Significance of transit and residence time parameters for improvement on radioecological assessment of marine environment

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INTRODUCTION

Instantaneous mixing of radionuclides in each compartment is a principal feature of the compartmental modelling, but this general assumption leads, in practical calculations, to instantaneous mixing in the whole ocean space and, therefore, inserts an additional systematic uncertainty into calculated results.

The developed in Norwegian Radiation Protection Authority (NRPA) modelling approach includes terms describing the radionuclide dispersion into oceanic space with time (non-instantaneous mixing in oceanic space) that is more liable to correct describe the water motion in large oceanic systems (Iosjpe *et al.*, 2002).

MODEL DESCRIPTION

The equations describing transfer of radionuclides between the compartments are of the form

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

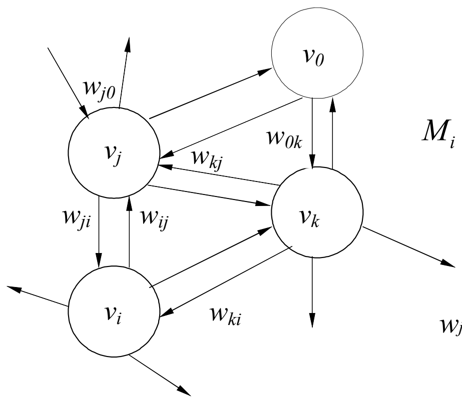
$A_i = 0, \quad t < T_i$

where $k_{ii}=0$ for all i, A_i and A_j are activities (Bq) at time t in compartments i and j; k_{ij} and k_{ji} are transfer rates (y^{-1}) between compartments i and j; k_i is an effective activity transfer rate (y^{-1}) from compartment 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 compartment i ($Bq\ y^{-1}$); n is the number of compartments in the system. T_i is the time of availability for compartment i (the first times when compartment 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 availability times $T_i = \min_{\mu_m(v_0,v_i)\in M_i} \sum_{j,k} w_{jk}$

are calculated as a minimized sum of the weights for all paths $\mu_0(v_0,\ldots,v_i)$ from the initial compartment (v_0) with discharge of radionuclides to the compartment i on the oriented graph $G=(V, E)$ with a set V of nodes v_j correspondent to compartments and a set E of arcs e_{jk} correspondent to the transfer possibility between the compartments j and k (graph elements and examples of available paths from the node v_0 to the node v_i are illustrated by Fig. 1). Every arc e_{jk} has a weight w_{jk} which is defined as the time required before the transfer of radionuclides from compartment j to compartment k can begin (without any way through other compartments). 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 compartment (v_0) to the compartment i (v_i).



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

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

Figure 1. Graph elements and available paths.

The structure of water compartments is developed with regards to improved description of Polar, Atlantic and Deep waters in the Arctic Ocean and the Northern Seas (Karcher & Harms, 2000) and site-specific information for description of the boxes. The volume of the water layers in Arctic compartments has been calculated by using a detailed bathymetry in geographical information system (IBCAO, 2001). The ice module was developed for evaluation of the ice transport of radionuclides and includes processes of interactions of radioactivity between water, suspended sediment particles in water column, bottom sediment, ice, ice sediment and different (water, sediment and ice) model compartments.

The present version of the model is improved to calculate doses to biota, which are calculated on the basis of radionuclide concentrations in marine organisms, in water and sediment phases and radionuclides dose conversion factors.

RESULTS AND DISCUSSIONS

The times of availability can be evaluated by analysing of experimental data sets (Brown *et al*, 2002), on the basis of hydrodynamic model simulations (Karcher et al., 2004), by Dijkstra algorithm (Dijkstra, 1959) for the graph $G=(V, E)$ and can be easily interpreted as residence times and transit times for the first signal of radioactivity dispersion for actual compartments. For example, for discharge of radionuclides into the Ob Bay (Fig. 2) time of availability for the Kara Sea T_{KSE}=0.57 and can be interpreted as residence time for the Ob Bay. Results of calculations by the present approach in Fig 2 indicate that using of dispersion of ^{60}Co is still limited by the Ob Bay boundaries six months after the discharge of the radionuclide.

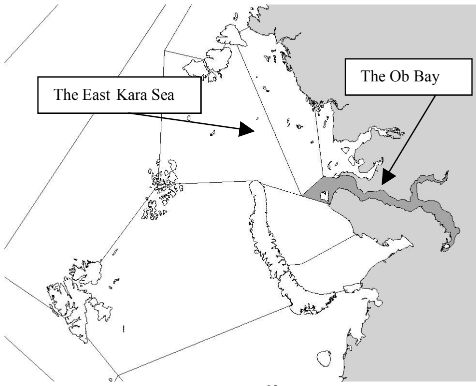


Figure 2. Simulations of the dispersion of ^{60}Co (dark gray colour) after six months of 1TBq discharged into the Ob Bay.

Fig. 3 shows a comparison between total doses for benthic fish for present approach and modelling with instantaneous mixing in oceanic space. Results of calculations in Fig. 3 show that even for the initial compartment (the Ob Bay), when the process of dispersion starts at the same time for both approaches (time of availability for the Ob Bay compartment is zero), differences between results are up to 30 percentages.

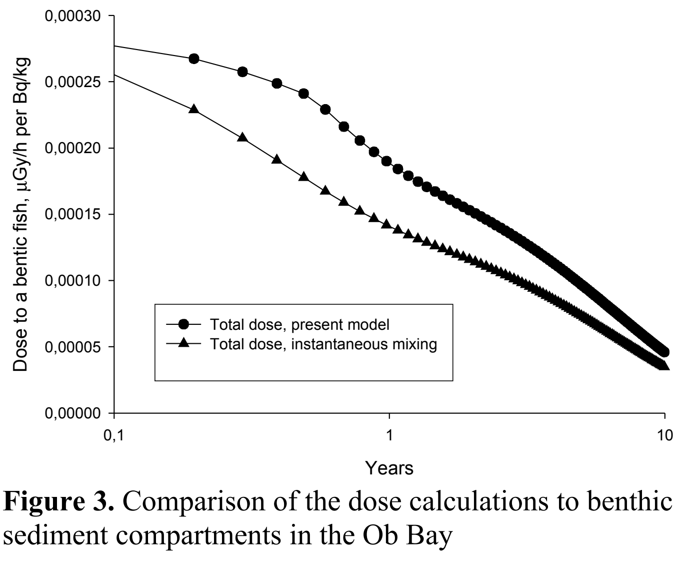


Figure 3. Comparison of the dose calculations to benthic fish and ^{60}Co concentrations in water and sediment compartments in the Ob Bay

Time of availability for the Labrador Sea for the same scenario is estimated as seven years. Table 1 shows a ratio between dose impact from the Labrador Sea and the Ob Bay for different radionuclides for present approach and modelling with instantaneous mixing in oceanic space. Table 1 indicates that direct including of residence and transit times in modelling leads to significant differences for results of calculations in comparison to approach with instantaneous mixing in oceanic space.

Table 1. Ratio of collective dose impacts from the Labrador Sea for 10 and 50 years after discharge of 1 TBq activity into the Ob Bay, present approach/traditional modelling (manSv/manSv).

Years	Compartment	^{60}Co	^{90}Sr	^{137}Cs
10	Labrador Sea	0.005	0.07	0.06
50	Labrador Sea	0.5	0.5	0.4
1000	Ob Bay	1.4	1.5	1.5

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