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POSEIDON/RODOS MODEL FOR RADIOLOGICAL ASSESSMENT OF MARINE ENVIRONMENT AFTER ACCIDENTAL RELEASES: APPLICATION TO COASTAL AREAS OF THE BALTIC, BLACK AND NORTH SEAS

S. LEPICARD
Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN)
BP 48, 92263 Fontenay-aux-Roses, France

R. HELING
NRG, Department Radiation & Environment, PO Box 9035, 6800 ET Arnhem, The Netherlands

V. MADERICH
Institute of Mathematical Machine and System Problems, Prospekt Glushkova 42, Kiev, 03187, Ukraine

Abstract

In the framework of the developments of the European system RODOS for emergency response to nuclear accident (Real-time On-line DecisiOn support System), the computer code POSEIDON, that was developed to assess the radiological consequences of radioactive releases into marine environment, was adapted to cope with emergency conditions, in situations of radioactive discharges into the oceans from direct deposition from the atmosphere, sunken ships and containers, from discharges of rivers and estuaries and from coastal run-off. Based on the box model developed within the 'Marina' project, POSEIDON can calculate the dose effects from radionuclide releases in the coastal waters of Europe integrated over long time periods. A dynamic food chain model was implemented to deal with the short-term dynamical uptake of radioactivity by specific marine plants and organisms. POSEIDON has been installed on a UNIX platform to be fully compatible with RODOS input/output databases and on a Windows platform with an interface based on web-based technology. The 3-D hydrodynamic model THREETOX is part of the POSEIDON/RODOS system. It has been applied to coastal areas of the Baltic Sea, the Black Sea, and the North Sea, to derive the parameters for a flexible system of well-defined model compartments to be adapted to emergency conditions. The activity concentrations in water and in the marine food web were calculated by means of POSEIDON for radioactive fallout resulting from bomb testing, from the Chernobyl accident, and from routine discharges from nuclear facilities. POSEIDON's model results were compared with measurement data, and with calculation results from THREETOX. The model results agreed with the measurement data sufficiently.

1. INTRODUCTION

The "POSEIDON" PC software [1] was originally developed by the French institute CEPN on a PC-Windows environment, with the support of the French Institute for Nuclear Safety and Radiation Protection (IRSN), to assess the radiological consequences of regular and accidental releases of radionuclides in the coastal water of Europe. The box modelling approach described in the European methodology 'MARINA' [2] was directly adopted, to cope with the required large temporal and spatial resolution.

This existing code has been modified and coupled with the existing hydrological module HDM (Hydrological Dispersion Module), part of the decision support system for management of nuclear emergencies RODOS (Real-time On-line DecisiOn support System) [3]. This work was performed in the framework of the INCO-COPERNICUS programme, co-ordinated by the European Commission (1998-2000) under the 4th framework Programme.

The modifications of the original POSEIDON model were aimed to deal with short-term emergency conditions, characterised by short pulses of radioactivity in the marine environment, in a more adequate way. The following steps were made to achieve that goal:

- The coupling of POSEIDON with the 3-D hydrodynamic model THREETOX, to improve the spatial resolution of the compartment model in marine areas with significant circulation,
- The coupling of POSEIDON with coastal run-off models to deal with the land-to-sea transfer of radioactivity resulting from wash-off processes,
- The addition of a dynamic radionuclide uptake model for marine organisms, to the existing “concentration factor-based” biota model.

The “POSEIDON-R” system was developed for the UNIX environment, to be fully compatible with the databases and with the graphical user interface of the RODOS system, and for the PC-Windows environment, based on WWW-, DHTML- and CGI technology.

The predictive power of POSEIDON-R was investigated by comparing measured concentrations in water and biota in the Baltic Sea, the Black Sea and the North Sea, with calculated concentrations obtained from the model in these areas, taking into account the input of radioactive materials into the marine environment associated with bomb testing, with the Chernobyl accident and with the releases from nuclear facilities.

2. RADIONUCLIDE TRANSPORTTHROUGH THE MARINE ENVIRONMENT

The marine environment is modelled as a compartment system; the compartments are subdivided in several vertical layers (see Figure 2.1). Three compartments are used for modelling the bottom sediments, and several vertical boxes were used for the water column. The lower compartment of the water column is referred to as “near bottom box”.

Inherent to box modelling is the assumption of complete homogeneity: each compartment is assumed to be full-mixed, and the parameters values (e.g. suspended sediment load, sedimentation rate, depth) within the volume of the compartment are assumed to be constant.

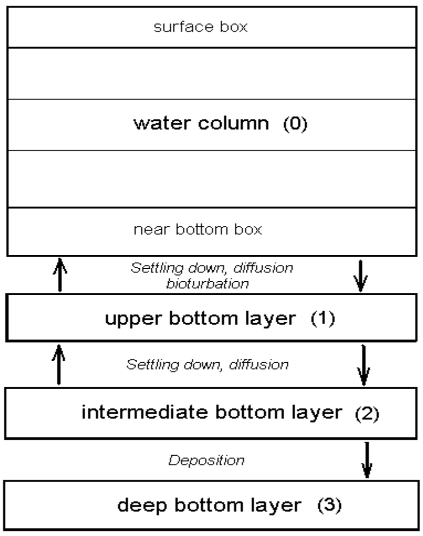

Figure 2.1 Structure of a generic compartment of the model

In the model the dispersion of radionuclides released in the marine environment is described by the water exchange between the compartments, by the exchange of radionuclides between the dissolved and the particulate phase via sorption processes, and by the remobilisation from the bottom sediments into the water layers due to bioturbation.

Radionuclides are transferred to the bottom sediments by the sedimentation process, settling particles scavenge dissolved radionuclides from the water layer. Diffusion and bioturbation (modelled as a diffusive process) operate on the boundary layer. The transfer of radioactivity from the upper sediment layer to the water column is described by diffusion and bioturbation. Radioactivity in the upper sediment layer migrates downwards by diffusion and by burial (caused by the ongoing settling of particles). The upwards transfer of radioactivity from the middle sediment to the top sediment layer occurs only by diffusion. Burial causes an effective loss of radioactivity from the middle to deep sediment layer. The model assumes a constant equilibrium between dissolved and particulate radioactivity, described by a distribution coefficient, in the literature often referred to as ‘K_d’.

To evaluate the radiological effects of daughter nuclides, the entire decay chain is taken into account when a significant dose contribution from the daughter nuclides is likely.

To assess the near-field radionuclide concentration close to the source, a “local” compartment can be coupled to the regional compartment system. These local compartments can be either pre-described in an input file or can be automatically determined by the system on the basis of the selection of the exact release location in the basin (near surface, inside water column, on the bottom). This option may be of particular interest for simulating the radiological consequences of releases of radioactivity from objects located on the seafloor such as sunken ships sunken submarines, or dumped vessels with nuclear waste.

3. TRANSFER OF RADIOACTIVITY THROUGH THE FOOD CHAIN

The original module for predicting the radionuclide concentration in marine biota was based on the steady-state approach, which assumes in a way very similar to the water-to-sediment exchanges as previously described, a constant equilibrium between the radioactivity concentration in water and in marine organisms, through the concentration factor ‘CF’.

This CF-approach is valid for long-term releases, when equilibrium between organisms ad the surrounding seawater can be reached. In the case of pulse releases situations however, the transport time of radionuclides in the marine environment close to the source, has a shorter time scale than the retention time in marine organisms and than the transfer times within the food web. To evaluate the radioactivity in the marine biota close to the source, it is therefore important to include the dynamical uptake behaviour of the various organisms and to take into account the prey-predator relationships of the marine food chain. This method results in a delayed response of the levels of radionuclides in the biota on a pulse of radioactivity in the seawater. This avoids both overestimations of radioactivity in organisms in the period of increasing concentration in the seawater, and underestimations in the period of decreasing after the peak concentration. For that purpose, an existing dynamic model of for the aquatic food chain [4] was modified for the marine environment, and implemented into POSEIDON (BURN-POSEIDON).

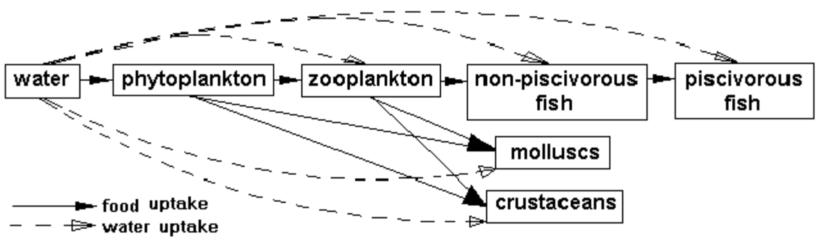

Figure 3.1 Schematic “BURN-POSEIDON” dynamic food chain and uptake model.

4. ARCHITECTURE OF POSEIDON-R AND COUPLED MODULES

POSEIDON-R was implemented on a UNIX platform for its compatibility with RODOS system. It can also be used as stand-alone software. POSEIDON-R includes simulation modules and a graphic user interface, based on client-server technology. The “RODOS RtGraph” task server allows the execution of the different modules on computers with different operation systems. The WWW graphic user interface simplifies the final use in decision-making. POSEIDON-R is accessible from any computer through Internet Web-browsers. The Hydrological Dispersion Module of RODOS is designed to evaluate the dose effects from the aquatic exposure routes, and POSEIDON completes the set of aquatic systems already covered by the different hydrological models. Therefore, in order to match the model requirements of the RODOS system, POSEIDON-R has been fully coupled to the hydrological models of hydrological module HDM of the RODOS system. The various models are briefly described below.

THREETOX is a 3D-hydrodynamical model designed for the calculation of the hydrodynamics of aquatic systems (flow, fluxes, currents, circulation), and for radionuclide dispersion of aquatic systems, developed by “IMMSP”, Ukraine [5]. Unique is, that this 3D model has been used to define the compartment structure of the POSEIDON model, and to find parameter values for the POSEIDON model. Not only offers this module the possibility to calculate the water fluxes between regional and local compartments (around the nuclear installation where the radionuclides are released during an accident), more precisely, also seasonal fluctuations of important parameters such as salinity, sediment characteristics and water temperature can be taken into account

RETRACE model was developed by SPA “Typhoon”, Russia [6], for the modelling of radionuclide wash-off from coastal zones.

DELTA/HYDRO is a distributed runoff and channel routing code for watersheds of complex topography, developed by NCSR “Demokritos”, Greece [3], for mountainous areas. The code has been further improved to be coupled with POSEIDON-R. DELTA/HYDRO is complementary to RETRACE-P, and is applicable to small mountain watersheds.

5. DOMAIN OF UTILISATION

As in the model developed in the “MARINA I” study [2], the spatial domain of the original POSEIDON model covers the European coastal waters seas, with compartments of variable size. To improve the compartments structure of original POSEIDON model for discharges in the Black Sea and the Baltic Sea, THREETOX has been customised on these two seas to derive the necessary model parameters for POSEIDON-R. This led to the improved compartment structures as shown in Figure 5.1.

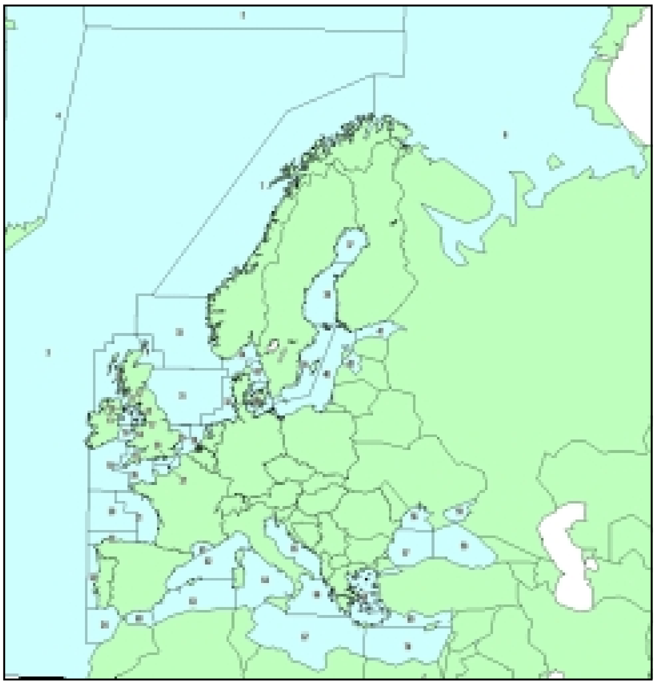

Figure 5.1 Compartment structure of POSEIDON-R

POSEIDON-R can deal with multiple sources of radioactivity. These sources can be described independently in time and space, each being connected to a different model compartment. Inputs can be of different nature: atmospheric fallout, river and estuaries discharges, coastal run-off, routine discharges from nuclear plants or point releases in any given location.

6. CASE STUDIES AND COMPARISON OF THE MODEL RESULTS WITH MEASUREMENTS DATA

POSEIDON-R model predictions have been compared with measurement data on environmental ^{137}Cs in the Baltic Sea, the Black sea and the North Sea. Data collected from 1961 to 1995 in the framework of MARINA-BALT study [7] were used for the Baltic Sea data comparison. Additional data on radionuclide concentrations in different kinds of fish were also provided by SPA "Typhoon" Russia. Measurement data for the North Sea (1985-1990) were collected by NRG, whereas Black Sea measurement data (1985-1991) on the radionuclide concentration in water and biota were collected and processed by NIMH, Bulgaria, and by SPA "Typhoon". Calculations have been carried out with the POSEIDON-R model for the time period 1950-2000. Sources of radioactivity considered for the comparative study included fallout from atmospheric nuclear bomb testing, fallout from the Chernobyl accident, and discharges of radionuclides from reprocessing plants and other nuclear installations.

Comparison results are presented on Figure 6.1, showing a scatter plot of observed versus predicted concentrations of ^{137}Cs in the Baltic Sea water. The solid line represents the ideal relationship. It clearly demonstrates, that the predicted radionuclide concentrations in water are in good agreement with the measurements. The results of simulation of ^{137}Cs concentrations in the fish and measured values are presented in Figure 6.2 for the Black Sea. Here, non-piscivorous fish is represented by a solid line, and piscivorous one by a dashed line. A good agreement was found, mainly due to the improved structure of the box model by using the 3D model THREETOX, and due to the implemented dynamic food chain model.

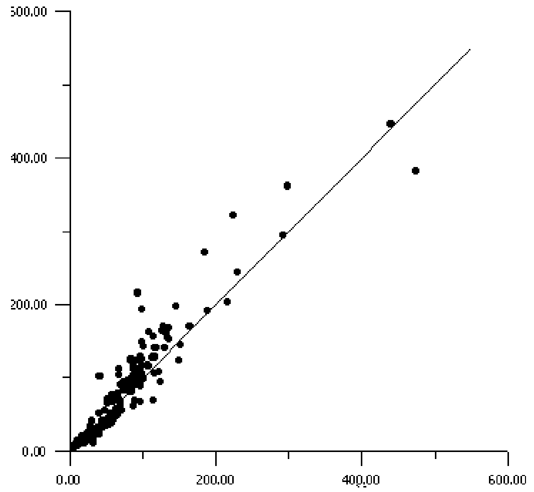

Figure 6.1 Computed vs. measured concentrations of ^{137}Cs in the Baltic Sea

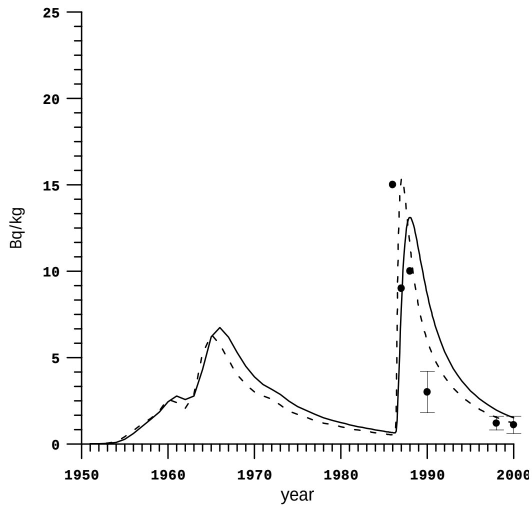

Figure 6.2 Computed ^{137}Cs concentration in fish vs. measurements for West Black Sea (surface compartment no 6)

In September 2000, one months after the Russian submarine "Kursk" sank in the Barents Sea, the POSEIDON-R model system was used to predict the environmental and radiological effects of a hypothetical discharge of radionuclides from that sunken submarine, on the basis of instantaneous release scenario, and permanent release scenario in the case the Kursk should permanently remain on the seafloor – it was not decided at that time to lift the submarine. The 3D hydrodynamical model THREETOX and the box model POSEIDON-R were combined to estimate the local and medium-scale effects and the regional and long-term effects. The results obtained with THREETOX showed that for the worst case scenario (instantaneous release), the activity concentration in the water column increased significantly only in a relatively small area and for a relatively short time period. Meanwhile the bottom contamination increased by one or two orders of magnitude from the background level in the accident area. If assuming a continuous release, the concentrations in the water, bottom and in biota, calculated by both models, were much lower than the background levels. This test demonstrated the successful operational use of POSEIDON- R in an – possible – emergency with a nuclear installation.

7. CONCLUSION

POSEIDON-R is the result of a two year collaboration project, in which a group of experts, both in the field of hydrological modelling and software design, worked closely together to achieve the main project objective, i.e. the implementation of the dispersion model "POSEIDON-R" into the RODOS decision support system for radionuclide dispersion and dose assessment.

Coupled with different complementary hydrological modules and a dynamic food chain uptake model that can be used to customise the software in a region of particular interest, POSEIDON-R is adapted to the evaluation of the dispersion of radioactive pollutants in accidental and routine situations, including a large spectrum of input sources: atmospheric fallout, rivers and estuaries discharges and coastal run-off. POSEIDON-R has also been used to compare model predictions with environmental ^{137}Cs measurements data in the Baltic Sea, the Black Sea and the North Sea.

The outcome of this project is adding functionality to the RODOS Decision Support System, and the modern web-technology and the use of the RtGraph server might stimulate the future increase of the flexibility of the RODOS system. Furthermore the enhanced vertical and horizontal compartment structure and use of 3D hydrodynamical model as tool might serve the innovation of the existing marine dispersion model as used in dose assessment codes such as PC-CREAM, POSEIDON-PC and other related projects. Extending the model structure by the present marine compartment model for the Arctic area will bring the compartimentation to the state-of-the-art level.

REFERENCES

[1] Lepicard S., Raffestin D., POSEIDON 3.0 – Logiciel pour l'évaluation des impacts radiologiques en milieu marin, CEPN-L-99/2, 1999.

[2] MARINA I European Commission (1990) The Radiation Exposure of the Population of the European Community from Radioactivity in North European Marine Waters Project 'Marina', RP 47, EUR 12483.

[3] Heling R., Lepicard S., Maderich V., Shershakov V., Mungov G., Catsaros N., Popov A., POSEIDON Final Report, A module to predict the effects of radioactive discharges in the coastal regions, Edited by NRG-Arnhem (NL), 2000.

[4] Heling, R., Niculae, C. MOIRA Project. The radiostrontium uptake model. Testing Burn98 on freshwater ecosystems.1999. NRG Report P20071/99.5597/P.

[5] Margvelashvili N., Maderich V., Zheleznyak M., THREETOX - computer code to simulate three-dimensional dispersion of radionuclides in homogeneous and stratified water bodies. Radiation Protection Dosimetry, Vol.73, 177-180, 1997.

[6] Heling R., Zheleznyak M., Raskob W., Popov A., Borodin R., Gofman D., Lyashenko G. Marinets A., Pokhil A., Shepeleva T., Tkalich P., Overview of modelling of hydrological pathways in RODOS, Radiation Protection Dosimetry, Vol.73, No.1-4, pp.67-70, 1997.

[7] Veleva B., Koziy L., Yushchenko S., Maderich V., Mungov G., Assessment of radionuclide contamination in the Black sea using POSEIDON-RODOS system, Radioprotection Vol. 37, In Proceedings of the Congress on the radioecology - ecotoxicology of continental and estuarine environments ECORAD 2001.

[8] MARINA BALT - Nielsen S. P. Ed. (2000) The radiological exposure of the population of the European Community to radioactivity in the Baltic Sea. Marian-Balt project. Proceedings of a seminar held at Hasseludden Conference Centre, Stockholm, 9 to 11 June 1998. Edited by Directorate-General Environment.