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1.0 INTRODUCTION

The United States and the former Soviet Union (now the Commonwealth of Independent States) have set up the Joint Coordinating Committee on Civilian Nuclear Reactor Safety (JCCCNRS) to enhance safe operation of civilian nuclear reactors. The agreement contains Section 7.1, "Environmental Transport," and Section 7.2, "Health Impacts." Activities under these sections are managed by the U.S. Department of Energy. U.S. Coordinators of Programs 7.1, "Environmental Transport," and 7.2, "Health Impacts," are Lynn R. Anspaugh at Lawrence Livermore National Laboratory (LLNL), Livermore, California and Marvin Goldman at the University of California, Davis, California. Program 7.1 consists of the following:

7.1.A. Research on Atmospheric Dispersion Modeling
(U.S. Coordinator, P. H. Gudikson at LLNL)

7.1.B. Wind-driven Respension of Toxic Aerosols
(U.S. Coordinator, L. R. Anspaush at LLNL)

7.1.C. External Exposure and Dose from Deposited Radionuclides
(U.S. Coordinator, H. L. Beck at the National Institute of Health)

7.1.D. Transfer of Radionuclides through Terrestrial Food Chains and Resulting Dose to Man
(U.S. Coordinator, F. O. Hoffman, formerly at Oak Ridge National Laboratory)

7.1.E. Long-Term Dose for the Contamination of Aquatic Food Chains
(U.S. Coordinator, W. Templeton at Pacific Northwest Laboratory)

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(c) V. Glushkov Institute of Cybernetics, Kiev, Ukraine
(d) Scientific Industrial Association TYPHOON, Obninsk, Russia

7.1.F. Modeling the Behavior of Radionuclides in Soil-Aquatic Systems Including Rivers and Reservoirs
(U.S. Coordinator, Y. Onishi at Pacific Northwest Laboratory)

7.1.G. Intercalibration of Methods for Measuring Radioactive Contaminants in the Environment
(U.S. Coordinator, H. L. Beck at the National Institute of Health)

Main objectives of the above seven programs under JCCCNRS are to test and improve methodologies, mathematical models, technologies, and techniques needed to better understand and to more accurately forecast radionuclide behavior in the environment following nuclear power plant accidents. These programs currently focus on problems from the Chernobyl Nuclear Power Plant accident. This paper describes the activities of Program 7.1.F.

2.0 DESCRIPTION OF PROGRAM 7.1.F

Program 7.1.F, "Modeling the Behavior of Radionuclides in Soil-Aquatic Systems Including Rivers and Reservoirs," deals with radionuclide transport and geochemistry in an aquatic environment consisting of surface water, groundwater, and overland flow.

The main joint research work under Program 7.1.F consists of the following four areas:

1. Characterization of radiochemistry through laboratory and field experiments on
   - adsorption and desorption
   - fuel particles.
2. Field data collection to
   - identify the controlling transport and geochemical mechanisms
   - conduct site characterization
   - obtain necessary data for mathematical modeling.
3. Overland flow, river/reservoir, and groundwater radionuclide simulations to
   - develop or modify mathematical models
   - test and validate mathematical models.
4. Environmental remediation assessment to
   - evaluate soil and water remediation techniques
   - determine the effectiveness of potential remediation options.

3.0 CURRENT ACTIVITIES

We are currently conducting the following three joint studies: surface water modeling of the Pripyat River and its flood plain, site characterization of the Iput River basin with the use of U.S. Landsat data, and watershed/groundwater modeling of an Iput River catchment.

3.1 PRIPYAT RIVER FLOOD PLAIN MODELING

The Chernobyl Nuclear Power Plant is estimated to have released approximately 1.3 million curies of ^{137}Cs and 0.24 million curies of ^{90}Sr during the 11 days following the April 26, 1986 accident. Many of these radionuclides were deposited on the land surface, as shown in Figure 1 for ^{137}Cs. The Pripyat River flood plain directly across from the Chernobyl plant received significant amounts of ^{137}Cs and ^{90}Sr deposition (see Figure 2) and contributes approximately half of all ^{90}Sr entering the Pripyat River, which joins the Dneiper River flowing into the Black Sea (Voytscekhovitch et al. 1990).

During January through March of 1991, an ice jam was formed in the Pripyat River near a bridge just downstream of the Chernobyl plant. This ice jam caused the river water to backup upstream and flow into the flood plain, resulting in increased ^{90}Sr concentrations in the Pripyat River from 1 to 10 pCi/ℓ level to 200 pCi/ℓ, which exceed the current local drinking water limit of 100 pCi/ℓ for ^{90}Sr. The Ukrainian government is currently constructing a dike along the river to prevent future flooding of this flood plain.

We are currently applying the sediment and contaminant transport model, FETRA (Onishi 1981) with the compatible hydrodynamic model, RMA-II (Norton and King 1977) to the Pripyat River and its flood plain to simulate ^{90}Sr and ^{137}Cs migration and accumulation during the flood period. The study area is approximately 10 km x 3 km with elevation varying 100 m above the Baltic Sea Level (BSL) at the river bottom to 112 m BSL. The RMA-II/FETRA modeling area and computational grids are shown in Figure 3.

FETRA is an unsteady, two-dimensional, finite-element model designed to simulate

- transport, deposition, and resuspension of both cohesive and non-cohesive sediments
- transport of dissolved contaminant with sediment-contaminant interactions
- transport, deposition, and resuspension of particulate contaminants
- erosion, deposition, and accumulation of sediment and particulate contaminant in the river bed.

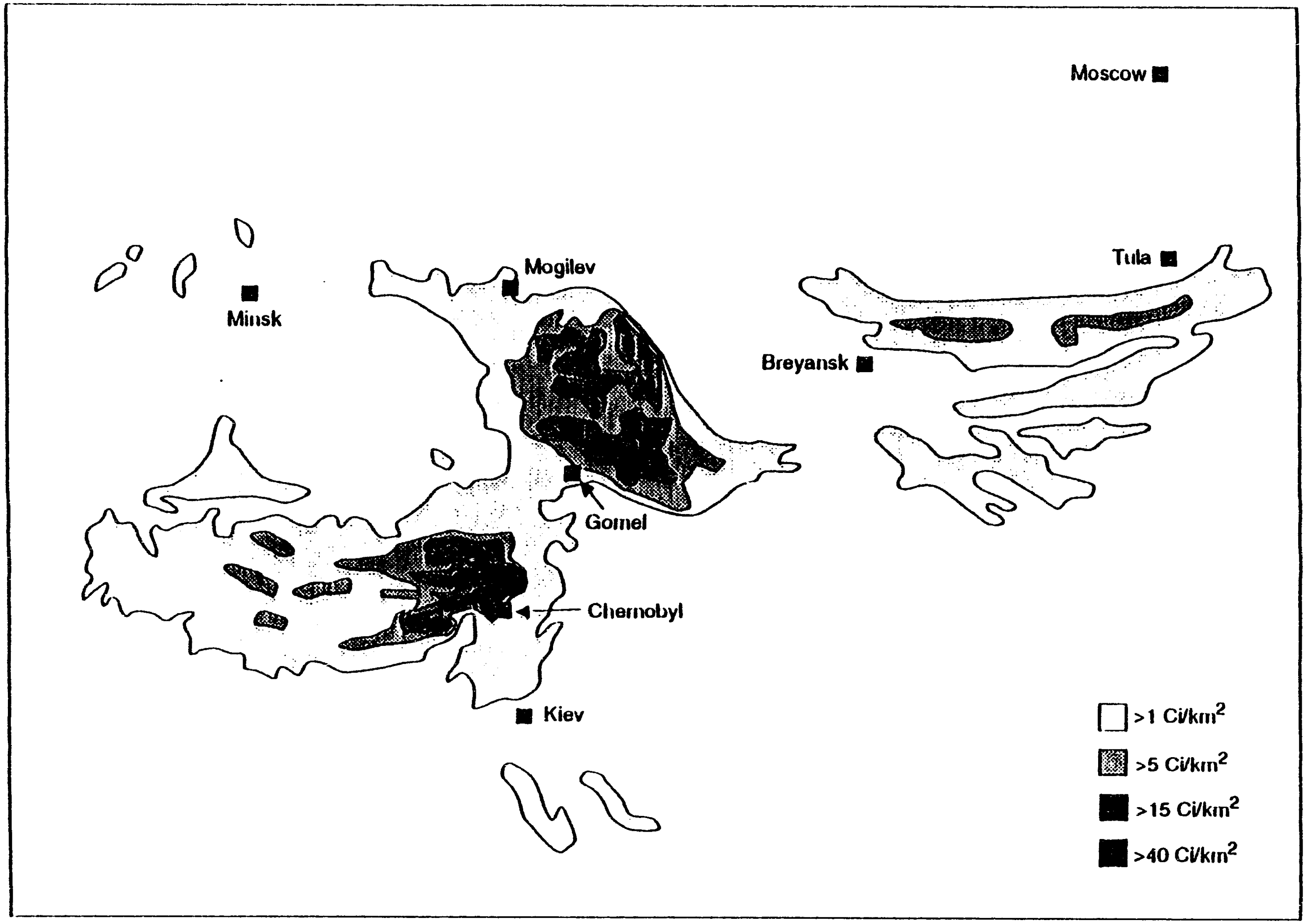

Figure 1. Measured ^{137}Cs Distribution on the Land Surface

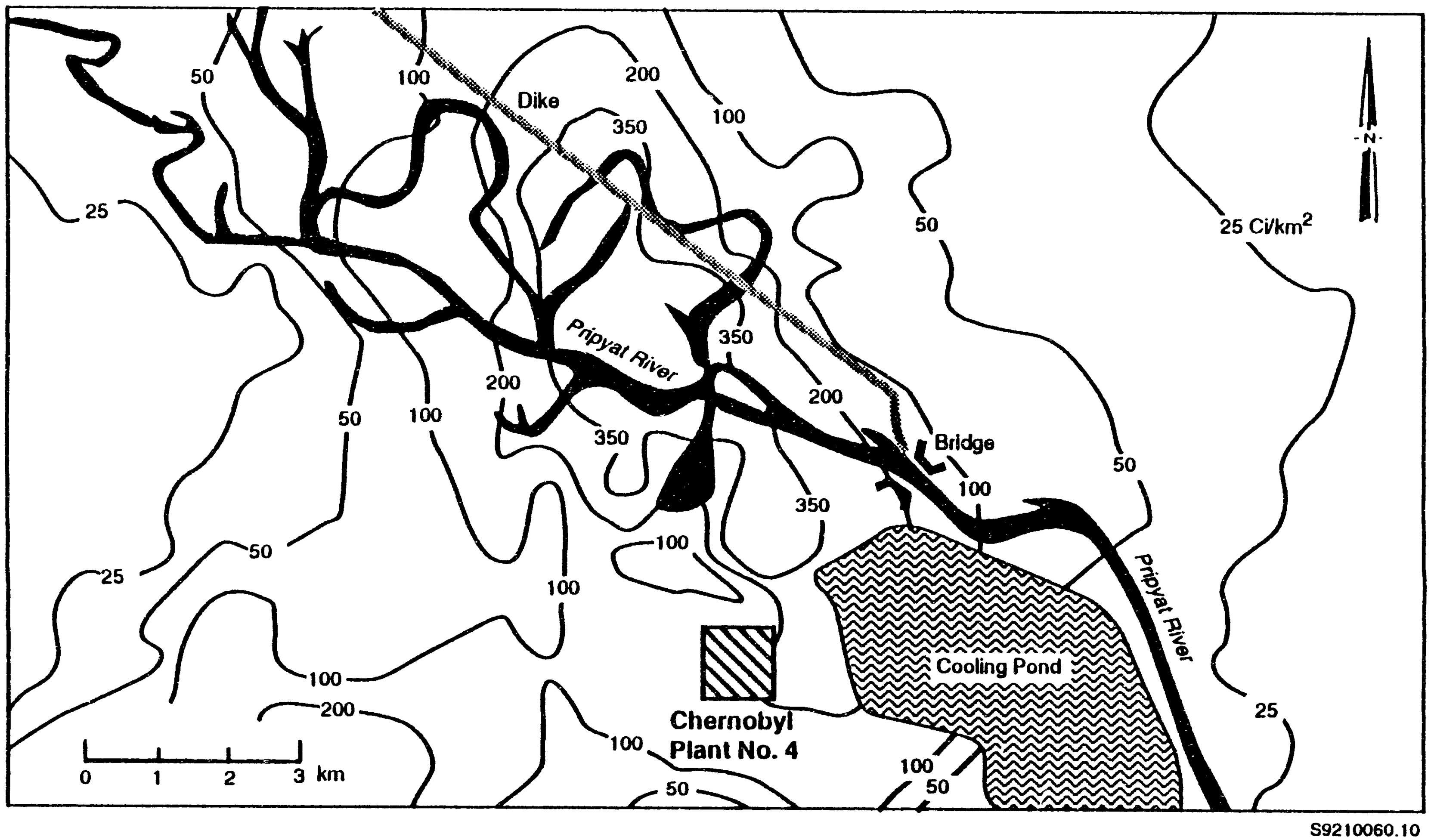

Figure 2. Measured ^{90}Sr Distribution around the Pripyat River Flood Plain

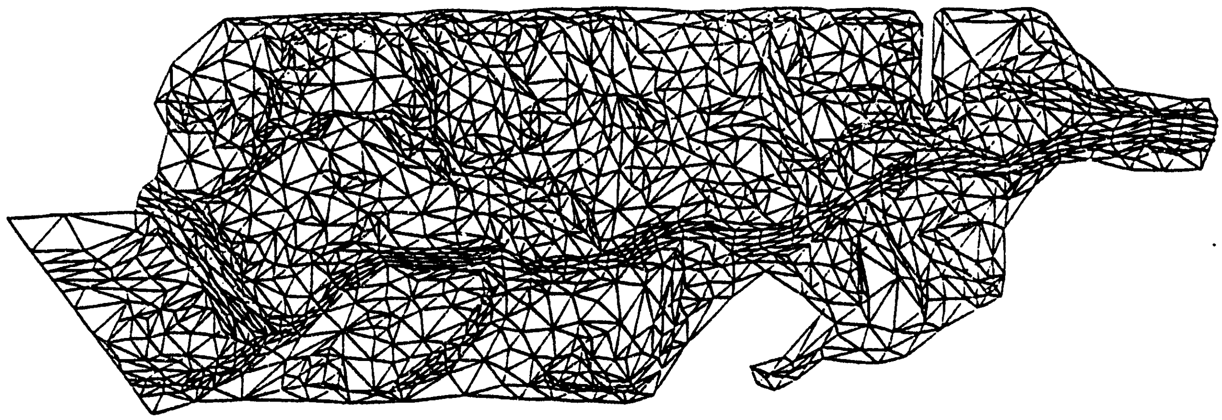

Figure 3. RMA-II and FETRA Computation Grids of the Pripyat River and Flood Plain

The objectives of this model application are to

- compare the model results with field data to test the applicability of FETRA to a nuclear plant accident having such complexities as adsorption/desorption, the presence of fuel particles, and flooding
- benchmark FETRA with other models, such as the COASTOX model (Zhoveznyalk et al. 1992)
- evaluate the effectiveness of the dike under construction to reduce radionuclide concentrations in the Pripyat River.

3.2 LANDSAT DATA AND RADIOLOGICAL ANALYSIS

The Geological Information System (GIS), combined with remote sensing data supported by ground truth information, is a very useful tool to obtain accurate site characterization over a large area. Under this study we are currently analyzing U.S. Landsat data taken on June 12, 1987 over an approximately 170-km x 170-km area of the Iput River basin in combination with measured ^{137}Cs distribution (see Figure 1). The Iput River basin is just north of Gomel.

The Iput River is a tributary of the Sozh River, which in turn flows into the Dneiper River. The Iput River Basin received the highest concentrations of ^{137}Cs and ^{90}Sr in Russia resulting from the Chernobyl accident. The study objectives are to

- correlate radionuclide concentrations and terrestrial biomass to evaluate potential radiation impacts on plants

- visualize and evaluate composite patterns of radionuclide distributions to assess radionuclide migration on the land surface to receiving water bodies.

Potential radiation impacts on plants were investigated by correlating the ^{137}Cs concentrations to plant biomass as estimated using the red and infra-red bands of the Landsat image (Estes 1983). Figure 4 shows the results of this very preliminary work in a scatter diagram of the biomass versus ^{137}Cs concentrations. The plot shows that there are a lack of data points in high ^{137}Cs with low biomass (lower right side of the figure). This suggests that future work might first concentrate on investigating the possibility that plants already under distress for other reasons (i.e., having low biomass to start with) were particularly susceptible to damage by radiation. For instance, if a land use map were generated, it would be useful, not only for other studies and remediation work, but for removing "noise" from the analysis of the effect of radiation on biomass (e.g., perhaps it is just chance that the high-level radiation zones occur on low biomass urban areas). Further work to improve the registration between biomass data and the radiation map is being planned. In particular, there were several anomalies identified in the radiation map that have to be resolved with the authors of the map. The analysis could also be significantly improved and tested by including Landsat images from other dates. In particular, these images could be used to both test theories (e.g., examine the correlation of biomass and radiation before and after the accident) and look for other possible changes over time. In addition, this exploratory work suggested several specific statistical procedures to refine and test the theories on the effects of radiation on biomass.

3.3 WATERSHED/GROUNDWATER MODELING OF IPUT RIVER CATCHMENT

The principal source of radionuclides entering the aquatic ecosystem is the adjacent terrestrial ecosystem. Radionuclides may be transported from the terrestrial ecosystem with sediments during periods when precipitation, streamflow, and/or snowmelt result in saturation of the soil or result in exceeding the infiltration capacity of the soil surface. The constant redistribution of moisture in the terrestrial ecosystem by the processes of evapotranspiration, infiltration, and saturated subsurface flow requires a dynamic analysis to assess the likehood of a specific area reaching the conditions required to transport radionuclides in the hydrosphere.

A PNL-developed, spatially distributed, physically based watershed hydrologic model is being applied to a small Iput River catchment (approximately 10 km x 10 km) to map the areas of greatest potential for mobilizing terrestrial radionuclides into the surface water aquatic ecosystem. This integrated hydrology-vegetation model simulating soil/vegetation water balance consists of the following four submodels:

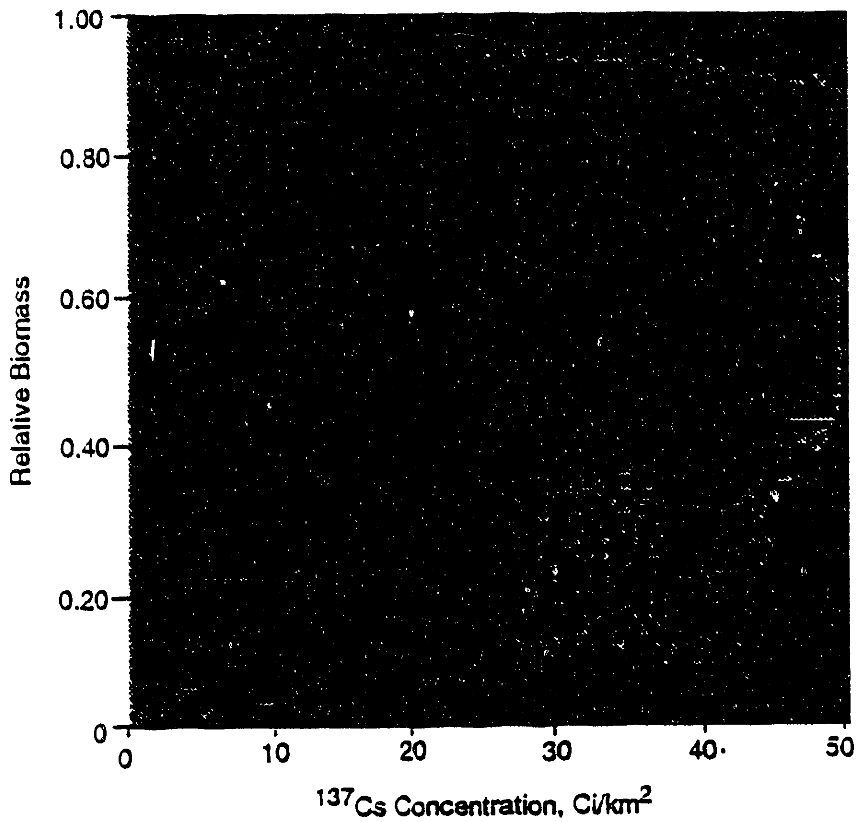

Figure 4. Correlation between Plant Biomass and ^{137}Cs Concentratons in the Iput River Basin

- two-layer canopy submodel for evapotranspiration
- an energy-balance submodel for snow accumulation and melt
- a two-layer unsaturated soil submodel
- a saturated subsurface flow submodel.

The model requires data on elevation, soils, vegetation, and climate. Elevation data are used to model topographic controls on incoming shortwave radiation, precipitation, air temperature, and downslope water movement. The vegetation (ground cover) information will be provided via the interpretation of the Landsat imaging as discussed previously.

4.0 NEXT JOINT STUDY

Simulation of the transport and accumulation of ^{137}Cs and ^{90}Sr in the Dneiper River/Reservoir system from the Kiev Reservoir to the Black Sea will be planned. We will use an unsteady, one-dimensional (branching), sediment-contaminant transport model, TODAM (Onishi et al. 1982) to cover the study duration of April 1986 to December 1991.

We also plan to conduct similar Landsat data analyses around the Chernobyl Site to visualize composite patterns of radionuclide distribution/migration patterns and to correlate plant biomass and radionuclide concentrations of ^{137}Cs and ^{90}Sr.

Some radionuclides originally deposited on the land surface, as well as Chernobyl accident debris, dead trees, and other radioactively-contaminated materials buried near the land surface, are leaching into groundwater systems in the Chernobyl/Kiev area. Thus, we are also considering investigating the regional groundwater flow with a quasi three-dimensional, analytic-element-method model incorporating a variety of boundary conditions, such as streams, reservoirs, and drains.

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