Radioprotection, vol. **44**, n° 5 (2009) 531–536

DOI: 10.1051/radiopro/20095098

Improvement of the dose assessment tools on the basis of dispersion of the ^{99}Tc in the Nordic Seas and the Arctic Ocean

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Abstract. Compartment models are widely used for the evaluation of radiological consequences to man and biota in the marine environment over large spatial and long temporal scales. The model developed at the Norwegian Radiation Protection Authority (NRPA) is based on a compartment modelling approach that includes terms describing dispersion of radionuclides into oceanic space with time (non-instantaneous mixing in oceanic space). In this paper the latest modification of the NRPA model will be presented. The main improvement concerns the "time of availability" parameters (i.e. the times at which dispersed radionuclides reach compartment boundaries). The modifications have been implemented through the use of a comprehensive ^{99}Tc data set collected under the course of the project "RADNOR" and through comparison with the results of simulations provided by the 3D hydrodynamic NAOSIM model. The present version of the NRPA model describes the dispersion of ^{99}Tc in the Arctic Ocean and seas with a significantly improved precision for some marine regions. Results of the calculations indicate that defined "time of availability" parameters are in good agreement with transit times observed in the actual marine environment.

1. INTRODUCTION

Compartment models are widely used for evaluation of radiological consequences to man and biota in marine environment with spatial and temporal scales of several thousand kilometres and millenniums, respectively [1]. The compartment modelling uses two rigid general assumptions for dispersion of radionuclides in oceanic space: (a) uniform and (b) instantaneous mixing in each compartment. The second assumption leads, in practical calculations, to instantaneous mixing in the whole ocean space and, therefore, inserts an additional systematic uncertainty into calculated results. The model developed in the Norwegian Radiation Protection Authority (NRPA) during last years is based on a compartment modelling approach, which includes terms describing the radionuclide dispersion into oceanic space with time (non-instantaneous mixing in oceanic space). It showed that the modified approach provides more realistic results compared to traditional compartment modelling and this approach is also more sensitive to processes near the sources of contamination and during the initial time of radionuclides dispersion [2]. Results between modified and traditional approaches can differ widely, especially for scenarios where redistribution of radionuclides between different marine areas was important [2, 3].

The present paper will present the first results for the new modification of the NRPA model, in which the main improvement concerns the parameters for describing non-instantaneous mixing in oceanic space and a corresponding set of water fluxes between compartments.

2. MODEL DESCRIPTION

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

$$\frac{\mathrm{d}A_i}{\mathrm{d}t} = \sum_{j=1}^{n} k_{ji}\gamma(t \geq T_{ji})A_j\gamma(t \geq A_j) - \sum_{j=1}^{n} k_{ij}\gamma(t \geq T_{ij})A_i - k_i A_i + Q_i, \quad t \geq T_i$$
$$A_i = 0, \quad t < T_i \tag{1}$$

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_{ij} is the time required before the transfer of radionuclides from the box i to the box j can begin without any way through other boxes; 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:

$$\gamma(t \geq T_i) = \begin{cases} 1, & t \geq T_i \\ 0, & t < T_i \end{cases}, \quad \gamma(t \geq T_{ij}) = \begin{cases} 1, & t \geq T_{ij} \\ 0, & t < T_{ij} \end{cases}$$

Methods for evaluation of "times of availability" $\{T_i\}$ and more detailed description of the model are discussed in the [2].

Under the present modification, the model parameters $\{T_{ij}\}$ are used not only for evaluation of parameters $\{T_i\}$, but are directly included into the main equation (1) describing transfer of radionuclides.

Traditional box modelling is a particular case of the present approach when all different times of availability $\{T_i\}$ and $\{T_{ij}\}$ are zero.

The model includes the processes of advection of radioactivity between compartments, sedimentation, diffusivity of radioactivity through the pore water, resuspension, mixing due to bioturbation and a burial process of activity in deep sediment. Radioactive decay is included in all compartments. The contamination of biota is further calculated from the radionuclide concentrations in filtered seawater in the different water regions. Doses to man are calculated on the basis of data for the procurement of seafood and assumptions about human diet.

The schematic surface structure of the model compartments for the Arctic Ocean, the Nordic Seas and the North Atlantic are shown in Figure 1.

3. RESULTS AND DISCUSSION

The main consequences after the present modification of the model are non-instantaneous water fluxes between boxes, which unlike the previous version of the model are "open" for dispersion of radionuclides. The term "water fluxes" here includes water streams as well as diffusion processes. Traditional models with instantaneous mixing of radionucludes in oceanic space have optimised a set of water fluxes with purpose to better describe existing experimental data as for instance in [4]. Apparently the present modification of the model also needs a similar procedure. This is also particularly important because of possible changes within the water fluxes system itself as a result of global climate change.

The model modification has been provided on the basis of comprehensive ^{99}Tc data set (approximately, three thousand experimental points) collected under the course of the project "RADNOR", supported by the Norwegian Research Council [5, 6].

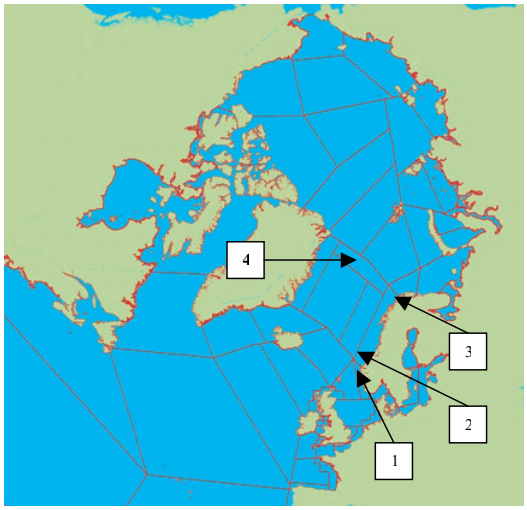


Figure 1. The schematic surface structure of the model compartments: (1) the North Sea (Norwegian coastal waters), (2) and (3) the South and North parts of the Norwegian Coastal Current and (4) the Spitsbergen Current.

^{99}Tc is anthropogenic radionuclide with low sediment distribution coefficient and physical half-life $2 \cdot 10^5$ years. Due to conservative features of ^{99}Tc and well-known history of discharges of ^{99}Tc into the marine environment (mainly from nuclear facilities at Sellafield and Cap la Hague) it can easily be used for evaluation and validation of the model parameters. For instance, signals after two release peaks from 1978 and 1994–1995, which are clearly shown in Figure 2, can be followed in different marine regions and used for model corroboration.

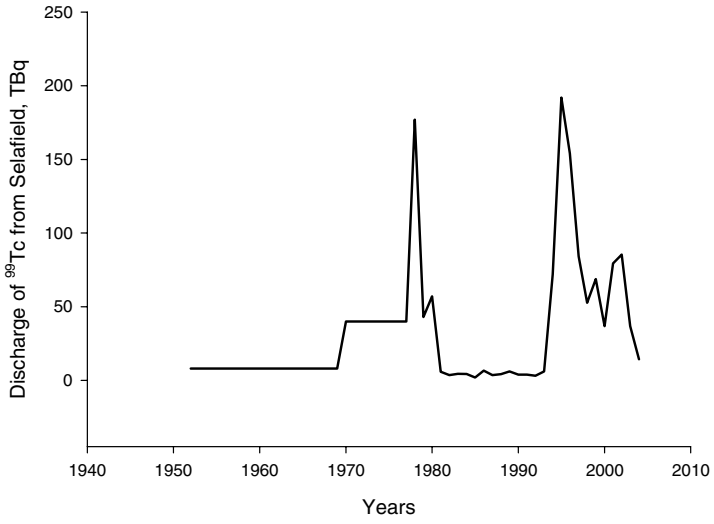


Figure 2. Annual liquid discharge of ^{99}Tc from Sellafield.

Improvement of the parameters (times of availability and water fluxes) was provided with as minimal changing as possible with preliminary local sensitivity analysis of adjacent marine regions with regards to water fluxes balance.

Sensitivity analysis was provided by the expression

$$S^{(L)} = \frac{dA_i}{dP} \frac{P^{(0)}}{A_i^{(0)}},$$

where P corresponds to investigated parameters and "0" corresponds to the basis variant.

Results of simulations from previous and present versions of the NRPA model for the North Sea (Norwegian coastal waters), the South and North parts of the Norwegian Coastal Current and the Spitsbergen Current are shown in Figures 3–6, correspondently (actual marine regions are shown

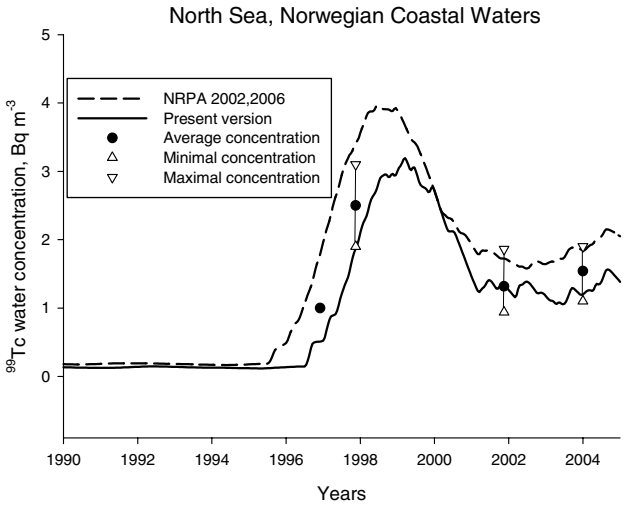


Figure 3. Average, minimal and maximal ^{99}Tc concentration in the North Sea in comparison with previous (dot line) and present (solid line) versions of the NRPA model.

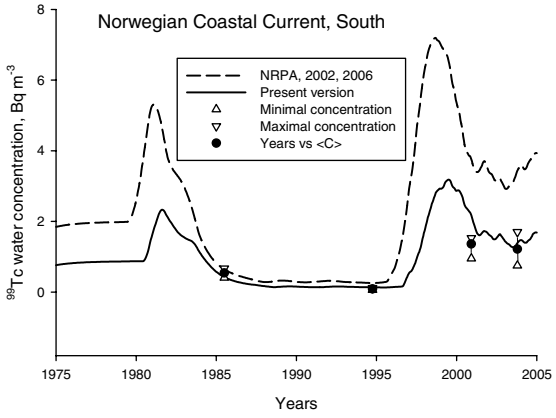


Figure 4. Average, minimal and maximal ^{99}Tc concentration in the south part of the Norwegian Coastal Current in comparison with previous (dot line) and present (solid line) versions of the NRPA model.

in Figure 1). Experimental data for ^{99}Tc distribution are shown in Figures 3–6 through average, minimal and maximal concentration in seawater in actual marine regions, where such information is available.

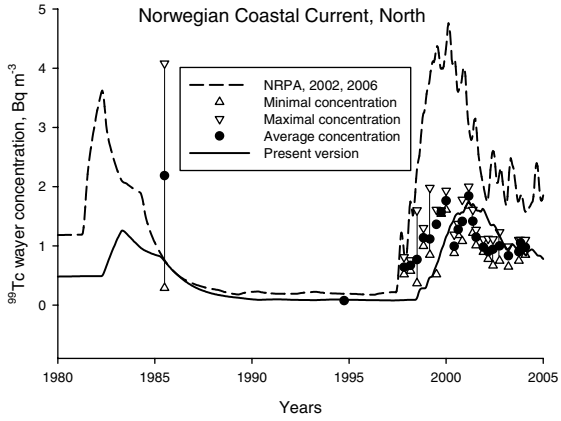


Figure 5. Average, minimal and maximal ^{99}Tc concentration in the north part of the Norwegian Coastal Current in comparison with previous (dot line) and present (solid line) versions of the NRPA model.

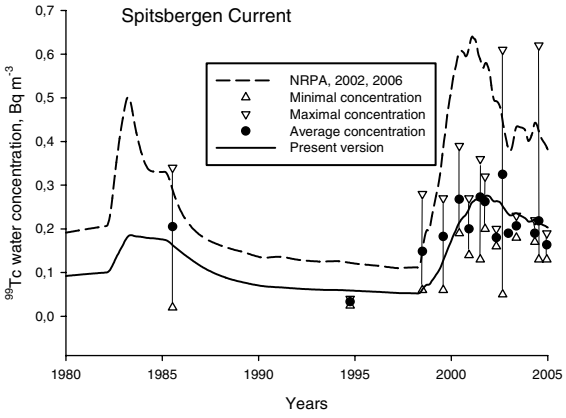
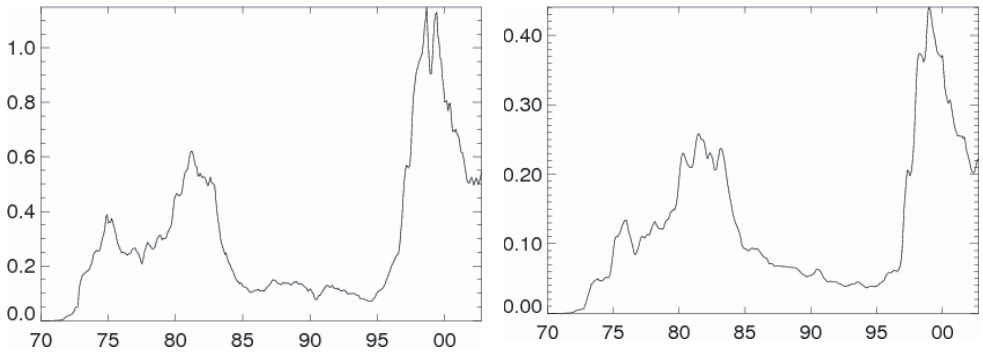


Figure 6. Average, minimal and maximal ^{99}Tc concentration in the Spitsbergen Current in comparison with previous (dot line) and present (solid line) versions of the NRPA model.

Results of the simulation show that for some compartments the differences between previous and present versions of the model relatively small (the North Sea, Norwegian Coastal Water). At the same time these differences are clearly significant for other compartments (the Norwegian Coastal Current and Spitsbergen Current) and indicate improved comparison with experimental data.

Comparison results of simulations between the NRPA model (Figures 5–6) and the *3D* hydrodynamic NAOSIM model [5] (Figure 7) demonstrate a relatively good agreement as for concentration levels and timing for signals in actual regions. This is especially important for following model improvement because even comprehensive data set cannot cover all actual marine regions particularly with time series.



a) b)

Figure 7. ^{99}Tc concentration in the (a) the north part of the Norwegian Current and (b) Spitsbergen Current simulated by the NOASIM model.

It is also interesting to note that parameters T_i of the model are in good agreement with the term "transit times". For instance, transit times from Selafield to the North Sea (Norwegian coastal waters) according to [7], and to the north part of Norwegian Coastal Current according to [8] are 3 and 3,5 $\pm$ 0,5 years correspondently, while the present model uses time of availability for these regions as 2,3 and 4,3 years.

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