Informational and modeling computer system for prediction, estimation and analysis of radioactive contamination of surface water objects

S. Kazakov, V. Kisselev, A. Krylov & N. Zhilina
Ecological Modeling Dep., IBRAE, Russia

Abstract

The given work presents description and practical representation of the system of computer models for estimation and analysis of consequences of radioactive accidents and other releases of radionuclides to surface water objects. A number of models are integrated in specialized geographical informational system (GIS). The GIS is based on the Mapinfo Professional ©.

The variety of models on prediction of concentration of radionuclides in water, suspended particles and bottom sediments in various types of water objects (rivers, lakes, etc.) is stipulated by large zones of influence of radioactively dangerous objects and thus broad circle of water objects potentially in danger. The models are integrated in the number of confined chains that enable full calculation from accident parameters to resulting pollution and health harm. On the base of calculated results appropriate actions are recommended.

Estimation can be done with minimum input data. But accuracy of predictions can be increased; more processes and factors can be taken into account if additional data is available. The System is «open» so it can be expanded and improved by other models. The system is designed to support decision-making on population protection in an emergency situations and radioactively dangerous objects projecting. The models were developed with the use of modern information technologies.

Some of models were validated on the Chernobyl accident contamination data and Mining and Chemical Combine (Krasnoyarsk region, Russia) contamination data. The system is in use in 'ROSENERGOATOM' Technical Crisis Center (TCC) in Nuclear Safety Institute of Russian Academy of Sciences.
Introduction

There are plenty of models for evaluation of radioactive contamination of water objects, for prediction of behavior of radionuclides in them, for estimation of population exposure, for analysis of possible health harm. The aim (and the result) of given work is an integration of several ecological and mathematical models into confined chain (see Figure 1).

Such integration (on the base of specialized geographical informational system) makes this system convenient for evaluation of radioactive accidents consequences, for calculation of limits of radioactive emission into water objects, for estimation of possible harm from various radioactively dangerous actions. This system should be convenient tool for decision support for radioactive safety professionals responsible for environment and population protection.

For this purpose we have developed an integrated system of computer models “Kassandra” (see Figure 2), which allows one to predict operatively consequences of radioactive pollution for wide variety of water objects.

The system has following main advantages:
1. The computer models are integrated into the confined chain. No data other than hydrology data, data on local population and appropriate information about an accident (atmospheric discharge, wastewater discharge etc) is necessary for radioactive doses and radioactive risk prediction and for developing recommendations on environment and population protection. Quick “from start to end” prediction is possible.
2. The system allows express-predictions with minimum input data available.
3. The system allows step-by-step prediction accuracy increase when additional information becomes available. In this case additional processes (and other factors affecting prediction results) can be taken into account. And they can be accounted more accurately.
4. The system is integrated with models of atmospheric propagation and fallout.
5. Coefficients, parameters, etc, that are necessary for predictions and analysis, are available as an appropriate databases.
6. The system enables one to use experimental data for further calculations instead of intermediate calculation results. That permits one to increase accuracy of final results (if experimental data are available).
7. The system is flexible. It is possible to use it jointly with other models. It enables one to use most appropriate models in each particular case.
8. GIS tools provide one with access to electronically stored geographical data, enables prompt, easy and convenient analysis of situation (see Figure 3).
9. Computer models included in the system are easy to use and have user-friendly interface.
10. It is possible to get final and intermediate results (at any stage) for an external processing. The system also gives one an opportunity to evaluate sensitivity of results to input data.
11. Some models were validated on the experimental data on contamination resulting from Chernobyl accident.
12. The models are in agreement with recommendations of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and environmental legislation of Russian Federation.

Description of the system

The system consists of the following elements:
1. Specialized geographical informational system Komponovka (based on GIS Mapinfo).
2. The model for prediction of radionuclides migration in simple low-flow water objects (computer model Basin).
3. The models of long term radionuclides migration in rivers (computer model Basin).
4. Model for prediction of radionuclides migration in steady flow rivers and near-shore zone of sea or large lake (computer model Rivlak).
5. The model for estimation of internal and external exposure for various groups of population (waterways of exposure). This model also evaluates radioactive risks and develops appropriate recommendations (computer model Inter).

Description of the models you can find in (Vorobiev [1]).

The system “Kassandra” requires hydrological data. GIS-based computer hydrological maps do exist nowadays. More precise information concerning basins (type of sediments, water humidity etc) could be found in special hydrological reference-books (see Elshin [2] for example). On the preparatory this information should be accumulated in GIS databases. Also information about various population groups rations and types of external activities should be collected and stored.

All these actions are carried out on the preparatory stage (before an accident). After that the scheme of operation of the system depends on:
1. Prediction objectives
2. Prediction time
3. Ways of radionuclides inflow into a water object.
4. Availability and reliability of input data
5. Particular properties of a water object

We will describe the scheme of “Kassandra” operation with the aid of an example. Let the contamination of a water object resulted from an atmospheric fallout of radionuclides. Let the information of radionuclides fallout was received from a computer model of atmospheric migration and fallout of radionuclides. The variety of such models was developed in our Institute. In this case data on atmospheric fallout is presented spatially (with no link to water objects). Then Komponovka determines intersection of contaminated area and local hydrology, and prepares information on contamination of each specific water object.
Radionuclides emission → Surface contamination

Wastewater discharge → Water object contamination → Prediction of radionuclides migration

Estimation of population exposure → Development of appropriate recommendations

Geographical (hydrological) information → Experimental data on surface contamination or results of calculations by an atmospheric propagation and fallout model or data on contamination from another source

Another ways of contamination → Geographical-informational system Komponovka → Computer models of radionuclides behavior prediction in water objects

Results:
1. Radioactive contamination prognosis
2. Estimation of doses
3. Estimation of risks
4. Recommendations on protection measures

Computer model Inter → Evaluation of internal and external exposure doses

Figure 1: Chain of models.

Figure 2: System structure.

After that depending on type of the water object a model for radionuclides migration behavior prediction is chosen. For simple water objects the Basin model is used, for rivers – one of the river models. On this stage other ways of contamination (wastewater discharges, washing out of the contaminated water collection area, secondary contamination of water from the sediments) could be taken into account.
Figure 3: Water objects colored depending on their contamination.

Figure 4: Example of comparison of modeling results and experimental data.

Then contamination of the water object is predicted for some period of time. Resulting contamination of water and sediments is delivered to the model “Internal and external exposure” Inte. After that according to collected previously data on population groups rations etc doses are estimated. The
estimation results are compared to appropriate limits. On this base computer model Inter analyzes critical (contributing most) ways of exposure and issues appropriate warnings and recommendations if necessary.

The results (final and intermediate) can be presented as graphs or maps. They also can be printed or reviewed interactively.

The system can operate without any of its parts or with another external model attached.

The system has bilingual (Russian and English) interface.

Models description

Computer model for radionuclides' migration prediction for radioactively contaminated simple low-flow water objects (BASIN).

From the large spectrum of models we have chosen the model described in (Vorobiev [1]). The reasons are following:

1. This model was developed for the type of water objects that is prevailing in Russia.
2. This model is supplied with real coefficients and parameters necessary. So it can operate with minimal input information.
3. The model was validated on the experimental data.

The method of calculation of radionuclides concentration in water and sediments is based on the well practically worked out two-chamber model of ideal mixing radioactive impurity. The model reflects exchange processes between radionuclides dissolved in water, sorbed on suspended particles and sited on sediments. Main processes of radionuclides transfer are: running water outflow out of the basin bounds; sorption and desorption of radionuclides; sedimentation of suspended particles; stirring up of contaminated sediments; diffusive exchange of radionuclides between water and sediments, etc.

The model was validated on the experimental data on contamination (resulting from Chernobyl accident) of water and sediments of five lakes: Chernobyl Nuclear Power Plant cooling pond (Kazakov [3]), Svyatoe Lake (Vorobiev [4]), Bracciano Lake (Monte [5]), Esthwaite Lake and Windermere Lake (McDougall [6]). Comparison shows that the model correctly reflects the experimental results in general (see Figure 4). But in some experimental points one can see deviations. Such deviation could be explained by the following:

1. Somewhat lack and inadequacy of experimental data concerning local hydrology and contamination scenario
2. Some disadvantages of the model.

Nevertheless the comparison results shows that the model is applicable to water objects which fit the model demands.
Models of long term radionuclides migration in rivers

There are two models of long term radionuclides migration in rivers in the "Kassandra". Both are included in computer model Basin.

The first takes into account following processes: inflow of radionuclides from sources of radionuclides, advection, turbulent (and any other) dispersion, radioactive decay, outflow of radionuclides, sorbtion and desorbtion of radionuclides on suspended particles, sedimentation of suspended particles, stirring up of contaminated sediments, running water outflow out of the basin bounds, diffusion of radionuclides in bottom sediments, diffusive exchange of radionuclides between water and sediments, evaporation and other water losses, etc.

The second model is the simplification of the first one. In this model the process of diffusion of radionuclides in bottom sediments is neglected. It is also assumed that:
1. Radionuclides in water and in bottom sediments are in equilibrium constantly
2. Characteristics of a river varies slightly in the time
3. Concentration of radionuclides varies slightly along the riverbed.

This model reduces the system of differential equations of the first model to single equation. And allows one to estimate roughly the speed of radionuclides migration along the river even without solving this equation.

Validation of this model is carried out now. The results of modeling are compared with experimental data on the contamination of the Yenisei river resulting from operation of Mining and Chemical Combine (Krasnoyarsk region, Russia).

Model for prediction of radionuclides migration in steady-flow rivers and near-shore zones of seas or large lakes (Rivlak)

This computer model is designed to model short-term radionuclides migration in steady-flow rivers and near shore zones of seas and large lakes. The model takes into account following processes: inflow of radionuclides from a source of radionuclides, advection, turbulent (and any other) dispersion, radioactive decay, outflow of water.
Figure 5: Model of long term migration in rivers (computer model Basin).

Figure 6: Internal exposure model (computer model Inter).
Computer model “Internal and external exposure (water ways)” /INTER

For decision making on radioactive protection along with radioactive contamination prediction, estimation of possible health harm for different population groups is required. For that purpose prediction of doses and radioactive risks is necessary. To find easiest way of reducing negative effects, one should find out what contributes most to final doses. These problems are solved by the computer model “Internal and external exposure” (Inter). This computer model was developed according to Nuclear Safety Regulations [7]. Similar models are recommended by U.S. Nuclear Regulatory Commission [8], Bundesministren Des Innern (Germany) [9].

This model is designed for prediction of doses of internal and external exposure (related to water objects), for estimation of risks and developing of appropriate recommendations. The model estimates effective dose (dose on an entire body) and equivalent doses for separate organs of human organism. It compares results to appropriate standards. This model takes into account the following ways of exposure related to water objects: exposure from consumption of contaminated food and drinking water (internal exposure); exposure from swimming, boating, staying at the beach, etc (external exposure). The model requires no information concerning contamination which cannot be calculated by computer models for prediction of radionuclides behavior in water objects (in our case this is radionuclides concentration in water and sediments). Computer model Inter is “quick”. So it can be used in extreme situations. One of the advantages of the model is its ability to estimate contribution to resulting dose of every radionuclide, every type of food and every type of external activity. So, one can determine critical (contributing to resulting doses more than others) ways of exposure. It enables reducing of doses with minimal side effects. For example, avoiding of consumption of some type of food responsible for the largest part of resulting doses may be the easiest and the cheapest way of population protection.

Conclusion

The system is in use in 'ROSENERGOATOM' Technical Crisis Center (TCC) in Nuclear Safety Institute of Russian Academy of Sciences. The prototype of the system was used on Command and Headquarters Training “Polyarnyc Zori - 95”. This Practical Game was held by EMERCOM and UN Department of Humanitarian Affairs and took place in Murmansk region, Russia in May of 1995. Some screen samples you can see in Figures 5 and 6.

In future we are going to give attention to additional processes and more complex models. We are also going to expand our database of coefficients and parameters and to validate on experimental data the rest of our models.
References


[5] Monte, Fratarcangeli, S., Pompei, F., Quaggia, S., Andrasi G., Modeling the behavior of $^{137}$Cs, $^{134}$Cs and $^{90}$Sr in lake systems, (results of research carried out using radioactivity measurement data collected following the Chernobyl accident), ENEA, ISSN 0393-6309, RT/PAS/89/31.


