Session E, Track 1: Monitoring, Measurement, and Modeling II

Thursday, September 10, 1998
2:15 p.m. - 4:40 p.m.

Chair: Peter Stang, United States Department of Energy

Aquatic Countermeasures in the Chernobyl Zone:
Decision Support Based on Field Studies and Mathematical Modelling

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INTRODUCTION

The water protection is one of the significant direction of post-Chernobyl accident countermeasure activities in Ukraine. Chernobyl Nuclear Power Plant (NPP) stays near the bank of the Pripyat River at 30 km from its outflow to the Kiev Reservoir of the Dnieper River (Fig. 1). The floodplain territory near Chernobyl NPP and surrounding watersheds are heavily contaminated by ^{137}Cs and ^{90}Sr. The spots of ^{137}Cs are in the upper Dnieper watershed in Russian and Belorussian territory and on the entire Pripyat watershed. The surface contamination leads to the permanent influx of ^{137}Cs and ^{90}Sr into the Kiev Reservoir (the capacity is 3.7 cub.km) that is an upper one in the cascade of six Dnieper reservoirs. The Dnieper River transports radionuclides through this cascade at 900 km to the Black sea. The aquatic pathway is considered in post-accidental period as a main one for the radionuclide dispersion from the Chernobyl zone after the early accidental phase [1,2].

The main objective of water remedial activities that have been implemented since 1986 was to prevent significant secondary contamination of the surface water bodies that are hydraulically linked with the areas of heavy fallout and to mitigate expansion of expected ground water contamination. The choice and design of the countermeasures was supported by the modelling of radionuclide transport in the aquatic system and by the field and laboratory studies of these processes [3-6]. The presentation summarizes an experience of the research and developments to support the water protection countermeasures in the Chernobyl area.

DISCUSSION

Field Studies

During the initial accidental release period after April 26, 1986, the surface water bodies around the Chernobyl NPP (Fig. 1) were directly contaminated by atmospheric fallout. Surface water contamination was characterized with a high level of radiation over a wide spectrum of short-lived radionuclides. The total beta-contamination of the open water bodies near the

Chernobyl NPP reached approximately 10^{-6} Ci/L (1Ci=37 GBq, 1Liter= 10^{-3} m^3) The beta-activity of the Pripyat River water downflow Chernobyl NPP in early May 1986 exceeded 10^{-8} Ci/L. The range of radioactivity in Dnieper River water near the main water intake of Kiev City (at 130 km downflow from the Chernobyl NPP) was from 10^{-10} to 10^{-8} Ci/L in May and June 1986. The largest contribution to water contamination in first months after the acident was from ^{131}I. Since 1987, the radionuclides ^{137}Cs and ^{90}Sr had the largest influence on the water contamination. The special regular water sampling program was organised in the Chernobyl Exclusion Zone to control the radionuclide dispersion from this territory via the Pripyat River. The detailed studies of the watershed pollution demonstrates that the most contaminated areas that could be flooded is the part of left-bank floodplain of the Pripyat River upstream the Chernobyl NPP (Fig.1). It was estimated the deposition of at 8000 Ci of ^{90}Sr on this rather small territory at 10 km along the river channel. The parameters of the radionuclide washing out from the floodplain soil was studied within the special laboratory experiments. The monitoring program for studies of the radionuclide concentrations in the water, suspended sediments and bottom deposition was implemented since 1986 for the whole Dnieper basin.

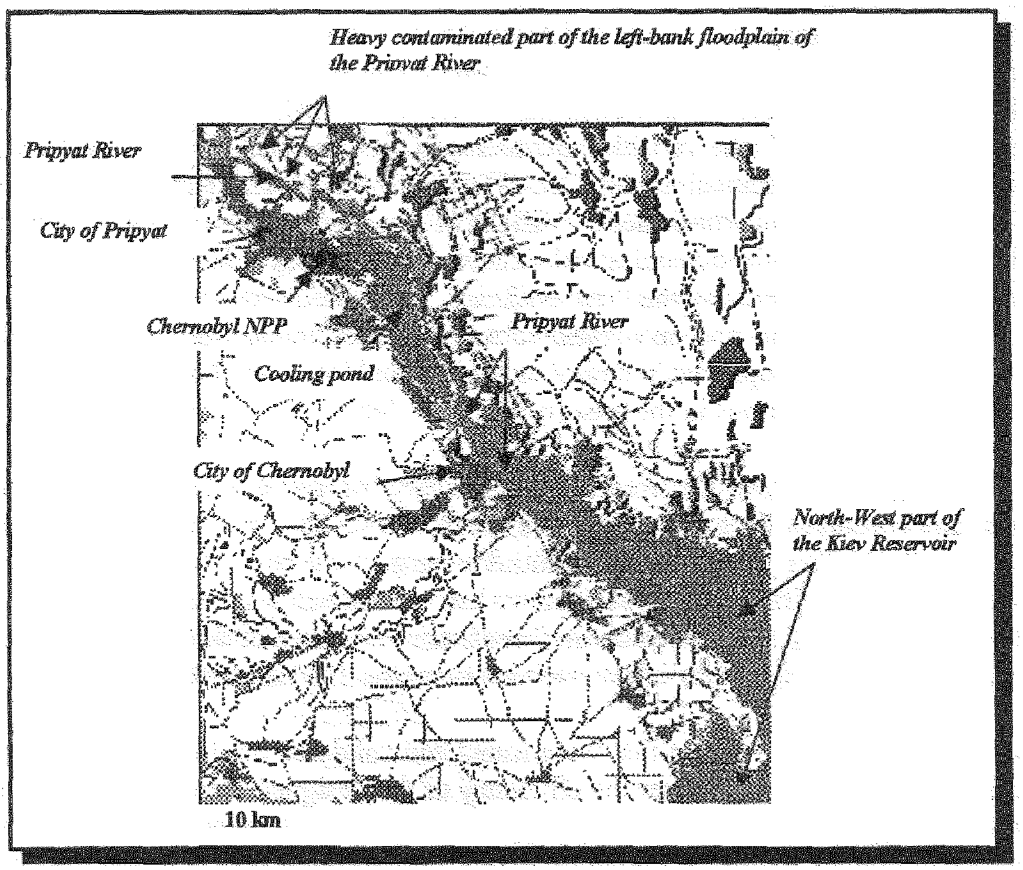

Figure 1. Scheme of water bodies surrounding Chernobyl Nuclear Power Plant

The main feature of the radionuclide release from the contaminated watersheds to the Kiev reservoir within 12 years after the accident is the significant diminishing of the ^{137}Cs influx to the reservoir, however, ^{90}Sr washing out to river net continued to be on a rather high level. Since 1992, the rate of ^{90}Sr release to Pripyat River was reduced due to the water protection measures (dike construction) on the floodplain near Chernobyl NPP. Annual total influx of ^{137}Cs and ^{90}Sr into the Kiev Reservoir from Pripyat River and Upper Dnieper changes after the accident as follows: 2620 Ci and 1030 Ci respectively in 1986; 365 Ci and 320 Ci in 1989; 130 Ci and 510 Ci in 1991, 45 Ci and 90 Ci in 1997. The difference in the behavior of the radionuclides appears also in the phenomenon that a large part of ^{137}Cs, as well as some other radionuclides, are associated in water with suspended particles. The experimental studies of the Chernobyl radionuclide fate in water bodies were an important part of the background for the water protection activities in the Chernobyl area.

Models

The simulation of the efficiency of countermeasures was done based on a set of models, describing radionuclide transport in rivers and reservoirs in different scales of resolution [3-5]. Wide range of scales is achieved by combining the box model WATOX, describing radionuclide concentration averaged over compartments (whole reservoir or its large part), one-dimensional river channel model RIVTOX (the variables are averaged over the channel cross-section), two-dimensional lateral-longitudinal model COASTOX (the variables are averaged over the flow depth), two-dimensional vertical model VERTOX (the variables are averaged over the flow width), THREETOX- 3-D hydrodynamics and radionuclide transport model. Each model at its specific level of resolution simulates the flow dynamics, suspended sediment transport, radionuclide transport in dilute and on suspended sediments, radionuclides fate in the bottom deposition. The models developed by Y.Onishi in the Pacific Northwest National Laboratories also were used for the simulations in the area [6]

The predictions of $_{137}$Cs and $_{90}$Sr concentration in the Dnieper reservoirs during spring flood were prepared in February-March each year since the accident. The predictions also were developed during the high rainstorm flood and other emergency events at Pripyat River watershed. The seasonal and short term predictions are in reasonable agreement with the measured data for the spring floods, rainstorm floods, consequences of the radionuclide releases from the Pripyat floodplain as results of the ice jams in winter 1991 and 1993 [4,5].

The models of radionuclide transport that were tuned and validated on the basis of the monitoring data gave a tool to simulate the efficiency of the designed water protection measures to diminish the radionuclide concentration in the water. This data was used to simulate deminishing of the collective dose as the result of the countermeasure implementation [1,2].

Water Protection Measures

The specifics of radionuclide transport defines the strategies of aquatic countermeasures. A lot of remedial strategies that have been proposed and implemented in the Chernobyl area and may be classified as follows:

A. Measures in drainage area
   a) Removal of contaminated soil;
   b) Alternations in the catchment area to minimize the run-off of radionuclides from land to water, e.g. , planting of trees, digging of channels/ditches, or adding the chemicals to bind the radioisotopes (e.g., lime, potash or dolomite);
   c) Prevention of flooding most contaminated territories attached to a water body (e.g., floodplain dikes);
   d) Construction to prevent radionuclide transport to surface water bodies by ground water flow (e.g. contra-seepage wall in soil).

B. Measures in water bodies
   a) Constructions to increase the sedimentation of contaminated suspended materials in rivers (e.g., a quarry - a bottom trap for contaminated sediments, dams, ditches and spurs).
   b) Construction to separate most contaminated parts of the water bodies from a main stream (e.g., dikes and dams dividing the water bodies);
   c) Dredging of contaminated deposits;
   d) Change in mode of the Dnieper reservoir management to optimize it on the minimum of the radionuclide concentration.
   e) Change in drinking water intakes (e.g., recommendation to switch on other water supply sources).

The computerized system was used to evaluate the efficiency of the countermeasures proposed to diminish the radionuclide concentrations in the Dnieper reservoirs. The demonstration of low efficiency of the large scale hydraulics projects for Kiev Reservoir, e.g., the construction of the new dam through the reservoir and submerged dike near Hydropower Plant, was background to stop these expensive projects. It was simulated and demonstrated low efficiency of the bottom traps designed for settling down of contaminated sediments in the Pripyat River channel.

CONCLUSION

The modelling results demonstrated the efficiency of the construction of the special dike around the contaminated floodplain area on the left bank of the Pripyat river at the Chernobyl [3,4] that was used as the background of the decision to construct the dam. The modeling predictions were confirmed by the data measured during the flooding of this area due to the ice jam in the Pripyat River in January 1991 [5,6]. The dike was constructed in 1992 and it is estimated now as the most efficient water protection measure in the Chernobyl zone. This dike prevented the remobilization of radionuclides, especially $_{90}Sr$ from the highly contaminated floodplain into the river, thus lowering the collective dose by 600 to 700 menSv. The construction of a dike along the right riverbank could further reduce the collective dose by 300 to 400 menSv.

Further action in the Chernobyl exclusive zone should be focused on the construction of the right riverbank dike upstream the NPP and on the decontamination or rehabilitation of the bottom sediment of the cooling pond after planned shutdown the Chernobyl NPP.

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Dose Refinement: ARAC's Role

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INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC), located at the Lawrence Livermore National Laboratory, since the late 1970's has been involved in assessing consequences from nuclear and other hazardous material releases into the atmosphere. ARAC's primary role has been emergency response. However, after the emergency phase, there is still a significant role for dispersion modeling. This work usually involves refining the source term and, hence, the dose to the populations affected as additional information becomes available in the form of source term estimates—release rates, mix of material, and release geometry—and any measurements from passage of the plume and deposition on the ground.

Many of the ARAC responses have been documented elsewhere.[1] Some of the more notable radiological releases that ARAC has participated in the post-emergency phase have been the 1979 Three Mile Island nuclear power plant (NPP) accident outside Harrisburg, PA, the 1986 Chernobyl NPP accident in the Ukraine, and the 1996 Japan Tokai nuclear processing plant explosion. ARAC has also done post-emergency phase analyses for the 1978 Russian satellite COSMOS 954 reentry and subsequent partial burn up of its on board nuclear reactor depositing radioactive materials on the ground in Canada, the 1986 uranium hexafluoride spill in Gore, OK, the 1993 Russian Tomsk-7 nuclear waste tank explosion, and lesser releases of mostly tritium. In addition, ARAC has performed a key role in the contingency planning for possible accidental releases during the launch of spacecraft with radioisotope thermoelectric generators (RTGs) on board (i.e. Galileo, Ulysses, Mars-Pathfinder, and Cassini), and routinely exercises with the Federal Radiological Monitoring and Assessment Center (FRMAC) in preparation for offsite consequences of radiological releases from NPPs and nuclear weapon accidents or incidents.

Several accident post-emergency phase assessments are discussed in this paper in order to illustrate ARAC's role in dose refinement. A brief description of the tools (the models) then and now, is presented followed by a description of how these models have been applied during the post-emergency phase to various events.

DISCUSSION

The ARAC Models

The ARAC wind flow model is a combination of two codes: MEDIC[2] interpolates meteorological observed winds to three-dimensional girded space; MATHEW[2] mass adjusts the winds in the presence of terrain using atmospheric stability to affect this adjustment so that mass is conserved in the three-dimensional space. The dispersion model ADPIC[3] is a Lagrangian particle model with random displacement diffusion and has the flexibility for specifying various source characteristics with full decay and ingrowth of daughter products during transport and after ground deposition. In addition to these models, ARAC has a computer code that matches radionuclide air and ground deposition measurements in time and space with the model-generated air concentrations and ground deposition concentrations.

Over the past four years, ARAC has been developing new models to replace the older ones. ADAPT[4] is the interpolation and mass adjustment flow model and LODI[5] is the dispersion model. Since these models are under development, the present versions have only limited capability and are not yet part of the ARAC production environment. Major improvements in the new models are continuous terrain representation rather than the block terrain of the older models, and variable and graded resolution in both the horizontal and vertical dimensions. Other attributes in these models will be horizontally varying turbulence and boundary layer depths.

Post-accident Responses

A FRMAC would most likely be formed for offsite consequences from a significant radiological release within or impacting the US and its territories. The FRMAC works with the State, local government and tribal authorities to determine the consequences and to mitigate the consequences to the extent possible from a radiological release to the environment. ARAC works with the FRMAC both from the ARAC Center in Livermore and by deploying staff members to the field.

Based on both a real need and considerable experience, the ARAC program has developed a methodology to derive the amount of radioactivity released by a matching procedure applied to model calculations and representative measurements. This is an iterative process of improving the source term estimate as more measurements are taken. The resulting refinement to the source term allows the dispersion model to better define the deposition boundaries and greatly adds to defining the airborne plume concentrations, which most likely will not be measured well during most accidental releases particularly during the earliest phase. ARAC may then answer with greater confidence who was exposed and at what dose. As a part of FRMAC exercises, ARAC routinely uses simulated measurements of ground deposition to re-scale the source term, and hence the computer generated air concentrations and ground deposition concentrations.

Chernobyl Accident

During the first few weeks following the 1986 Chernobyl accident, ARAC derived the first estimates of the total inventory released into the atmosphere using measurements that were then obtained from various European countries.[6] Calculations of projected air movement and radioactive air concentrations were matched with measurements from up to 20 sites throughout the Northern Hemisphere. Through an iterative process involving adjusting the source term geometry and release rates, ARAC was able to refine estimates of how the radioactivity released varied with time and how the radioactivity was initially distributed in the air. ARAC is presently working with Russian scientists (SPA Typhoon) to acquire additional meteorological data in the region surrounding the reactor in order to calculate a refined reconstruction of the dispersion. The refined plume may lead to improved dose reconstruction in the region. Since the Chernobyl accident, the available meteorological data sets, and improved ARAC models and tools permit better iterative plume and source term reconstructions.

General Chemical Accident

For several months after a 1993 major rail tank car spill of sulfur trioxide (oleum) in Richmond, California, ARAC participated in an intensive effort to assess the source release rates and total exposure to the population from the released sulfuric acid cloud.[7] Even though this event was not a radiological release, it did provide additional insight for plume reconstruction. Using just the standard reporting meteorological station data that were available through the World Meteorological Organization's global distribution system, the ARAC initial calculated plume did not follow the path that staff meteorologists believed it should have. The staff meteorologists had knowledge of non-reporting meteorological tower data in the vicinity of the plume. After rerunning the ARAC models with this additional data, the plume was judged to be in the right place. Later runs of a prognostic mesoscale forecast model[8] confirmed this flow pattern.

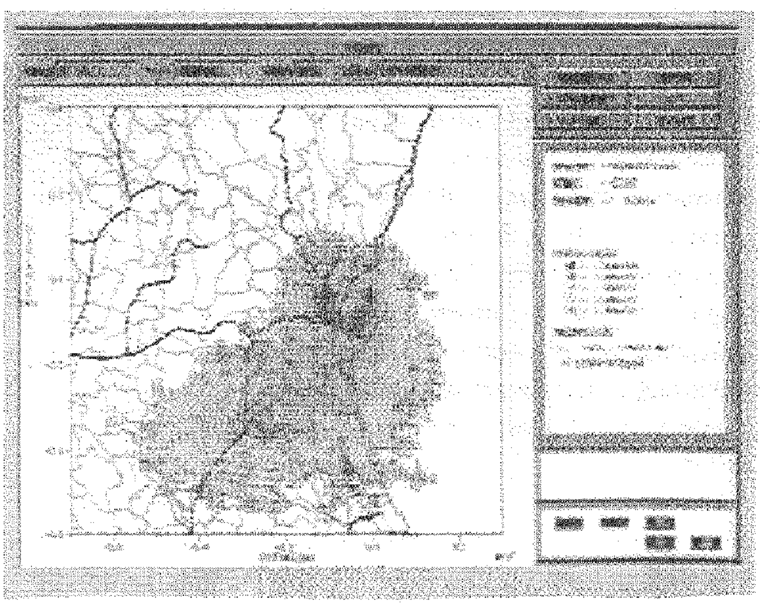
Over the next several months, the quantity of material released from the rail tank car was determined along with estimates of the release rates over a four-hour duration. ARAC and a private firm both recalculated the plume based on this new source term. Apart from one sampler that measured concentrations in the passing plume, the only source of information on exposure to the population from the cloud was the plume calculation. Litigation proceeded using plume calculations. This event serves as an example for what could occur for an unmonitored remote radiological release, particularly where the release is composed of mostly non-depositing noble gases and short lived radioactive iodines.

Tokai Accident

In March of 1997, PNC-Tokai corporation of Japan, located on the JAERI facility, experienced a fire and subsequent explosion in a fuels reprocessing facility. ARAC and JAERI were (and still are) collaborating on the development and evaluation of a nuclear accident assessment information Internet-based communication protocol, incorporating televideo, whiteboards and web pages.

During the Tokai accident and shortly thereafter, ARAC and JAERI were able to view each system's model assessment plots, discuss differences, locate measurements sites and values, discuss differences due to differences/deficiencies in meteorological data and then recompare and discuss results when comparable data were used in both systems. The dialogue with whiteboard interaction proved highly effective in communicating mutual understanding as well as unique insights. Shortly after assuring that both had the same meteorological data, JAERI received preliminary radiological measurement data and rapidly, using the graphical web pages on whiteboard, identified the locations and preliminary readings at three locations.

The shortfall of not having full live video was evident but not-detrimental. The results accomplished over a two-week period in a cooperative response to an actual event would have been impossible to achieve using conventional exchanges via phone, e-mail and telefax. The combination of the web pages and the teleconferences yielded a collaborative effort which could only have been otherwise achieved by actual face-to-face meetings. In fact, this prototype system even provides an advantage over the face-to-face exchange, as each participant is acting from their own institutional environments, where all local data and even colleagues are readily accessible, whereas travelers must reduce their tools and information to fit in a suitcase.



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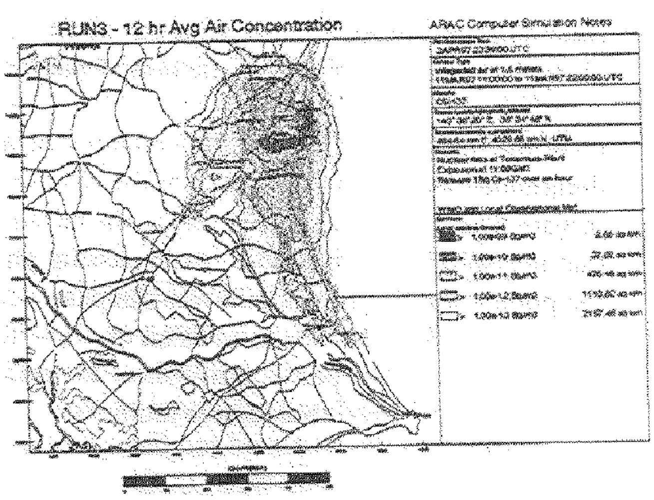

ARAC

Since the ARAC and SPEEDI transport and dispersion models provided similar results including estimates of the release magnitude within ±15% after using the same input data, both centers judged the interactive refinement process to be useful for the estimation of source term coupling with monitoring.

This work fits within the context of the Global Emergency Management Information Network Infrastructure (GEMINI) and is an example of the benefits of exploiting cyber technology for timely and enhanced accident assessment. We intend to offer this as a start toward an international "mutual aid" structure.

CONCLUSION

Examples of post-emergency phase assessments by ARAC for three real hazardous releases to the atmosphere were presented. The 20 years or more of ARAC experience in training for and responding to emergency releases of hazardous materials into the atmosphere has demonstrated the need for post-emergency assessment transport and dispersion model calculations for most major events until the exposure to the population has been fully determined. This is an iterative refinement process as source term estimates and air and surface concentrations measurements of the released material become available.

ACKNOWLEDGMENTS

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