.8E1	1.2E1	1.0E3	IAEA, 2014
		8.6E1				ERICA, 2019; Brown et al., 2008
		1.0E2				IAEA. 2004
		3.0E2				Iosjpe et al., 2022
	Eu	7.3E2				IAEA, 2014
		3.0E2				IAEA, 2004
		4.4E2				ERICA, 2019; Brown et al., 2008
		2.50E1				Iosjpe et al., 2022; Suolanen, 2021
	I	9.0				IAEA, 2004
	Nb	3.0E1				IAEA, 2004
	Ni	2.5E2	2.0E2	5.5E1	6.7E2	IAEA, 2014
		1.0E2				Iosjpe et al., 2022
		1.7E2				ERICA, 2019; Brown et al., 2008
		1.0E3				IAEA, 2004
	Np	1.0				IAEA, 2004
		8.8				Erica, 2019
	Pm	3.0E2				IAEA, 2004
	Pu	6.9E2	3.4E2	2.0E2	4.8E3	IAEA, 2014
		3.5E3				ERICA, 2019; Brown et al., 2008
		1.0E2				IAEA, 2004

Table A1. The concentration ratios (continued).						
		4.0E1				Iosjpe et al., 2022
	Ru	2.9E1	1.6E1	5.5	1.0E2	IAEA, 2014
		2				IAEA, 2004
	Sb	6.0E2				IAEA, 2004
	Sm	3.0E2				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	4.4E1	3.3E1	1.5E-1	1.4E2	IAEA, 2014
		3.0E0				IAEA, 2004
		2.3E1				ERICA, 2019; Brown et al., 2008
		2.0E1				Iosjpe et al., 2022
	Te	1.0E3				IAEA, 2004
		6.0E2				ERICA, 2019
	Th	6.0E2				IAEA, 2004
		1.0E3				IAEA, 2014
	U	1.0				IAEA, 2004
	U	8.8	7.3	2.0	1.8E1	IAEA, 2014; Erica, 2019
	Y	2.0E1				IAEA, 2004
	Zr	2.0E1				IAEA, 2004
		8.5E1	6.6E1	3.7E1	2.0E2	IAEA, 2014
Piscivorouss fish / Pelagic large fish	Ag	1.1E4	8.1E3	7.2E2	2.4E4	IAEA, 2014
		1.0E4				IAEA, 2004
	Am	1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022; Suolanen, 2021
	Ba	1.0E1				IAEA, 2004
		2.5E1				ERICA, 2019
	Ce	5.0E1				IAEA, 2004
		3.9E2	2.1E2	2.1E1	1.1E3	IAEA, 2014
	Cm	1.0E2				IAEA, 2004
		1.4E3				Erica, 2019
	Co	1.1E4	5.0E3	28	7.8E4	IAEA, 2014
		7.0E2				IAEA. 2004
		3.0E2				Iosjpe et al., 2022
		5.6E3				ERICA, 2019; Brown et al., 2008
	Cs	7.9E1	5.9E1	7.4E0	3.6E2	IAEA, 2014
		1.0E2				IAEA. 2004
		8.6E1				ERICA, 2019; Brown et al., 2008
		3.0E2				Iosjpe et al., 2022

Table A1. The concentration ratios (continued).

	Eu	4.4E2				ERICA, 2019; Brown et al., 2008
		3.0E2				IAEA, 2004
		2.50E1				Iosjpe et al., 2022
	I	9.0				IAEA, 2004
	Nb	3.0E1				IAEA, 2004
	Ni	1.7E2				ERICA, 2019; Brown et al., 2008
		2.5E2	2.0E2	5.5E1	6.7E2	IAEA, 2014
		1.0E3				IAEA, 2004
		1.0E2				Iosjpe et al., 2022
	Np	1.0				IAEA, 2004
		8.8				Erica, 2019
	Pm	3.0E2				IAEA, 2004
	Pu	3.5E3				ERICA, 2019; Brown et al., 2008
		1.9E2	1.4E2	1.0E0	5.5E2	IAEA, 2014
		1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022
	Ru	2.9E1	1.6E1	5.5	1.0E2	IAEA, 2014
		2				IAEA, 2004
	Sb	6.0E2				IAEA, 2004
	Sm	3.0E2				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	3.8E1	2.0E1	2.0E-1	1.9E2	IAEA, 2014
		3.0E0				IAEA, 2004
		2.3E1				ERICA, 2019; Brown et al., 2008
		2.0E1				Iosjpe et al., 2022
	Te	1.0E3				IAEA, 2004
		6.0E2				ERICA, 2019
	Th	6.0E2				IAEA, 2004
		1.0E3				IAEA, 2014
	U	1.0				IAEA, 2004
		8.8	7.3	2.0	1.8E1	IAEA, 2014; ERICA, 2019
	Y	2.0E1				IAEA, 2004
	Zr	2.0E1				IAEA, 2004
		8.5E1	6.6E1	3.7E1	2.0E2	IAEA, 2014

Table A1. The concentration ratios (continued).

Deposit-feeding invertebrate	Ag	2.7E4				IAEA, 2014
	Am	4.5E1	3.3E1	6	120	IAEA, 2014
	Ba	4.6E-1				ERICA, 2019
	Ce	2.2E3				ERICA, 2019
	Cm	4.5E1				ERICA, 2019
	Co	8.3E3	5.3E3	1.0E3	2.0E4	IAEA, 2014
	Cs	1.8E2	1.3E2	1.0E1	5.1E2	IAEA, 2014
	Nb	8.8E2				ERICA, 2019
	Ni	4.2E3				IAEA, 2014
	Np	9.9E2				ERICA, 2019
	Pu	1.5E3	8.4E2	1.0E2	4.1E3	IAEA, 2014
	Ru	2.9E1		1.3E1	4.4E1	IAEA, 2014
	Sb	4.5E3				ERICA, 2019
	Sr	4.6E-1				IAEA, 2014
	Te	4.5E3				ERICA, 2019
	U	9.9E2	9.1E2	4.2E2	1.8E3	IAEA, 2014; ERICA, 2019
	Zr	3.3E3				ERICA, 2019
Mollusk	Ag	3.6E4	1.6E4	3.3E2	1.0E5	IAEA, 2014
		6.0E4				IAEA, 2004
	Am	9.9E3	6.7E3	2E2	2E4	IAEA, 2014
		1.0E3				IAEA, 2004
	Ba	1.0E1				IAEA, 2004
		1.5E2				ERICA, 2019
	Ce	2.0E3				IAEA, 2004
		2.2E3	1.1E3	6.0E1	1.0E4	IAEA, 2014
	Cm	1.0E3				IAEA, 2004
		3.2E4	2.4E4	1.2E4	5.7E4	IAEA, 2014; ERICA, 2019
	Co	5.3E3	1.7E3	1.7E2	4.1E4	IAEA, 2014
		2.0E4				IAEA, 2004
		5.1E3				ERICA, 2019; Brown et al., 2008
Mollusk	Cs	5.0E1	3.5E1	2.0E0	2.1E2	IAEA, 2014
		6.0E1				IAEA, 2004
		6.6E1				ERICA, 2019; Brown et al., 2008
	Eu	6.9E3				IAEA, 2014; ERICA, 2019; Brown et al., 2008
		7.0E3				IAEA, 2004
	I	8.8E3	3.8E3	1.4E1	5.0E4	IAEA, 2014
		1.0E1				IAEA, 2004
	Nb	8.8E2				IAEA, 2014

Table A1. The concentration ratios (continued).						
		1.0E3				IAEA, 2004
	Ni	6.4E3	2.8E3	5.5E1	2.1E4	IAEA, 2014; ERICA, 2019; Brown et al., 2008
		2.0E3				IAEA, 2004
	Np	4.0E2				IAEA, 2004
		3.8E2	2.7E2	1.1E1	8.9E2	IAEA, 2014; ERICA, 2019
	Pm	7.0E3				IAEA, 2004
	Pu	1.1E3	6.6E2	1.8E0	9.2E3	IAEA, 2014; ERICA, 2019; Brown et al., 2008
		3.0E3				IAEA, 2004
	Ru	1.6E3	1.3E3	1.0E3	2.2E3	IAEA, 2014
		5.0E2				IAEA, 2004
	Sb	3.0E2				IAEA, 2004
	Sm	7.0E3				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	1.5E2	1.1E2	1.0E-1	5.0E2	IAEA, 2014
		1.0E1				IAEA, 2004
		1.2E2				ERICA, 2019; Brown et al., 2008
	Te	1.0E3				IAEA, 2004
		1.5E3				ERICA, 2019
	Th	1.0E3				IAEA, 2004
		1.7E3	9.0E2	9.0E1	6.3E3	IAEA, 2014
	U	3.0E1				IAEA, 2004
		3.2E1	2.4E1	4.0	9.7E1	IAEA, 2014; ERICA, 2019
	Y	1.0E3				IAEA, 2004
	Zr	5.0E3				IAEA, 2004
		3.3E3	1.3E3	4.4E1	2.0E4	IAEA, 2014
Crustacean	Ag	2.0E5				IAEA, 2004
		3.6E4				ERICA, 2019
	Am	5.0E2				IAEA, 2014
		4.0E2				IAEA, 2004
	Ba	0.7				IAEA, 2004
		4.95E1				ERICA, 2019
	Ce	1.0E3				IAEA, 2004
		1.0E2				IAEA, 2014
	Cm	4.0E2				IAEA, 2004
		5.0E2				ERICA, 2019
	Co	3.5E3	1.7E3	2.2E2	2.2E4	IAEA, 2014
		7.0E3				IAEA, 2004

Table A1. The concentration ratios (continued).

	Co-60	1.8E3				ERICA, 2019; Brown et al., 2008
	Cs	5.0E1				IAEA, 2004
		5.3E1	2.1E1	5.5E-1	1.3E3	IAEA, 2014
		4.1E1				ERICA, 2019; Brown et al., 2008
	Eu	4.0E3				IAEA, 2004; ERICA, 2019; Brown et al., 2008
	I	3.0				IAEA, 2004
		3.9E1				ERICA, 2019
	Nb	1.0E2				IAEA, 2014
		2.0E2				IAEA, 2004
	Ni	1.0E3				IAEA, 2004
		5.5E2				ERICA, 2019; Brown et al., 2008
	Np	1.0E2				IAEA, 2004
		1.1E2				IAEA, 2014; ERICA, 2019
	Pm	4.0E3				IAEA, 2004
	Pu	1.2E2	9.7E1	3.8E1	2.7E2	IAEA, 2014
		2.0E2				IAEA, 2004
		1.6E2				ERICA, 2019; Brown et al., 2008
	Ru	5.0E2				IAEA, 2004
		1.6E3				ERICA, 2019
	Sb	3.0E2				IAEA, 2004
	Sm	4.0E3				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	4.9E1	2.7E1	1.5E-1	2.3E2	IAEA, 2014
		5.0E0				IAEA, 2004
		1.3E1				ERICA, 2019; Brown et al., 2008
	Te	1.0E3				IAEA, 2004
	Th	1.0E3				IAEA, 2004
		3.8E4				ERICA, 2019
	U	1.0E1				IAEA, 2004
		3.6				ERICA, 2019
	Y	1.0E3				IAEA, 2004
	Zr	2.0E2				IAEA, 2004
		4.9E1				IAEA, 2014
	Ag	1.1E4	8.1E3	7.2E2	2.4E4	IAEA, 2014
		1.0E4				IAEA, 2004
	Am	3.2E2	1.9E2	1.7E1	1.5E3	IAEA, 2014
		1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022
	Ba	1.0E1				IAEA, 2004
		2.5E1				ERICA, 2019
	Ce	5.0E1				IAEA, 2004

Table A1. The concentration ratios (continued).						
		3.9E2	2.1E2	2.1E1	1.1E3	IAEA, 2014
	Cm	1.0E2				IAEA, 2004
	Co	4.8E2	2.8E2	5.3E1	3.3E3	IAEA, 2014
		7.0E2				IAEA. 2004
		3.0E2				Iosjpe et al., 2022
	Co	5.6E3				ERICA, 2019; Brown et al., 2008
	Cs	1.0E2				IAEA. 2004
		7.1E1	3.1E1	5.0E0	1.8E3	IAEA, 2014
		3.0E2				Iosjpe et al., 2022
		8.6E1				ERICA, 2019; Brown et al., 2008
	Eu	3.0E2				IAEA, 2004
		2.50E1				Iosjpe et al., 2022
		4.4E2				ERICA, 2019; Brown et al., 2008
	I	9.0				IAEA, 2004
	Nb	3.0E1				IAEA, 2004
	Ni	2.5E2	2.0E2	5.5E1	6.7E2	IAEA, 2014
		1.0E3				IAEA, 2004
		1.0E2				Iosjpe et al., 2022
		1.7E2				ERICA, 2019; Brown et al., 2008
	Np	1.0				IAEA, 2004
	Pm	3.0E2				IAEA, 2004
	Pu	2.5E3	7.3E2	2.0E0	2.7E4	IAEA, 2014
		1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022
		3.5E3				ERICA, 2019; Brown et al., 2008
	Ru	2.9E1	1.6E1	5.5	1.0E2	IAEA, 2014
		2				IAEA, 2004
	Sb	6.0E2				IAEA, 2004
	Sm	3.0E2				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
Demersal fish	Sr	1.1E1	7.4E0	3.0E0	6.0E1	IAEA, 2014
		3.0E0				IAEA, 2004
		2.0E1				Iosjpe et al., 2022
		2.3E1				ERICA, 2019; Brown et al., 2008
	Te	1.0E3				IAEA, 2004
		6.9E2				ERICA, 2019
	Th	6.0E2				IAEA, 2004
		1.0E3				IAEA, 2014
	U	1.0				IAEA, 2004
		8.8	7.3	2.0	1.8E1	IAEA, 2014
	Y	2.0E1				IAEA, 2004

Table A1. The concentration ratios (continued).						
	Zr	2.0E1				IAEA, 2004
		8.5E1	6.6E1	3.7E1	2.0E2	IAEA, 2014
Bottom predator	Ag	1.1E4	8.1E3	7.2E2	2.4E4	IAEA, 2014
		1.0E4				IAEA, 2004
	Am	3.2E2	1.9E2	1.7E1	1.5E3	IAEA, 2014
		1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022
	Ba	1.0E1				IAEA, 2004
		2.5E1				ERICA, 2019
	Ce	5.0E1				IAEA, 2004
		3.9E2	2.1E2	2.1E1	1.1E3	IAEA, 2014
	Cm	1.0E2				IAEA, 2004
	Co	5.3E3	1.8E3	2.8E1	7.8E4	IAEA, 2014
		7.0E2				IAEA. 2004
		5.6E3				ERICA, 2019; Brown et al., 2008
		3.0E2				Iosjpe et al., 2022
	Cs	8.4E1	4.8E1	5.0E0	1.8E3	IAEA, 2014
		1.0E2				IAEA. 2004
		8.6E1				ERICA, 2019; Brown et al., 2008
		3.0E2				Iosjpe et al., 2022
	Eu	3.0E2				IAEA, 2004
		2.50E1				Iosjpe et al., 2022
		4.4E2				ERICA, 2019; Brown et al., 2008
	I	9.0				IAEA, 2004
	Nb	3.0E1				IAEA, 2004
	Ni	2.5E2	2.0E2	5.5E1	6.7E2	IAEA, 2014
		1.0E3				IAEA, 2004
		1.7E2				ERICA, 2019; Brown et al., 2008
		1.0E2				Iosjpe et al., 2022
	Np	1.0				IAEA, 2004
	Pm	3.0E2				IAEA, 2004
	Pu	1.5E3	3.6E2	1.0E0	4.5E4	IAEA, 2014
		3.5E3				ERICA, 2019; Brown et al., 2008
	Pu	1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022
	Ru	2.9E1	1.6E1	5.5	1.0E2	IAEA, 2014
		2				IAEA, 2004
	Sb	6.0E2				IAEA, 2004
	Sm	3.0E2				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	2.5E1	1.4E1	1.5E-1	1.9E2	IAEA, 2014
		3.0E0				IAEA, 2004

Table A1. The concentration ratios (continued).						
		2.0E1				Iosjpe et al., 2022
	Te	1.0E3				IAEA, 2004
		6.9E2				ERICA, 2019
	Th	6.0E2				IAEA, 2004
		1.0E3				IAEA, 2014
	U	8.8	7.3	2.0	1.8E1	IAEA, 2014
	Y	2.0E1				IAEA, 2004
	Zr	2.0E1				IAEA, 2004
		8.5E1	6.6E1	3.7E1	2.0E2	IAEA, 2014
Coastal predator	Ag	1.1E4	8.1E3	7.2E2	2.4E4	IAEA, 2014
		1.0E4				IAEA, 2004
	Am	3.2E2	1.9E2	1.7E1	1.5E3	IAEA, 2014
		1.0E2				IAEA, 2004
		4.0E1				Iosjpe et al., 2022; Suolanen, 2021
	Ba	1.0E1				IAEA, 2004
		2.5E1				ERICA, 2019
	Ce	5.0E1				IAEA, 2004
		3.9E2	2.1E2	2.1E1	1.1E3	IAEA, 2014
	Cm	1.0E2				IAEA, 2004
	Co	5.3E3	1.8E3	2.8E1	7.8E4	IAEA, 2014
		7.0E2				IAEA. 2004
		5.6E3				ERICA, 2019; Brown et al., 2008
		3.0E2				Iosjpe et al., 2022
	Cs	8.4E1	4.8E1	5.0E0	1.8E3	IAEA, 2014
		1.0E2				IAEA. 2004
		3.0E2				Iosjpe et al., 2022
		8.6E1				ERICA, 2019; Brown et al., 2008
	Eu	3.0E2				IAEA, 2004
		4.4E2				ERICA, 2019; Brown et al., 2008
		2.50E1				Iosjpe et al., 2022; Suolanen, 2021
	I	9.0				IAEA, 2004
	Nb	3.0E1				IAEA, 2004
	Ni	2.5E2	2.0E2	5.5E1	6.7E2	IAEA, 2014
		1.7E2				ERICA, 2019; Brown et al., 2008
		1.0E3				IAEA, 2004
		1.0E2				Iosjpe et al., 2022; Suolanen, 2021
	Np	1.0				IAEA, 2004
	Pm	3.0E2				IAEA, 2004
	Pu	1.5E3	3.6E2	1.0E0	4.5E4	IAEA, 2014

Table A1. The concentration ratios (continued).						
	Pu	1.0E2				IAEA, 2004
		3.5E3				ERICA, 2019; Brown et al., 2008
		4.0E1				Iosjpe et al., 2022
	Ru	2.9E1	1.6E1	5.5	1.0E2	IAEA, 2014
		2				IAEA, 2004
	Sb	6.0E2				IAEA, 2004
	Sm	3.0E2				IAEA, 2004
	Sn	5.0E5				IAEA, 2004
	Sr	2.5E1	1.4E1	1.5E-1	1.9E2	IAEA, 2014
		3.0E0				IAEA, 2004
		2.3E1				ERICA, 2019; Brown et al., 2008
		2.0E1				Iosjpe et al., 2022
	Te	1.0E3				IAEA, 2004
		6.9E2				ERICA, 2019
	Th	6.0E2				IAEA, 2004
		1.0E3				IAEA, 2014
	U	1.0				IAEA, 2004
		8.8	7.3	2.0	1.8E1	IAEA, 2014
	Y	2.0E1				IAEA, 2004
	Zr	2.0E1				IAEA, 2004
		8.5E1	6.6E1	3.7E1	2.0E2	IAEA, 2014
Seal /mammals	Ag	2.2E4	1.6E4			IAEA, 2014
		7.0E4				IAEA, 2004
	Am	1.35E3				ERICA, 2019
	Ba	1.6E2				ERICA, 2019
	Ce	2.2E3				ERICA, 2019
	Co	5.0E2	1.7E2			IAEA, 2014; ERICA, 2019; Brown et al., 2008
	Cm	1.35E3				ERICA, 2019
	Cs	2.1E2				ERICA, 2019; Brown et al., 2008
		2.2E2	8.4E1	8.7E0	8.2E2	IAEA, 2014
(muscle)		4.0E2		3.1E1	1.0E3	IAEA, 2004
(liver)		3.0E2				IAEA, 2004
	Eu	4.4E2				ERICA, 2019; Brown et al., 2008
	I	6.8E-1	6.4E-1			IAEA, 2014
	Nb	8.8E2				ERICA, 2019
(liver)	Ni	1.7E2				ERICA, 2019; Brown et al., 2008
	Np	8.8				ERICA, 2019
	Pu	1.1E3	9.2E2	1.0E2	4.0E3	IAEA, 2014
		1.35E3				ERICA, 2019; Brown et al., 2008

Table A1. The concentration ratios (**continued**).

	Ru	1.6E3				ERICA, 2019
	Sb	8.3E3				ERICA, 2019
	Sr	1.4E0				ERICA, 2019; Brown et al., 2008
		1.6E2	6.8E1	1.4E0	1.0E3	IAEA, 2014
	Te	8.3E3				ERICA, 2019
	Th	1.7E3				ERICA, 2019
	U	8.8				ERICA, 2019
	Zr	8.5E1				ERICA, 2019
Sea Bird	Am	4.1E2				ERICA, 2019
	Ba	1.6E2				ERICA, 2019
	Ce	2.2E3				ERICA, 2019
	Co	5.0E2				ERICA, 2019; Brown et al., 2008
	Cm	4.1E2				ERICA, 2019
	Cs	4.8E2	2.9E2	5.0E1	3.5E3	IAEA, 2014
		4.4E2				ERICA, 2019; Brown et al., 2008
	Eu	4.4E2				ERICA, 2019; Brown et al., 2008
	I	6.8E-1				ERICA, 2019
	Nb	8.8E2				ERICA, 2019
	Ni	1.7E2				ERICA, 2019; Brown et al., 2008
	Np	8.8				ERICA, 2019
	Pu	1.5E2				ERICA, 2019; Brown et al., 2008
	Ru	1.6E3				ERICA, 2019
	Sb	8.3E3				ERICA, 2019
	Sr	1.4E0				ERICA, 2019; Brown et al., 2008
	Te	8.3E3				ERICA, 2019
	Th	1.7E3				ERICA, 2019
	U	8.8				ERICA, 2019
	Zr	8.5E1				ERICA, 2019

A2. Kinetic parameters of the model for bioaccumulation of radionuclides in biota. Parameteres in Tables A2-A6 are described in equation (9-10). The symbol "*" in tables A2-A6 corresponds to the parameters obtained in this study or selected from existing databases.

Table A2. Ingestion rates, (kg/d)/kg f.w.

Organism	IR	References
Zooplankton	0.105*	Thomann, 1981; Iosjpe et al., 2022; the Iosjpe et al, 2022; present report
	1	de With et al., 2021
Non-piscivorous fish / Pelagic small fish	0.017*	Thomann, 1981; the Iosjpe et al, 2022; present report
	0.03	Keum et al., 2015
	0.03	de With et al., 2021; PREPARE, 2015
Piscivorouss fish / Pelagic large fish	0.009*	Thomann, 1981; Hosseini et al., 2017; the Iosjpe et al, 2022; present report
	0.0055	PREPARE, 2015
	0.007	de With et al., 2021
	0.03	Keum et al., 2015
Deposit-feeding invertebrate	0.02	de With et al., 2021; the Iosjpe et al, 2022; present report
Mollusk	0.06*	de With et al., 2021; PREPARE, 2015; the Iosjpe et al, 2022; present report
	0.064	Keum et al., 2015
	0,2	Hosseini et al., 2017
Crustacean	0.015*	de With et al., 2021; PREPARE, 2015; the Iosjpe et al, 2022; present report
	0,027	Keum et al., 2015; Hosseini et al., 2017
Demersal fish	0.007*	de With et al., 2021; the Iosjpe et al, 2022; present report
	0.03	Keum et al., 2015
Bottom predator	0.03	Keum et al., 2015
	0.007*	de With et al., 2021; the Iosjpe et al, 2022; present report
Coastal predator	0.007	de With et al., 2021; the Iosjpe et al, 2022; present report
	0.03	Keum et al., 2015
Seal	0.072*	Hosseini et al., 2017; the Iosjpe et al, 2022; present report
Sea Bird	0.28*	Hosseini et al., 2017; the Iosjpe et al, 2022; present report

Table A3. Consumption for species with food preferences.

Species	w	Consumption	References
Zooplankton	1*	Phytoplanctoon	Thomann, 1981; de With et al., 2021; the Iosjpe et al, 2022; present report
Non-piscivorous fish / Pelagic small fish	1*	Zooplanctoon	Thomann, 1981; de With et al., 2021; the Iosjpe et al, 2022; present report
Piscivorouss fish / Pelagic large fish	1*	Non-piscivorous fish / Pelagic small fish	Thomann, 1981; de With et al., 2021; the Iosjpe et al, 2022; present report
Deposit-feeding invertebrate	0.5	Bottom deposit (organic matter)	de With et al., 2021
	0.5	Macroalgae	
Mollusk	0.8*	Phytoplankton	PREPARE, 2015; the Iosjpe et al, 2022; present report
	0.2*	Zooplankton	
	0.6	Phytoplankton	de With et al., 2021
	0.2	Zooplankton	
	0.2	Macroalgae	
Crustacean	0.2*	Phytoplankton	PREPARE, 2015; the Iosjpe et al, 2022; present report
	0.8*	Zooplankton	
	0.1	Phytoplankton	de With et al., 2021
	0.8	Zooplankton	
	0.1	Macroalgae	
Demersal fish	0.1*	Bottom deposit (organic matter)	de With et al., 2021; the Iosjpe et al, 2022; present report
	0.7*	Deposit-feeding invertebrate	
	0.1*	Mollusk	
	0.1*	Crustacean	
Bottom predator	0.3*	Deposit-feeding invertebrate	de With et al., 2021; the Iosjpe et al, 2022; present report
	0.2*	Mollusk	
	0.2*	Crustacean	
	0.3*	Demersal fish	
Coastal predator	0.2*	Non-piscivorous fish	de With et al., 2021; the Iosjpe et al, 2022; present report
	0.25*	Deposit-feeding invertebrate	
	0.1*	Mollusk	
	0.2*	Crustacean	

Table A3. Consumption for species with food preferences. (continued).			
	0.25*	Demersal fish	
Seal	1*	Piscivorouss fish / Pelagic large fish	Hosseini et al., 2016; the Iosjpe et al, 2022; present report
Sea Bird	1*	Piscivorouss fish / Pelagic large fish	Hosseini et al., 2016; the Iosjpe et al, 2022; present report

Table A4. Assimilation efficiency rates.

Organism	Radionuclide	AE	References
Zooplankton	Cs-137; Cs-134; Co-60	0.5*	Thomann, 1981; Iosjpe et al, 2022; present report
		0.2	PREPARE, 2015
	Ni-59; Ni-63	0.2*	Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.05*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241	0.01	Thomann, 1981
	Am-241	0.02*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.02*	The present report
	General approach that has been applied to **Sr-90**, **I-131**, Cs-134, and Cs-137	0.2*	PREPARE, 2015; de With et al., 2021; Iosjpe et al, 2022; present approach
Non-piscivorous fish/Pelagic small fish	Cs-137; Cs-134; Co-60; Ni-59; Ni-63	0.5*	Thomann, 1981; Brown et al., 2004; PREPARE, 2015; Hosseini et al., 2017; Iosjpe et al, 2022; present report;
		0.64	Keum et al., 2015
	Eu-152; Eu-154; Eu-155	0.5*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242		The present report
	Sr-90	0.64	Keum et al., 2015
	Sr-90	0.3*	Vives i Batlle et al., 2016; Brown et al., 2004; Iosjpe et al, 2022; present report
Non-piscivorous fish/Pelagic small fish	General approach that has been applied to Sr-90, **I-131**, Cs-134, and Cs-137	0.5*	PREPARE, 2015; de With et al., 2021; the present approach
Piscivorouss fish/ Pelagic large fish	Cs-137; Cs-134	0.5*	Thomann, 1981; Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
		0.64	Keum et al., 2015
	Eu-152; Eu-154; Eu-155; Co-60; Ni-59; Ni-63	0.7*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.1*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.1*	The present report
	Sr-90	0.64	Keum et al., 2015
	Sr-90	0.3*	Vives i Batlle et al., 2016; Brown et al., 2004; Iosjpe et al, 2022; present report

Table A4. Assimilation efficiency rates (continued).			
	General approach that has been applied to Sr-90, **I-131**, Cs-134, and Cs-137	0.7*	PREPARE, 2015; de With et al., 202; the present approach1
Deposit-feeding invertebrate	General approach that has been applied to **Sr-90**, **I-131**, **Cs-134, Cs-137, Co-60; Ni-59; Ni-63**	0.3*	de With et al., 2021; Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.1*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.01*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.01*	The present report
Mollusk	Cs-137; Cs-134; Ni-59; Ni-63	0.5*	Vives i Batlle et al., 2016; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.1*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241; Cm-244, Cm-242	0.01*	Iosjpe et al, 2022; present report
	Sr-90	0.28	Vives i Batlle et al., 2016; Keum et al., 2015
	General approach that has been applied to **Sr-90**, **I-131**, Cs-134, and Cs-137; Co-60	0.5*	de With et al., 2021; PREPARE, 2015; Iosjpe et al, 2022; present report
Crustacean	Cs-137; Cs-134; Co-60; Ni-59; Ni-63	0.5*	Vives i Batlle et al., 2016; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.1*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.01*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.01*	The present report
	Sr-90	0.28	Vives i Batlle et al., 2016; Keum et al., 2015
	General approach that has been applied to **Sr-90**, **I-131**, Cs-134, and Cs-137	0.5*	de With et al., 2021; PREPARE, 2015; Iosjpe et al, 2022; present report
Demersal fish	Cs-137; Cs-137; Eu-152, Eu-154, Eu-155; Co-60; Ni-59; Ni-63	0.5*	Brown et al., 2004; de With et al., 2021; Hosseini et al., 2017 Iosjpe et al, 2022; present report;
		0.64	Keum et al., 2015
	Pu-238; Pu-239; Pu-240	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.05*	The present report
	General approach that has been applied to Sr-90, I-131, Cs-134, and Cs-137	0.5	de With et al., 2021; PREPARE, 2015

Table A4. Assimilation efficiency rates (continued).			
	Sr-90	0.64	Vives i Batlle et al., 2016; Keum et al., 2015
	Sr-90, I-131	0.3*	Iosjpe et al, 2022; present report
Bottom predator	Cs-137 ; Cs-134	0.7	de With et al., 2021; Hosseini et al., 2017
		0.5*	Iosjpe et al, 2022; present report
		0.64	Keum et al., 2015
	Eu-152; Eu-154; Eu-155; Co-60; Ni-59; Ni-63	0.7*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.1*	Iosjpe et al, 2022; present report
	Cm-244c, Cm-242	0.1*	The present report
	Sr-90	0.64	Vives i Batlle et al., 2016; Keum et al., 2015
	Sr-90	0.3*	Iosjpe et al, 2022; present report
	General approach that has been applied to Sr-90, **I-131**, Cs-134, and Cs-137	0.7	de With et al., 2021; PREPARE, 2015: the present report
Coastal predator	Cs-137	0.5*	Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
		0.64	Keum et al., 2015
	Eu-152; Eu-154; Eu-155; Co-60; Ni-59; Ni-63	0.7*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.1*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.1*	The present report
	Sr-90	0.64	Vives i Batlle et al., 2016; Keum et al., 2015
	Sr-90	0.3*	Iosjpe et al, 2022; the present report
	General approach that has been applied to Sr-90, I-131, Cs-134, and Cs-137	0.7*	de With et al., 2021; the present report
Seal	Cs-137, Cs-134	1*	Gwynn et al., 2006; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Co-60; Ni-59; Ni-63	0.5*	Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.2*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.05*	The present report
	Sr-90, I-131	0.3*	Iosjpe et al, 2022; present report
Sea Bird	Cs-137, Cs-134	1	Hosseini et al., 2017

Table A4. Assimilation efficiency rates (continued).			
		0.5*	Iosjpe et al, 2022; present report
	Ni-59; Ni-63	0.5*	Iosjpe et al, 2022; present report
	Co-60	0.1*	Iosjpe et al, 2022; present report
	Eu-152; Eu-154; Eu-155	0.1*	Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.01*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.01*	The present report
	Sr-90, I-131	0.3*	Iosjpe et al, 2022; present report

Table A5. Rate of direct uptake of activity from water column (k_u), $l \cdot kg^{-1} \cdot d^{-1}$ (Some investigators use k_u dimensionality as d^{-1} under assumption that weght of 1 liter is equal to 1 kg).

Organism	Radionuclide	k_u	References
Zooplankton	Cs-137	0.49*	Thomann, 1981; Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	18.7*	Thomann, 1981; Iosjpe et al, 2022; present report
	Cm-244, Cm-242	18.7*	The present report
	General approach	1.5*	PREPARE, 2015; de With et al., 2021; Iosjpe et al, 2022; present report
Non-piscivorous fish/Pelagic small fish	Cs-137	0.07*	Thomann, 1981; Iosjpe et al, 2022; present report
		0.01	Brown et al., 2004; Hosseini et al., 2017
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.3*	Thomann, 1981; Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.3*	The present report
	General approach	0.1*	PREPARE, 2015; de With et al., 2021; Iosjpe et al, 2022; present report
Piscivorouss fish/ Pelagic large fish	Cs-137	0.01*	Thomann, 1981; 0.01 Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241	0.01	Thomann, 1981
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.05*	The present report

Table A5. (continued).

	General approach	0.075*	PREPARE, 2015 PREPARE, 2015; de With et al., 2021; Iosjpe et al, 2022; present report
Deposit-feeding invertebrate	General approach	0.1*	de With et al., 2021; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.1*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.1*	The present report
Mollusk	Cs-137; Sr-90; I-131; Eu-152; Eu-154; Eu-155, Co-60, Ni-59, Ni-63	0.15*	de With et al., 2021; PREPARE, 2015; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	2.04*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	2.04*	The present report
		4.75	Hosseini et al., 2017
Crustacean	Cs-137	0.49	Hosseini et al., 2017
	General approach	0.1*	de With et al., 2021; PREPARE, 2015; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.06*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.06*	The present report
Demersal fish	General approach	0.05	de With et al., 2021
	Cs-137	0.01	Brown et al., 2004; Hosseini et al., 2017
	Cs-137	0.07*	Thomann, 1981; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.01*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.01*	The present report
	Sr-90, I-131, Eu-152, Eu-154, Eu-155, Co-60, Ni-59, Ni-63	0.1*	Iosjpe et al, 2022; present report
Bottom predator	General approach	0.05	de With et al., 2021
	Cs-137	0.01*	Thomann, 1981; Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.05*	The present report
	Sr-90, I-131, Eu-152, Eu-154, Eu-155, Co-60, Ni-59, Ni-63	0.075*	Iosjpe et al, 2022; present report
Coastal predator	Cs-137	0.01*	Thomann, 1981; Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report

Table A5. (continued).			
	General approach	0.075*	de With et al., 2021; Iosjpe et al, 2022; present report
	Cm-244, Cm-242	0.05*	The present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241	0.05*	Iosjpe et al, 2022; present report
Seal	All radionuclides	0*	Brown et al., 2004; Hosseini et al., 2017; Iosjpe et al, 2022; present report
Sea Bird	All radionuclides	0*	Hosseini et al., 2017; Iosjpe et al, 2022; present report

Table A6. excretion rate (k_e, d^{-1}) for selected radionuclides and marine organisms and Biological half-life of radionuclides in organisms ($T_{1/2}$, d). parameter range (minimum and maximum values) is shown where possible in paranses.

Organism	Radionuclide	k_e	$T_{1/2}$	References
Zooplankton	Am-241	0.020	34	Beresford et al., 2015
	Ba-140	0.139*		The present report
	Ce-141	3E-1*		The present report
	Cs-137; Cs-134	0.03*		Thomann, 1981; Iosjpe et al, 2022; present report
	Cs-136	5.17E-2*		The present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241; Cm-244, Cm-242	0.05*		Thomann, 1981; Iosjpe et al, 2022; present report
	Eu-152, Eu-154, Eu-155, Co-60, Ni-59, Ni-62	0.139*		Iosjpe et al, 2022; present report
Zooplankton	General approach	0.139*	5	Iosjpe et al, 2022; present report PREPARE, 2015; de With et al., 2021: Iosjpe et al, 2022; present report
	I-131	8.36E-2*		The present report
	Nb-95	1.98E-2*		The present report
	Np-237	2.0E-2*		The present report
	Np-235	2.94E-1*		The present report
	Pm-145, Pm-147	4.0E-1*		The present report

Table A6. (continued)				
	Ru-106	2.0E0*		The present report
	Ru-103	2.0*		The present report
	Ru-105	3.75*		The present report
	Sb-125	0.02*		The present report
	Sb-127	1.8E-1*		The present report
	Sm-151	0.5*		The present report
	Sm-153	0.5*		The present report
	Sn-126	5.0E-2*		The present report
	Te-132	0.2*		The present report
	Te-125m	0.2*		The present report
	Te-127	1.78*		The present report
	Te-129m	0.2*		The present report
	Te-129	14.3*		The present report
Non-piscivorous fish/Pelagic small fish	Ba-140	5.44E-2*		The present report
	Ce-141	1E-1*		The present report
	Co-60	4.99E-2	13.9	Beresford et al., 2015
	Cs-137	0.003*		Thomann, 1981; Iosjpe et al, 2022; present report
		0.0107		Hosseini et al., 2017
		0.053	13	Keum et al., 2015; Vives i Batlle et al., 2016
		0.0107	65	Vives i Batlle et al., 2016
		7.3E-3	95 (White fish)	Iosjpe et al, 2022; present study. Suolanen, 2021
	Cs-136	5.17E-2*		The present report
	Eu-152	0.03455*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.03466*		Iosjpe et al, 2022; present report
	I-131	8.0E-1*		The present report
	Nb-95	8E-1*		The present report

Table A6. (continued)				
	Ni-59, Ni-63	0.01*		Iosjpe et al, 2022; present report
	Np-237	5.0E-1*		The present report
	Np-235	5.0E-1*		The present report
Non-piscivorous fish/Pelagic small fish		7.32E-3 (3.09E-3; 1.96E-2)	94.7 (35.4; 224)	Beresford et al., 2015
	Ru-106	8.0E-1*		The present report
	Ru-103	8.0E-1*		The present report
	Ru-105	3.75*		The present report
	Sb-125	1.4E-2*		The present report
	Sb-127	1.8E-1*		The present report
	Sm-151	1.0E-1*		The present report
	Sm-153	3.59E-1		The present report
	Sn-126	6.0E-4*		The present report
	Sr-90	0.053	13	Keum et al., 2015; Vives i Batlle et al., 2016
	Sr-90	0.0139*		Iosjpe et al, 2022; present report
	Sr-90	4.95E-03	140	Vives i Batlle et al., 2016
	Pm-145, Pm-147	1.0E-1*		The present report
	Pu-238; Pu-239; Pu-240; Pu-241; Am-241; Cm-244, Cm-242	0.02*		Thomann, 1981; Iosjpe et al, 2022; present report
	General approach	1.39E-03 9.24E-03 3.47E-02 0.231	500 (Bone) 75 (Flesh) 20 (Organs) 3 (Stomach)	PREPARE, 2015; de With et al., 2021
	Co-60	0.0112*		Iosjpe et al, 2022; present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Piscivorouss fish / Pelagic large fish	Co-60	1,89E-02 (1.40E-2; 2.40E-2)	36.6 (28.9; 9.5)	Beresford et al., 2015 (Whole organism)
		1,85E-02 (1.42E-2; 2.67E-2)	37.5 (26; 48.7)	Beresford et al., 2015 (Intestine)

Table A6. (continued)

		1.34E-02 (1.15E-2; 1.80E-2)	51.6 (38.5; 60.3)	Beresford et al., 2015 (Muscle)
		1,60E-02 (1,44E-2;1,81E-2)	43.3 (38.4; 8.1)	Beresford et al., 2015 (Liver)
	Ba-140	5.44E-2*		The present report
	Ce-141	2.13E-2*		The present report
	Cs-137	1.8E-03*		Thomann, 1981; Iosjpe et al, 2022; present report
		0.0107		Hosseini et al., 2017
		0.053	13	Keum et al., 2015;
		0.0107	65	Vives i Batlle et al., 2016
		2.3E-3	300 (Pike)	Iosjpe et al, 2022; present study. Suolanen, 2021
		3E-3 (2.8E-3; 3.5E-3)	225 (200-250) (Small and large Pearch)	Iosjpe et al, 2022; present study. Suolanen, 2021
	Cs-136	5.17E-2*		The present report
	I-131	8.63E-2*		The present report
Piscivorouss fish / Pelagic large fish	Pu-238; Pu-239; Pu-240; Pu-241; Am-241; Cm-244, Cm-242	0.01*		Thomann, 1981; Iosjpe et al, 2022; present report
	Pm-145, Pm-147	8.0E-3*		The present report
	Ru-106	4.0E-3*		The present report
	Ru-103	1.77E-2*		The present report
	Ru-105	3.75*		The present report
	Sb-125	1.0E-2*		The present report
	Sb-127	1.8E-1*		The present report
	Sn-126	6.0E-3*		The present report
	Sr-90	0.053	13	Keum et al., 2015;
		4.95E-03	140	Vives i Batlle et al., 2016
	Sr-90	4.88E-03*		Iosjpe et al, 2022; present report
	Sm-151	4.0E-3*		The present report
	Sm-153	3.59E-1		The present report
	Eu-152	0.0172*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0173*		Iosjpe et al, 2022; present report

Table A6. (continued)				
	Co-60	0.005*		Iosjpe et al, 2022; present report
	Ni-59, Ni-63	0.009*		Iosjpe et al, 2022; present report
	General approach	6.93E-04 4.62E-03 1.73E-02 0.139	1000 (Bone) 150 (Flesh) 40 (Organs) 5 (Stomach)	PREPARE, 2015; de With et al., 2021
	Np-237	8.0E-3*		The present report
	Np-235	2.94E-1*		The present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Deposit-feeding invertebrate	Cs-137	1.02E-1 (3.50E-2; 2.67E-1)	6.77 (2.6; 19.8)	Beresford et al., 2015
	Cs-136	5.17E-2*		The present report
	General approach	4.62E-02*	15	de With et al., 2021; Iosjpe et al, 2022; present report
	Ba-140	5.44E-2*		The present report
	Co-60	3.06E-2 (9.50E-3; 8.80E-02)	22.7 (7.9; 73)	Beresford et al., 2015
	Ce-141	2.13E-2*		The present report
	Pu-238, Pu-239, Pu-240, Pu,241, Am-241	0.029*		Iosjpe et al, 2022; present report
	Sb-127	1.8E-1*		The present report
	Sr-90, Co-60	1.04E-02*		Iosjpe et al, 2022; present report
	Eu-152	0.0381*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0382*		Iosjpe et al, 2022; present report
	Ni-59, Ni-63	1.04E-02*		Iosjpe et al, 2022; present report

Table A6. (continued)				
Mollusk	Am-241	2.51E-2 (1.78E-2; 4.31E-2)	27.6 (16.1; 39)	Beresford et al., 2015
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-244, Cm-242	2.5E-2*		Iosjpe et al, 2022; present report
	Ba-140	5.44E-2*		The present report
	Ce-141	8E-1*		The present report
	Co-60	5.21E-3 (1.51E-2; 2.21E-3)	133 (31.4; 460)	Beresford et al., 2015
Mollusk	Pu-238, Pu-239, Pu-240	7.22E-3 (9.79E-4; 1.07E-1)	96.1 (6.5; 708)	Beresford et al., 2015
	Pm-145, Pm-147	1.5E-1*		The present report
	Ru-106	2.0E0*		The present report
	Ru-103	2.0E0*		The present report
	Ru-105	3.75*		The present report
	Sb-125	5E-2*		The present report
	Sb-127	1.8E-1*		The present report
	Sn-126	2.5E-3*		The present report
	Sr-90	1.18E-2 (5.98E-3; 6.73E-2)	58.7 (10.3; 116)	Beresford et al., 2015
		3.01E-02	23	Keum et al., 2015;
	Sr-90, Ni-59, Ni-63	1.39E-02*		Iosjpe et al, 2022; present report
		2.175E-02	32	Vives i Batlle et al., 2016
	Nb-95	2.0E-1*		The present report
	I-131	8.63E-2*		The present report
	Np-237	1.0E-2*		The present report
	Np-235	2.94E-1*		The present report
	Eu-152	0.0694*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0695*		Iosjpe et al, 2022; present report
	Cs-137	1.70E-2 (4.33E-1; 7.70E-3)	40.8 (1.6; 90)	Beresford et al., 2015
	Cs-137, Co-60	1.39E-02*		Iosjpe et al, 2022; present report
		3.01E-02	23	Keum et al., 2015;

Table A6. (continued)

		3.85E-02	18	Vives i Batlle et al., 2016
		0.04		Hosseini et al., 2017
	General approach	1.39E-02	50	PREPARE, 2015; de With et al., 2021
	Sm-151	2.5E-1*		The present report
	Sm-153	3.59E-1		The present report
	Cs-136	5.17E-2*		The present report
	Te-132	2.0E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.0E-1*		The present report
	Te-129	14.3*		The present report
Crustacean	Co-60	4.45E-2; (2.57E-2; 1.00E-1)	15.6 (6.9; 27)	Beresford et al., 2015
	Ce-141	1.5E-1		The present report
	Ba-140	5.44E-2*		The present report
	I-131	1.5E-1*		The present report
	Pu-238, Pu-239, Pu-240	2.59E-2 (4.62E-2; 1.82E-2)	26.8 (15; 38)	Beresford et al., 2015
	Pu-238, Pu-239, Pu-240, Pu-241, Am-241; Cm-244, Cm-242	0.033*		Iosjpe et al, 2022; present report
	Sm-151	4.0E-2*		The present report
	Sm-153	3.59E-1		The present report
	Sn-126	5.0E-4*		The present report
	Pm-145, Pm-147	4.0E-2*		The present report
	Nb-95	1.0E-1*		The present report
	Np-237	9.0E-1*		The present report
	Np-235	2.94E-1*		The present report
	Ru-106	2.4E-1*		The present report
	Ru-103	2.4E-1*		The present report
	Ru-105	3.75*		The present report
	Sr-90	2.42E-2 (1.58E-2; 5.17E-2)	28.7 (13.4; 44)	Beresford et al., 2015
		1.50E-02	46	Keum et al., 2015;
	Sb-125	9.5E-3*		The present report
	Sb-127	1.8E-1*		The present report
	Sr-90	6.93E-03*		Iosjpe et al, 2022; present report

Table A6 (continued)				
		1.20E-02	58	Vives i Batlle et al., 2016
Crustacean	Eu-152	6.82E-03*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155, Co-60, Ni-59, Ni-63	6.93E-03*		Iosjpe et al, 2022; present report
	I-131	0.0867		The present report
	Cs-137	2.31E-02	30	Beresford et al., 2015
		0.01		Hosseini et al., 2017
		1.50E-02	46	Keum et al., 2015;
		0.34	2	Vives i Batlle et al., 2016
	Cs-136	5.17E-2*		The present report
	General approach	6.93E-03*	100	PREPARE, 2015; de With et al., 2021; Iosjpe et al, 2022; present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Demersal fish	Co-60	9.99E-03 (4.18E-3; 2.24E-2)	69.4 (31; 166)	Beresford et al., 2015
	Ce-141	2.13E-2*		The present report
	Ba-140	5.44E-2*		The present report
	Sb-125	1E-2*		The present report
	Sb-127	1.8E-1*		The present report
	Sr-90	6.30E-3	110	Beresford et al., 2015
		0.053	13	Keum et al., 2015;
		4.95E-03	140	Vives i Batlle et al., 2016
	Sr-90	0.0139*		Iosjpe et al, 2022; present report
	I-131	0.0863*		The present report
	Cs-137	1.64E-2 (1.02E-2; 3.85E-2)	42.2 (18; 68)	Beresford et al., 2015
		0.0107	65	Hosseini et al., 2017; Vives i Batlle et al., 2016
		0.003*		Iosjpe et al, 2022; present report
		5.33E-02	13	Keum et al., 2015;
	Cs-136	5.17E-2*		The present report

Table A6. (continued)				
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-244, Cm-242	0.02*		Iosjpe et al, 2022; present report
	Pm-145, Pm-147	8.0E-3*		The present report
	General approach	1.39E-03 9.24E-03 3.47E-02 0.231	500 (Bone) 75 (Flesh) 20 (Organs) 3 (Stomach)	With et al., 2021
	Eu-152	0.03455*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.03466*		Iosjpe et al, 2022; present report
	Co-60	0.0112*		Iosjpe et al, 2022; present report
	Np-237	8.0E-3*		The present report
	Np-235	2.94E-1*		The present report
	Nb-95	1.98E-2*		The present report
	Ni-59, Ni-63	0.01*		Iosjpe et al, 2022; present report
	Ru-106	4.0E-3*		The present report
	Ru-103	1.77E-2*		The present report
	Ru-105	3.75*		The present report
	Sm-151	4.0E-3*		The present report
	Sm-153	3.59E-1		The present report
	Sn-126	2.5E-3*		The present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Bottom predator	Co-60	1.10E-02	63	Beresford et al., 2015
	Ce-141	2.13E-2*		The present report
	Ba-140	5.44E-2*		The present report
	Sr-90	1.59E-3 (1.00E-3; 3.89E-3)	436 (178; 693)	Beresford et al., 2015
		0.053	13	Keum et al., 2015;
		4.95E-03	140	Vives i Batlle et al., 2016
	Ru-106	4.0E-3*		The present report
	Ru-103	1.77E-2*		The present report
	Ru-105	3.75*		The present report
	Sb-125	1E-2*		The present report

Table A6. (continued)				
	Sb-127	1.8E-1*		The present report
	Sr-90	4.88E-03*		Iosjpe et al, 2022; present report
	I-131	0.0863*		The present report
	Cs-136	5.17E-2*		The present report
	Cs-137	2.04E-02	34	Beresford et al., 2015
		0.0107		Vives i Batlle et al., 2016; Hosseini et al., 2017
		0.0018*		Iosjpe et al, 2022; present report
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-244, Cm-242	0.01*		Iosjpe et al, 2022; present report
	Pm-145, Pm-147	8.0E-3*		The present report
	General approach	6.93E-04 4.62E-03 1.73E-02 0.139	1000 (Bone) 150 (Flesh) 40 (Organs) 5 (Stomach)	With et al., 2021
	Eu-152	0.0172*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0173*		Iosjpe et al, 2022; present report
	Co-60	0.005*		Iosjpe et al, 2022; present report
	Np-237	8.0E-3*		The present report
	Np-235	2.94E-1*		The present report
	Nb-95	1.98E-2*		The present report
	Ni-59, Ni-63	0.009*		Iosjpe et al, 2022; present report
	Sm-151	4.0E-3*		The present report
	Sm-153	3.59E-1		The present report
	Sn-126	2.5E-3*		The present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Coastal predator	Cs-137	7.32E-3 (3.09E-3; 1.96E-2)	94.7 (35.4; 224)	Beresford et al., 2015
	Cs-137	5.33E-02	13	Keum et al., 2015;
	Cs-137	0.0107	65	Hosseini et al., 2017; Vives i Batlle et al., 2016

Table A6. (continued)				
		0.0018*		Iosjpe et al, 2022; present report
	Cs-136	5.17E-2*		The present report
	Ce-141	2.13E-2*		The present report
	Ba-140	5.44E-2*		The present report
	Sr-90	0.053	13	Keum et al., 2015;
	Sr-90	4.95E-03	140	Vives i Batlle et al., 2016
	Ru-106	4.0E-3*		The present report
	Ru-103	1.77E-2*		The present report
	Ru-105	3.75*		The present report
	Sr-90, I-131	4.88E-03*		Iosjpe et al, 2022; present report
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-242; Cm-244	0.01*		Iosjpe et al, 2022; present report
	Pm-145, Pm-147	8.0E-3*		The present report
	General approach	6.93E-04 4.62E-03 1.73E-02 0.139	1000 (Bone) 150 (Flesh) 40 (Organs) 5 (Stomach)	PREPARE, 2015; de With et al., 2021
	Eu-152	0.0172*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0173*		Iosjpe et al, 2022; present report
	Ce-141	2.13E-2*		The present report
	Co-60	0.005*		Iosjpe et al, 2022; present report
	I-131	8.63E-2*		The present report
	Nb-95	1.98E-2*		The present report
	Ni-59, Ni-63	0.009*		Iosjpe et al, 2022; present report
	Np-237	8.0E-3*		The present report
	Np-235	2.94E-1*		The present report
	Sb-125	1E-2*		The present report
	Sb-127	1.8E-1*		The present report
	Sn-126	2.5E-3*		The present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report

Table A6. (continued)

Seal	Cs-137	0.0239*		Gwynn et al., 2006; Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Cs-136	5.17E-2*		The present report
	Ce-141	1E-1*		The present report
	Ba-140	5.44E-2*		The present report
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-244, Cm-242	2.0E-03*		Iosjpe et al, 2022; present report
	Eu-152	0.0172*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0173*		Iosjpe et al, 2022; present report
	I-131	5.0*		The present report
	Sr-90, I-131	4.88E-03*		Iosjpe et al, 2022; present report
	Co-60	0.05*		Iosjpe et al, 2022; present report
	Nb-95	7.0E-2*		The present report
	Ni-59, Ni-63	0.02*		Iosjpe et al, 2022; present report
	Np-237	9.0E-1*		The present report
	Np-235	2.94E-1*		The present report
	Pm-145, Pm-147	7.0E-2*		The present report
	Ru-106	8.0E-2*		The present report
	Ru-103	8.0E-2*		The present report
	Ru-105	3.75*		The present report
	Sm-151	8.0E-2*		The present report
	Sm-153	3.59E-1		The present report
	Sb-125	5E-3*		The present report
	Sb-127	1.8E-1*		The present report
	Sn-126	6.0E-2*		The present report
	Te-132	2.17E-1*		The present report
	Te-125m	1.21E-2*		The present report
	Te-127	1.78*		The present report
	Te-129m	2.06E-2*		The present report
	Te-129	14.3*		The present report
Sea Bird	Cs-137	0.036*		Hosseini et al., 2017; Iosjpe et al, 2022; present report
	Cs-136	5.17E-2*		The present report
	Ce-141	2.13E-2*		The present report

Table A6. (continued)				
	Ba-140	5.0*		The present report
	I-131	5E-1*		The present report
	Am-241, Pu-238, Pu-239, Pu-240, Pu-241; Cm-244, Cm-242	1.4E-02*		Iosjpe et al, 2022; present report
	Pm-145, Pm-147	3.0E0*		The present report
	Sr-90, I-131	5.28E-03*		Iosjpe et al, 2022; present report
	Eu-152	0.0345*		Iosjpe et al, 2022; present report
	Eu-154, Eu-155	0.0346*		Iosjpe et al, 2022; present report
	Ba-140	5.44E-2*		The present report
	Co-60	0.05*		Iosjpe et al, 2022; present report
	Nb-95	3.0*		The present report
	Ni-59, Ni-63	0.04*		Iosjpe et al, 2022; present report
	Np-237	15*		The present report
	Np-235	15*		The present report
	Ru-106	2.4E0*		The present report
	Ru-103	2.4E0*		The present report
	Ru-105	3.75*		The present report
	Sb-125, Sb-127	3.5*		The present report
	Sm-151	1.4*		The present report
	Sm-153	1.4*		The present report
	Sn-126	2.4*		The present report
	Te-132	3.5*		The present report
	Te-125m	3.5*		The present report
	Te-127	3.5*		The present report
	Te-129m	3.5*		The present report
	Te-129	14.3*		The present report

Bibliographic Data Sheet **NKS-472**

Title	Application of biokinetic parameters for some representative accident cases based on state of the art modelling
Author(s)	[1] Mikhail Iosjpe, [2]Mats Isaksson, [3]Hans Pauli Joensen, [4]Gísli Jónsson, [5]Vesa Suolanen
Affiliation(s)	[1] Norwegian Radiation and Nuclear Safety Authority (DSA), [2]Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, [3]Fróðskaparsetur Føroya, [4]Icelandic Radiation Safety Authority, [5]VTT Technical Research Centre of Finland Ltd
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Abstract max. 2000 characters	The release scenario corresponding to a potential accident with a modern operating Russian nuclear submarine reactors in the Southwest part of the Barents Sea has been assessed. The evaluation of the kinetic parameters for bioaccumulation process for a wide set of radionuclides and biota has been provided. Evaluation of the kinetic parameters has been provided based on literature review, the extraction from existing databases and mathematical experiments including the successive simulations of bioaccumulation processes during increasing trophic levels. The importance of implementing the kinetic bioaccumulation model for consequences from short-lived radionuclides has been provided. The sub-model with the modified kinetic parameters for bioaccumulation process has been used based on simulations from the compartmental model, which uses the non-instantaneous dispersion of radioactivity in the marine environment. Concentrations of radionuclides in biota, doses to humans and dose rates to the marine organisms have been evaluated. The results of the present study can be used to improve the ability to evaluate the consequences to humans and biota after a radioactive release into marine environment.
Key words	Bioaccumulation of radionuclides, kinetic modelling, dose assessment to humans and biota