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MODEL TESTING OF RADIOACTIVE CONTAMINATION CS-137 OF SOILS AND BOTTOM SEDIMENTS IN THE ROMACHKA RIVER (TOMSK REGION, RUSSIA)

O.S. Dmitrieva[1,2], L.P. Rikhvanov[2], P. Boyer[3], C. Quantin[1]

[1]University of Paris Sud, IDES, Orsay Cedex, France

[2]Tomsk Polytechnic University, Tomsk, Russia

[3]Institut de Radioprotection et de Surete Nucleaire (IRSN), France

This paper presents results of testing models for the radioactive contamination of river water and bottom sediments by ^{137}Cs. The scenario for the model testing is based on data from the Romashka River, which was contaminated as a result of accidents at the Siberian Chemical Combine (Russia, Region of Tomsk). The input data include the following: estimates of inventories of ^{137}Cs in the floodplain of the downstream part of Romashka River; the estimated annual runoff of ^{137}Cs from the downstream part of Romachka River; data on the precipitation, hydrological and hydrochemical characteristics of the river. The endpoints of the scenario are model predictions of the activity concentrations of ^{137}Cs in water and bottom sediments along the Romachka River in 2012–2013. Calculations for the Romashka scenario were performed by the Institute of radioprotection and nuclear safety (model CASTEAUR and HAMSTER. As a whole, the radionuclide predictions for^{137}Cs for all considered models. At the same time the CASTEAUR model estimate the activity concentrations of ^{137}Cs and in water more precisely than in bottom sediments.

Key words: contamination, water, bottom sediments, tom river, model, testing.

Introduction

During last decades, a number of projects have been launched to validate models for predicting the behaviour of radioactive substances in the environment. Some of these projects were dedicated to the prediction of the behaviour of the radionuclides in the freshwater environment (Onishy, 1994; Kryshev et al., 1999; Monte et al., 2000, 2002). Both the BIOMOVS (BIOspheric Model Validation Study; BIOMOVS, 1990) and the VAMP (VAlidation of Model Predictions; IAEA, 2000) projects stimulated intensive efforts at improving the reliability of the models aimed at predicting the migration of ^{137}Cs in lakes (IAEA, 2000) and of ^{137}Cs in rivers (Smith et al., 2004).

The scenario for the present model testing is based on data from the Romashka, Pesotchka Rivers (Siberia, Russia), which ware contaminated mainly during the period 1978–1993 as a result of discharges of liquid radioactive waste into the river [1]. The Romashka River is an appropriate aquatic system for the assessment of radioactive impact on human populations and the natural environment, as well as for studying the processes of radionuclide migration and accumulation. The results of this work can help in assessing the capabilities of the models to deal with the processes that drive radionuclide transfer in river systems and more specifically to the bottom sediments.

Context

Contamination of rivers and soils of the Tomsk region by domestic, urban and industrial activities: consequences on the metal dynamics in the Tom River catchment.

This paper aims at studying the impact of the present anthropogenic activities in the region of Tomsk on the contamination of soils and rivers located in the Tom River watershed. This river, which joins the Ob downstream to Tomsk, receives waters of Ushayka, river crossing the city of Tomsk from east to west, and those crossing the Siberian chemical complex (SCC) of Seversk, the so known under the name of Tomsk-7, situated 15 km downstream to Tomsk. The Ouchaika River drains forest and agricultural areas upstream then the city of Tomsk, in particular the East part of the city, in which are implanted various chemical and petrochemical industries. Furthermore, the city of Tomsk rejects important quantities of domestic effluents in Ushayka

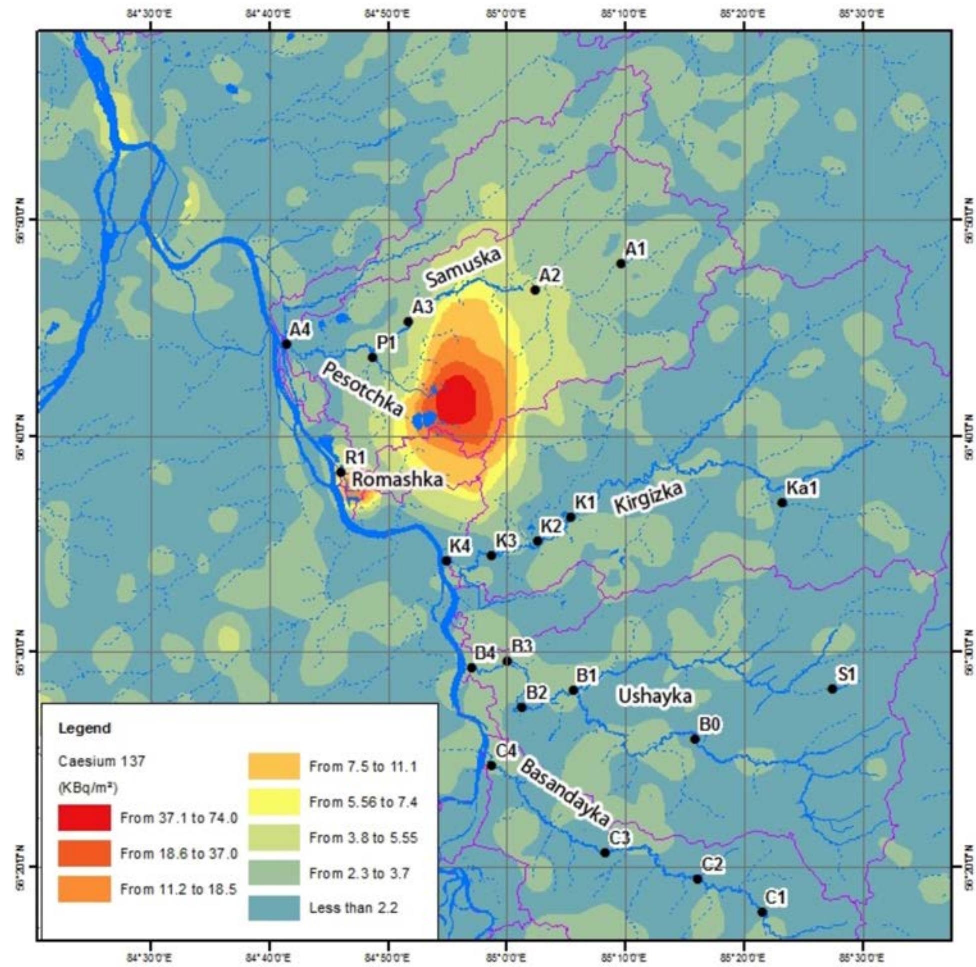

Fig. 1. *Watersheds of study area (sampling map) and caesium contamination of soils around SCC*

River. The SCC of Seversk, originally dedicated to the military nuclear power, contains 5 nuclear reactors out of function, dedicated to the production of electricity and plutonium, various radiochemical and chemical installations, as well as numerous ponds of storage of radioactive wastes. Seversk is crossed the Romashka channel. The studies led further to the accident of 1993 revealed a strong contamination in radionuclides (^{137}Cs, ^{90}Sr, I, U, Th) of the areas situated at once on the West by Seversk drained by the Romashka channel, as well as in the North towards the river Samuska. If some studies have shown that the SCC of Seversk contributed significantly to the contamination of the Ob [2, 3], situated in hundreds of km downstream, no information is available concerning the impact of the global urban and industrial activities of the region of Tomsk on the quality of waters and soils surroundings.

In the urban watersheds, the main "natural" and anthropological sources of contamination are the atmospheric deposits, the erosion of soils, channel banks and deposits of alluvial plain, runoff, leaks of sewer systems when they exist, the effluent discharges directly in channels, industrial or mining activities, automobile activity, or remobilisation from bottom sediments.

The methods used for this study involved hydrological and soil science investigations, bulk and isotopic geochemistry, mineralogy, spectroscopy alpha, beta, gamma.

Description of the Tom river scenario

A number of industrial facilities of federal significance are functioning in the town of Tomsk and its vicinity. They are: the Siberian Chemical Combine, the Tomsk Oil-Chemical Combine, radio-technical, instrumental, electrotechnical and other plants mostly belonging to the military-industrial complex.

Fig. 1 demonstrates that, according to the survey data, an increase of Cs-137 is detected not only to the north-east from the SCC along the main wind rose, but to the south-west as well, forming local spots of soil contamination by this radionuclide with the fallout density up to 10–20 kBq/m^2 (between the Prosino and Gubino villages) and increased accumulation with 2–3-fold excess relatively to the regional background (1,85 kBq/m^2).

Description of the model Romashka river: Run-off modelling with HAMSTER

There is the modeling of the average annual flow of run-off and analytical solutions adopted in the case of

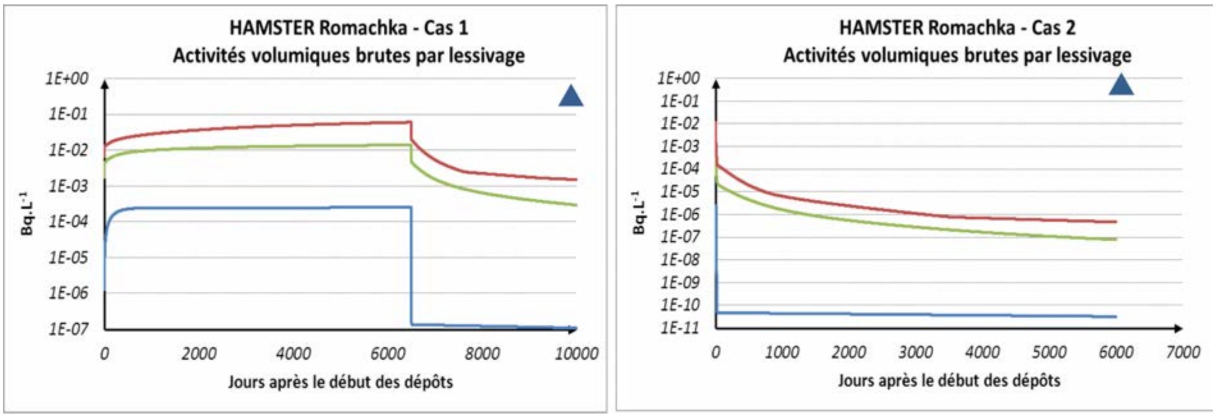

Fig. 2 and 3. *Hamster modeling application for Romashka river*

atmospheric deposition of accidental types modeled by a square-wave signal. This evaluation has two major sources of uncertainty related to the modeling of run-off (a transfer function), and the related modeling source term.

Surface catchment of the Romashka River is equal to 110 km^2. Total deposit: 3,7 E^{11} Bq (crossing deposits and surfaces watershed)

Uncertainties on deposit periods suppose two scenarios:

– Case 1) Constant deposit during operated period.
– Case 2) Single deposit after the last accident with Cs^{137} (1978) (Figure 2 and 3).

Concentration levels observed in the Romashka river cannot be explained by the run-off of Cs^{137} deposited on the watershed, but mostly by direct discharges during operation of the site.

Model CASTEAURv0,1

Four modules of the code CASTEAURv0,1 were used: hydrographical, hydraulic, sedimentary and radioecological models for the water and the solid matter [1].

– The hydrographical model describes the geometry of the river. Based on a succession of reaches, constituting a linear hydrographic network, the aim of the model is to give a linear grid as a function of a precise space step determined by the user. To this end, a simplified trapezium bathymetric form is considered to describe the sections. The variables are the hydrographical parameters at each space step: length, width, bank angle and slope. The input data are a linear succession of reaches.
– The hydraulic module assesses the spatial and temporal evolutions of the water column. The modelling is based on two equations allowing the determination of the water flow and the water depths.
– The sediment model calculates the stocks and the fluxes of matter in the water column and the bottom sediments. The model can take into account several classes of matter and considers three bottom sediment layers: an interface, an active and a passive layer. The interface layer is a very fine layer, recent deposited but not yet compacted. It is assumed that whatever the matter, their behaviour in this layer is always non-cohesive. The active layer results from the compaction of the interface layer. It is called active because the interstitial water remains sufficiently mobile to allow the dissolved radionuclide phases to be exchanged with the column by interstitial diffusion. The compaction of the active layer feeds the passive layer. In this third layer consolidation becomes strong enough to reduce the mobility of interstitial water and the exchange of dissolved radionuclide phases become negligible. The bottom sediment layers are characterized by: maximal thickness of the interface layer, water content of the interface layer, maximal thickness of the active layer, water content of the active layer, coefficient of consolidation of the active layer, water content of the passive layer, and coefficient of consolidation of the passive layer [4, 5].
– The radioecological model uses the results provided by the hydraulic and sediment models to compute the spatio-temporal distributions of the radionuclides activities (Bq) in their dissolved and solid forms in the different compartments: water column, interface, active and passive layers. Considering the small thickness of the interface layer, an equilibrium hypothesis between this layer and the water column is assumed. Thus, these two compartments are combined in the radioecological model [6, 7].

The variables of the radioecological model are the activities in the different components: dissolved and particulate activities in the water column, in the interface, active and passive layers.

The input data are: radioactive decay, coefficient of equilibrium between dissolved and solid phases, specific radionuclide import under particulate and dissolved phases [9].

Two kinds of radionuclide fluxes are taken into account: between reaches and components, and between solid and dissolved phases.

Description of the Tom River scenario

The present model is able to predict distribution of radioactive elements in the bottom sediments, water of the Romachka river. Input parameters are flow (Q), coefficient of Kd, suspended matter disribution, Caesium inventory within the watershed and chronology of accidents.

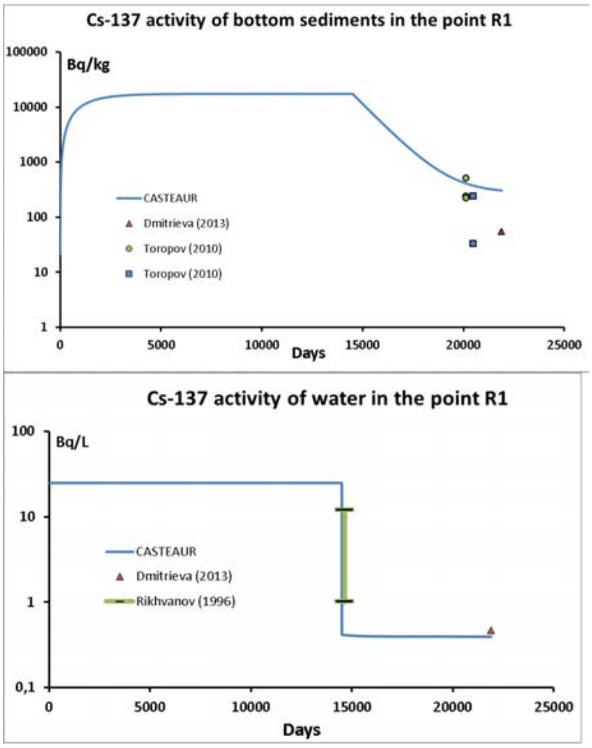

Fig. 4 and 5. *Casteaur modeling application for Romashka river*

Conclusion

Results feature good qualitative and quantitative agreement with experimental data. Field results indicate metal contamination of suspended matter and soils, radioactive contamination of soils and bottom sediments

For ^{137}Cs the agreement between empirical data and model predictions was good, but not for all the observations of ^{239,240}Pu in the river water-bottom sediment system. The modelling of ^{239,240}Pu distribution proved difficult because, in contrast to ^{137}Cs, most of models have not been previously tested or validated for plutonium.

As shown in this paper, models make use of different hypotheses to approach the complex problem of modelling the physical and chemical behaviour of radioactive substances in water bodies. The equations that are used by models represent more or less coarse approximations of complex processes that, in principle, depend on a variety of environmental, hydraulic and hydro chemical characteristics of the water body.

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