Scenario FP

Wash-off of ^{90}Sr and ^{137}Cs from the Floodplain into the Pripyat River

ABSTRACT

The "Floodplain" scenario (scenario FP) was developed to test models concerned with the movement of trace contaminants from soil to surface water during flooding events. In particular, this scenario provides an opportunity for (1) evaluation of the movement of contaminants from the floodplain to the river, (2) calculation of the alteration and migration of contaminants in soil, (3) increased understanding of contaminant transport in the soil-water system at the process level, (4) development and testing of methods for estimating key parameters, and (5) assessment of the effectiveness of hydrological countermeasures.

The Scenario is based on 3 flooding events which took place in the vicinity of the Chernobyl NPP: a winter ice-jam in 1991, a winter ice-jam followed by a spring flood in 1994, and a spring flood in 1999. During this period, the following complex of water-protecting actions was executed on the Pripyat River floodplain:

- 1991-1993 – construction of the sandy protective dike on the left bank of the floodplain
- 1994 – construction of the first chain of the sandy protective dike on the right bank
- 1999 – construction of the temporary right bank dike

Thus, along with an excellent data set allowing the testing of models of secondary contamination of water bodies from spatially distributed source, the scenario also provides an opportunity for evaluation of the effectiveness of countermeasures applied to protect a river's water.

The input data for the scenario include the following: the topography of the Pripyat River floodplain area; ^{90}Sr and ^{137}Cs deposition densities in the Pripyat River floodplain area; ^{90}Sr and ^{137}Cs activity concentrations for the input cross section; hydrological and meteorological data; chemical composition of the Pripyat River water; soil characteristics; vertical distributions of radionuclides in soil; and particle size distributions for soil and suspended sediment.

The scenario midpoint is the calculated ^{90}Sr and ^{137}Cs vertical distributions in the floodplain soil in 1991. The scenario endpoint is the calculated ^{90}Sr and ^{137}Cs activity concentrations in the output cross section. Test data include the measured concentrations of these quantities and will be made available at a later date.

INTRODUCTION

This Scenario is the continuation of the series of hydrological post-Chernobyl scenarios. The previous Scenario W (Konoplev et al., 1996; 1999) was devoted to movement of trace contaminants from terrestrial sources, including natural catchments, to water bodies, due to run-off processes (e.g., snowmelting and rainstorms).

A floodplain plays an important role in formation of river water quality. This role is enhanced by the fact that industrial facilities are often located on river banks because of technological requirements. In the case of a potential accident, the floodplain becomes a long-term source of contamination for the river water. Therefore, reliable models are required for prediction of the migration of contaminants from the floodplain to the river. Validation of such models is the main objective of the present scenario. In particular, this scenario provides an opportunity for (1) evaluation of the movement of contaminants from the floodplain to the river, (2) calculation of the alteration and migration of contaminants in soil over different time scales, (3) increased understanding of contaminant transport in the soil-water system at the process level, (4) development and testing of methods for estimating key parameters, and (5) assessment of the effectiveness of hydrological countermeasures.

The Scenario is based on three flooding events which took place in the vicinity of the Chernobyl NPP. This area, including a part of the Pripyat River floodplain, was highly contaminated as a result of the Chernobyl accident in 1986. In spite of being relatively small, this area can significantly contribute to the water contamination level of the Pripyat. It is well known that short-term changes of activity concentration in a river are normally inversely related to changes in water discharge. However, the two peaks of ^{90}Sr activity concentration observed in the Pripyat River near the Chernobyl NPP in 1988 and 1991 do not follow this tendency (Voitsekhovich et al., 1995; 1996). These peaks occurred as a result of the radionuclide washout from the Pripyat River floodplain due to rain-induced runoff in 1988 and to the ice jam in 1991. The observed pronounced effect of the floodplain on the ^{90}Sr activity in the river water during flooding events and the availability of the required input data provide a good opportunity for validation of the relevant models.

A detailed description of the Floodplain scenario is provided below, along with a list of the types of test data available. The scenario description is followed by tables containing information to be used as input data. The physico-chemical processes involved are the same as described in Scenario W (Konoplev et al., 1996; 1999). The Floodplain scenario is being considered for use in a model testing exercise in the International Atomic Energy Agency's EMRAS (Environmental Modelling for Radiation Safety) program[1]. Therefore, the test data are not included in the present version of the scenario, but will be made available at a later date.

DESCRIPTION OF THE FLOODPLAIN SCENARIO

In the present scenario, the Pripyat River floodplain is understood as a small embanked part of the floodplain, 12 km long and 4 km wide, adjacent to the Chernobyl NPP in the northwest (Fig. 1). The Pripyat River enters the considered area near the exclusion zone boundary (Input cross section) and flows out near the Yanov Bridge (Output cross section). The floodplain was subjected to the heaviest impact of radioactive contamination after the Chernobyl accident in 1986 and became an object for regular radiological monitoring, since it plays a key role in formation of secondary contamination of the Pripyat River (Voitsekhovitch et al., 1990).

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[1] For further information on the EMRAS program, please contact the International Atomic Energy Agency, Waste Safety Section, Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria; Fax +43 (1) 26007-22692.

Description of Events

1991 ice jam

In January 1991, an ice jam formed in the Pripyat River channel between Yanov Bridge and the town of Chernobyl. The water level in the Pripyat River upstream of the jam increased abruptly. As a result, a significant part of the Pripyat floodplain near the NPP became flooded for the first time since the accident. This caused washout of radionuclides to the river with the flood water. Even though only 30% of the whole area was flooded, it was enough for the ^{90}Sr activity concentration in the Pripyat River near the town of Chernobyl to increase up to the critical level.

After unsuccessful aircraft bombing of the jammed ice cover, it was decided to clean up this part of the river channel using an ice-breaker. As a result, the water level rapidly decreased to normal values.

1994 ice jam during spring flood

The 1994 event was similar to the ice jam of 1991. The principal difference was that the ice jam and partial flooding of the floodplain in 1994 occurred in the final phase of the winter low water and the initial phase of spring flood, rather than in the period of deep winter low water with low water discharge in the river channel. As a result, the wash-off of radionuclides from the floodplain surface after destruction of the ice jam was coincident with the beginning of the rise in water level of the river. Due to this fact, the influx of radionuclides from the floodplain was more protracted in time, and dilution of contaminated runoff entering the river by cleaner waters of the Pripyat river was more efficient than that in 1991.

Moreover, a protective sand dike on the left bank of the Pripyat River floodplain was built in 1992 (Fig. 2b), and the left bank part of the floodplain was not flooded thereafter. Therefore, the source of contamination in 1994 was the right bank part of the floodplain, rather than its whole area.

1999 spring flooding

It was after the completion of the left bank dam on the Pripyat River that an extremely high spring flood occurred in 1999. The maximum water discharges in the river were as high as 3000 $m^3\ s^{-1}$ and were the highest reported in the river since the historically high flood of 1979 (4500 $m^3\ s^{-1}$). By 1999, the construction of the dam on the right bank was already under way (Figs. 2c and 3); this dam was meant to cut off the most contaminated floodplain areas on the right bank. The construction, however, was not complete (see section Description of countermeasures, below), and part of the right bank floodplain was flooded for 2 weeks, primarily due to dam overflow. Therefore, the dam did not prevent wash-off from the floodplain, but only lengthened the formation of floodplain flows and reduced a possibly higher peak in the river contamination, which could have occurred with more rapid flow of water from the floodplain.

It is proposed that 2 sources of radionuclide contamination of the river be considered for the 1999 flood:

1. Areas on the right bank floodplain with elevation below 107.5 m which were flooded as a result of the dam overflow. The contaminated water from these areas entered the river

after the decrease in water level by filtration through the dam and by washed out channels.

2. The Yanov Bay, which was filled with water during the water level increase through the stone filtration dam built in 1987. The runoff from the bay started on 4 April and continued to the end of May. Over this time, between 0.8×10^6 and 1.0×10^6 m^3 of water containing about 1000 pCi L^{-1} ^{90}Sr and about 70 pCi L^{-1} of ^{137}Cs was discharged. The water discharges were roughly the following: 50-75 L s^{-1} on 4-6 April, 100 L s^{-1} on 10-12 April, 350 L s^{-1} on 15 April, 600-700 L s^{-1} on 16-18 April, 300 L s^{-1} on 22 April and 100 L s^{-1} on 30 May.

Description of countermeasures

After the event of 1991, construction of water protective facilities was initiated. These facilities were intended to change the conditions of water flow in the river floodplain and radionuclide wash-off from the surface. These changes should be kept in mind when generating input files accounting for the contamination source in the scenarios for 1994 and 1999.

By the end of 1992, a left bank dam was built, as is shown on the satellite image (Fig. 2b). The construction involved bringing sand from the river bed and the drainage channel on the inside of the dam. The dam width at the foundation was up to 200 m, and the elevation was 111 m BS. This elevation excludes overflow of water even in case of realization of the scenario providing for water discharge up to 6000 m^3 s^{-1}, the frequency of which is once in 100 years. The filtration flows from the dammed area are also very small, as the purposely built drainage system and regulation of water regime in this area make it possible to keep it dry during the entire year.

By the beginning of the 1999 flood, the right bank dam was partially built (Fig. 2c). It was anticipated that the highest level of the dam would be not less than 109 m. However, by the spring of 1999, its height in many parts was not more than 107-107.5 m. When the water level increased above this height, dam overflow occurred, and the right bank was flooded. The dam was built by bulldozer and using sacks, and, therefore, first, its filtration ability was rather high, and second, it was not very strong. Because of this, after a sharp decrease in the river water level during the flood of 1999, the contaminated water was flowing vigorously through the dam via washed out parts and filtration prisms.

Description of Input Data

The topography of the floodplain is given in its original state (before implementation of countermeasures) in three commonly used formats:

1. Plain ASCII XYZ file "FP_GK5.xyz" (developed at UHMI). The file has the following structure:

1st Column	2nd Column	3rd Column
X coordinate (m)	Y coordinate (m)	Altitude (m)

Statistics for the floodplain topography calculated using Surfer Software procedures and the FP_GK5.xyz file as an input are shown in Table 1.

2. TABS(RMA2) compatible file “FP_GK5.geo”. This file contains a triangulated mesh of the floodplain area developed at UHMI.
3. MapInfo format set of files (extracted from a digital map of the Chernobyl Exclusion Zone):

   Dotted isolines of the altitude with 1 m increment:

   FP_Topo10.tab
   FP_Topo10.id
   FP_Topo10.dat
   FP_Topo10.map

   Basic shape of the Pripyat River cross sections in ASCI and MAPINFO formats:

   FP_Channel10.tab
   FP_Channel10.id
   FP_Channel10.dat
   FP_Channel10.map

All the coordinates in the presented maps are given in Gauss-Kruger (the 5th zone). The right bank of the input cross section in this coordinate system is 5708700 m and 5707400 m; the right bank of the output cross section is 5717600 m and 5702300 m.

The user must adjust the topographic map to the specific shape after different countermeasures were applied using standard software and procedures. The information required for doing this is given in the section “Description of countermeasures” (above) and in Fig. 2.

The deposition density of ^{137}Cs and ^{90}Sr ($\mathrm{Ci\ km^{-2}}$) in the area is given in the files “FP_CS137.DAT” and “FP_SR90.DAT”, respectively. The structure of these files is the same as for “FP_GK5.xyz”, but the estimated density of deposition of ^{137}Cs or ^{90}Sr for each grid node is presented instead of elevation. Distributions of radionuclides on the surface at different elevations are included in Table 1.

Hydrological and meteorological data are given in Tables 2, 3 and 4 for the events of 1991, 1994 and 1999, respectively. The tables contain data on water levels for the gauge stations D3 and BNS (Fig. 1), located upstream and downstream of the Output cross section, respectively. The water surface levels upstream of the point D3 can be estimated in several ways.

1. The levels can be estimated by the methods of channel hydraulics using input data available in files “FP_Channel10.tab”, “FP_Channel10.id”, “FP_Channel10.dat” and FP_Channel10.map”.
2. For approximate estimates, data on river surface slopes can be used; these are calculated using data on river levels at points D3 and BNS (Tables 2-4).
3. It is possible to use results of hydraulic calculations performed earlier by UHMI. It was shown that for the period of low water in the considered river section upstream of the measuring section D3, the increment in the water surface level is 12-15 cm for each

running km; in the period of downstream levels during ice jams and at the peak of flooding, the increment is 3-5 cm per running km.

Data on water discharge and suspended sediment load in the Output cross section, and air temperature and precipitation measured at the Chernobyl Meteostation, are also provided in Tables 2-4. All data are presented with 1-day resolution.

Activity concentrations of ^{137}Cs (the dissolved and particulate states) and ^{90}Sr (the dissolved state) in the Input cross section are given in Tables 2, 3 and 4 for the events of 1991, 1994 and 1999, respectively, with 1-day resolution.

The chemical composition of the Pripyat River and of internal lakes is given in Table 5. Table 6 presents granulometric characteristics of the Pripyat River suspended sediment for winter conditions. Typical activity concentrations in water bodies of the floodplain area are given in Table 7. Values for the Manning *n*-roughness coefficient are presented in Table 8.

The major part of the floodplain area is represented by alluvial acid soddy soils; however, soddy sand gley soils occur at elevated sites. The typical physico-chemical characteristics of the upper horizon for the alluvial acid soddy soil are given in Table 9. The main physical properties of the upper 10-cm layer of this soil are as follows: soil density, 1.45 g cm^{-3} dry weight; soil porosity, 45 cm^{3} per cm^{3}; hydraulic conductivity, 0.33 mm min^{-1}. The depth of soil freezing on the eve of the flooding was more than 50 cm. Groundwater table depth for the end of winter is about 1.0 m. Typical particle size distribution of the alluvial acid soddy soil from the floodplain area is given in Fig. 4. The main type of floodplain vegetation is mixed meadow grasses. An insignificant part of the floodplain area (largely at a high level) is covered by thin oak and willow planting.

To obtain kinetic parameters of radionuclide exchange in a flooded soil-water system, experimental data (Laptev and Voitsekhovich, 1993) can be used. The data were obtained for soils collected just before the flooding in 1991, using original methodology presented by Bulgakov et al. (1991). According to Laptev and Voitsekhovich (1993), the rate constant of radionuclide exchange between soil and water during a flooding event varies in the range of 0.01-0.04 day^{-1}, with a mean value of 0.02 day^{-1}.

DATA FOR MODEL TESTING

The following types of data will be made available for model testing at a later date:

(a) Vertical distribution and chemical speciation of ^{90}Sr in the alluvial acid soddy soil in 1991;

(b) Vertical distribution and chemical speciation of ^{137}Cs in the alluvial acid soddy soil in 1991;

(c) Activity concentrations of dissolved and particulate ^{137}Cs in the Output cross section with 1-day resolution for each event;

(d) Activity concentrations of dissolved ^{90}Sr in the Output cross section with 1-day resolution for each event.

EXPERIMENTAL DETAILS

Radiocesium activity on the soil surface was estimated by utilising the data of helicopter surveys using an onboard-installed γ-spectrometer. The flight routes were taken to be parallel to the dike with 200 m distance to each other, which made it possible to obtain detailed information.

Activity of ^{90}Sr was determined based on radiochemical analysis of spatially distributed samples, with further comparison of the ^{137}Cs/^{90}Sr ratio in samples and the radiocesium data obtained by γ-survey. Results of more than 50 samples were used for this purpose.

The vertical distribution of radionuclides in soil was determined by taking two soil cores from two plots located on the left bank of the floodplain (Popov et al., 1993). The cores were taken 23 July 1991 using steel cylinders of 7.5-cm diameter and 15-cm length. The plot 1 and 2 coordinates are 52.4517 N, 30.0504 E and 51.4379 N, 30.0688 E, respectively.

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