Simulators for Russia and the Ukraine: A Status Report on U.S. assistance

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Introduction

The United States Department of Energy (U.S. DOE) is one of two implementing agencies participating in the United States government’s International Nuclear Safety Program (INSP) to improve the level of safety of Soviet-designed nuclear power plants in Eastern Europe including Russia, and the Ukraine. The program is conducted consistent with policies established by the U.S. Department of State for International Development and in close collaboration with the Nuclear Regulatory Commission.

The objective of the INSP is the comprehensive improvement in safety culture, power plant operation and physical conditions, and infrastructures in countries operating Soviet-designed reactors. This is achieved by:

- strengthening the operational and physical condition of the plants
- enhancing the safety culture among the designers, constructors and operators of the Soviet-designed nuclear power plants, and
- supporting the development of the indigenous nuclear safety infrastructure for sustaining satisfactory safety levels.

The program areas are categorized into elements that relate to:

- Management and Operations
- Engineering and Technology
- Plant Safety Analysis
- Fuel Cycle
- Legislative and Regulatory Framework

The major activities in the Management and Operation program area include the development and implementation of training programs based on simulators. It also includes activities related to development and validation of EOIs that are strongly coupled to the availability of simulators.

The program guidelines clearly state that by providing simulators it is expected that the following objectives will be met; a) improve overall understanding of nuclear power plant operating
characteristics on the part of operators, technical support staff and management, b) improve reactor operator training, c) improve the analytical capabilities of technical support staff, and d) establish host country capabilities to design and manufacture simulators and plant analyzers.

Consistent with these identified needs and policies, control room simulators, analytical simulators, plant analyzers and training is provided in these programs. In general, the U.S. support organizations work with the host country personnel from the nuclear power plants and support organizations to determine the requirements and develop specifications, purchase associated simulator hardware and/or associated software, develop or adjust analytical models for specific nuclear power plants, provide training in the use or development of the simulators and transfer simulator technology to host countries.

It is widely recognized that simulators play an essential and extremely important role in establishing viable training programs for a nuclear power plant. The changes in the former Soviet Union, and the subsequent opportunities for cooperation with the Western countries, resulted in many programs designed to improve the conditions at nuclear power plants across Eastern Europe. Training programs and especially simulators are viewed as providing a relatively fast, cost-effective technology transfer that will result in measurable improvement in the safety culture and operation of the power plants. The United States is participating in these programs, in cooperation with other countries, to improve the safety of nuclear power plants in Eastern Europe. In the following, a summary of the simulator programs will be presented to give an update on the present status of these projects.

The actual implementation of the simulator programs is performed by participants from U.S. DOE and national laboratories. The simulator projects are designed by considering the requirements at each nuclear power plant site, the existence of any training program, available resources and host country capabilities. Table 1a lists the simulator projects in Russia and Table 1b lists similar projects in the Ukraine.

**Simulator Models**

There are many different simulation models available to represent the reactor cores and nuclear power plant systems and these are offered by various vendors to fit specific plant and training program requirements. The advances in computing power sparked two parallel paths of developments:

- **Hardware/Cost considerations:**

  In this approach, high fidelity models are selected and installed in a low cost computing environment consisting of specific one or two processor workstations or even coupled PCs. This is not a truly workable solution, as yet, due to the complex system behaviors in demanding transient scenarios. Requirements related
to graphic capabilities are very demanding, but there are many new products and solutions available for the designers.

In general, the approach of using the latest and/or most advanced models coupled with low cost workstations or even PC environment will be the most likely platform for any future upgrade projects. However, it must be pointed out that in any simulator project, the largest cost is associated with plant specific model developments and possibly with control panel fabrication with I/O devices. The cost of any computer hardware is a relatively insignificant portion of the total budget and not necessarily the determining factor.

Model considerations:

There is an ever increasing need for model improvements regarding not only fidelity, but the capability of modeling large scale time dependent or hitherto not modeled transients. The capability of modeling time-dependent scenarios involving severe accident models enables training programs to experience and practice accident management scenarios. The developments in these areas may include models such as advanced one and half, two-group or nodal neutronic models, five-six equation one or even three-dimensional T-H models for the primary system, advanced two-phase flow models for simulating the environment inside the containment, modeling of fuel slumping and core degradation and tracking core-concrete interaction, analyzing source terms and calculating potential releases to the environment.

All of these modeling capabilities are made possible by the use of parallel architecture advanced microcomputers that provide amazingly fast computational speed with the ease of parallel processors.

Typical simulation models consist of software modules that analyze certain portions of the plant systems and are integrated together with an overlaying executive. There are many different software packages available for each of the individual tasks and each is selected based on the specific requirements of the plant systems and the fidelity requirements established in the training program. The projects that provide simulators in Eastern Europe utilize many different computer architecture and software package combinations to achieve the optimum solution.

Reactor core modeling: All projects as a minimum use a reactor core model where each fuel assembly is separately represented as a calculational node in the radial plane with 7-13 axial nodes. The codes solve the space-time neutron kinetics equation, in either a 1-⅔ or 2-group model, with high order approximations. The models also consider the geometric complexity due to the hexagonal fuel elements in Russian-designed reactor cores. Full T-H feedback is incorporated in the solution method and effects of moderator density, Doppler feedback, control rods, boron and poisons are all included.
Reactor primary system modeling: The basic solution of the T-H equations is based on a five-equation drift-flux nonequilibrium two-phase model fully coupled with the neutronic model. The solution represents critical and subcritical flows through piping structures and components. Heat-transfer coefficients are also represented through the various regimes including convection, liquid, boiling and vapor phase. Noncondensible gases are also modeled that enables these models to analyze large break LOCAs and other accident events with air entrainment or tracking gas generation during core heat-up.

The primary system is modeled using one-dimensional representation, but a new advanced code is also available using three-dimensional mapping of the core region. This allows the calculation of effects difficult to analyze using the one-dimensional models, such as: a single reactor coolant pump trip, steam generator level, etc.

Containment and Severe Accident Modeling: Models are available to analyze the environment in the containment after a design base or beyond design base accidents. These models employ two-phase nonequilibrium gas and liquid models enabling the models to analyze large LOCA or interfacing LOCA scenarios. Severe accident models are also available to analyze to progress of any beyond design basis scenario. These include the capability to calculate fuel heat-up, oxidation, melt and relocation, degraded core geometry, core melt down and relocation.

The following is a brief description of the individual projects:

Projects in Russia

Balakovo - Unit 4 NPP, Model VVER-1000/320

The power plant has an already operating full-scope simulator and is an integral part of the newly improved training program. The simulator was found extremely beneficial, but its use by individual operators is quite limited due to the large operating staff. In order to provide additional training tools in a cost-effective manner, an analytical simulator will be installed at the site. The simulator will incorporate the existing software model with important upgrades of selected software modules. The core and primary system models will use the latest analytical packages and plant specific upgrades will be installed with respect to the electrical and control systems.

The analytical simulator will be based on an advanced microcomputer-based platform and will incorporate the improved full-scope simulator model. The model development will serve as an intermediate point for the eventual upgrade of the full-scope simulator, where the computer capacity is already saturated. The project is envisioned to be completed in 16 months and be in place for training in the second half of 1997. The project is fully funded by the U.S. side with significant manpower contribution from the power plant.
Kalinin - Unit 2 NPP, Model VVER-1000/338

The full-scope simulator project is jointly funded by the U.S. side and the Kalinin NPP. The selected hardware platform will be capable of supporting the most advanced two-group neutronic and 3-D T-H models. The software development has recently started after plant data collection was completed. The control panels with the instrumentations are going to be built in Russia through a competitive bidding process. Expected completion is at the end of 1998.

Kola - Unit 4 NPP, Model VVER-440/213

The full-scope simulator project for the Kola NPP is structured similarly to the Kalinin project. The U.S. side is contributing the computer complex and also funds the design and construction of the control panels with the instrumentation and the I/O system. The project is in the initial design phases with the computer complex being delivered to Moscow where the software development has already started by VNIIAES, the simulator vendor. The control panel design is also in its initial phase.

Novovoronezh - Unit 3 NPP, Model VVER-440/179

The analytical simulator for Unit 3 at Novovoronezh will be completed by S3 Technologies using a previously developed VVER-440 model. This reactor is an early design in the VVER-440 series plants that will require extensive modifications on the existing model. The plant has already implemented new EOIs that are similar to U.S. symptom based approach. The simulator will eventually be instrumental in the full implementation of EOI programs.

Projects in Ukraine

Khmelnytsky NPP, Model VVER-1000/320

This simulator is the first one in the U.S. supported programs to improve the training capabilities in Russia and the Ukraine. The simulator contract was awarded to S3 Technologies. The control panels, from the as yet incomplete Unit 3, are being modified to simulate the Unit 1 configuration. The main computer will use a six-processor microcomputer with at least 50% spare capacity. This will allow for future modeling changes contemplated due to planned modification of the instrumentation and control system. The system model developments are nearly completed and hardware/software integration will start in the next few months that will take place at the site. As part of the project, members of a new Simulator Support Center in Kiev were trained in simulator model developments and participated in other technology transfer activities. The Center will serve as a Ukrainian design organization developing and supporting simulator activities in the future.
Rivno - Unit 3 NPP. Model VVER-1000/320

This will be the first simulator project fully developed by a Ukrainian team based on the technology transfer activities and license obtained under the Khmelnytskyi project. The U.S. side will contribute the hardware such as the computer complex and certain components related to the control panels. Under the Khmelnytskyi project, additional technology transfer has taken place related to control panel manufacturing. All of these infrastructure developments, enable future projects, such as the Rivno one, to utilize all the technology transfer elements. For example, the control panels will be fully manufactured in the Ukraine using the resources of the power plant. The U.S. side will provide assistance only in those areas where the internal infrastructure is not fully developed. Other simulator projects are similarly structured and make full use of the investment in technology transfer.

South Ukraine - Unit 1 NPP. Model VVER-1000/302

In the completion of this project, maximum use will be made of a similar plant model that is presently being developed. In this manner, the model development stage will be compressed and full use will be made of earlier projects. The U.S. side encourages this type of development since the approach ultimately results in a cost-effective and timely completion of plant specific simulators. The major advantage is that the training programs could start using the simulators in a short time improving plant safety and reliability. In this case, the U.S. side will contribute most of the hardware including the computer complex and the control panels. The software development will be the responsibility of the Simulator Support Center in Kiev similarly to the Rivno project.

South Ukraine - Unit 3 NPP. Model VVER-1000/320

The full-scope simulator for Unit 3 has been ordered from the Russian simulator vendor, VNIIAES, in 1985. The U.S. side was asked and decided to assist in obtaining certain hardware related items to complete the project. The project is scheduled to be completed in the second half of 1997 and will make an important contribution to the training program at the site.

Chornobyl - Unit 3 NPP. Model RBMK-1000

The two remaining operational units, Unit 1 and 3, are planned to be decommissioned in the future notwithstanding the uncertainties regarding the actual implementation of this process. There is an immediate need in improving the training infrastructure of the plant to increase the short term safety of the plant and enhance the capabilities of the operators to deal with various transient conditions. The project will provide an analytical simulator using an existing model to the maximum extent. The approach will allow to provide an operational and useable simulator with appropriate plant models in 1997. The RBMK model will contain a neutronic model analyzing all individual fuel assemblies and the T-H model will represent the nearly 2000 fuel channels with appropriate approximations.
Summary

The U.S., in coordination with other Western countries, is in the process of providing or supporting needed training simulators in Russia and the Ukraine. At the completion of these programs almost all power plants in the Ukraine and Russia will have either a full-scope or analytical simulator in place to provide enhanced training capabilities to their operators with a resultant increase in plant safety. The future challenge is to insure that all training facilities and the simulators are properly incorporated into the plant training programs. This will assure that the training facilities in Russia and the Ukraine impart the highest standard of training possible insuring an increased level of safe operation of all Soviet-designed nuclear power plants.

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Table 1a: Simulator Projects in Russia

<table>
<thead>
<tr>
<th>Power Plant</th>
<th>Simulator Type</th>
<th>Simulator Vendor</th>
<th>U.S. Contribution</th>
<th>NPP Funded</th>
<th>Estimated Completion</th>
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<tbody>
<tr>
<td>Balakovo</td>
<td>Analytical</td>
<td>S3 Technologies</td>
<td>Hardware Software</td>
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<td>September 1997</td>
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<tr>
<td>Kalinin</td>
<td>Full-Scope</td>
<td>GET</td>
<td>Hardware Software</td>
<td>Software Control Panels</td>
<td>1999</td>
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<td>Kola</td>
<td>Full-Scope</td>
<td>GET</td>
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<td>Software</td>
<td>1998</td>
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<td>Novovoronezh</td>
<td>Analytical</td>
<td>S3 Technologies</td>
<td>Hardware Software</td>
<td></td>
<td>June 1997</td>
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### Table 1b: Simulator Projects in the Ukraine

<table>
<thead>
<tr>
<th>Power Plant</th>
<th>Simulator Type</th>
<th>Simulator Vendor</th>
<th>U.S. Contribution</th>
<th>NPP Funded</th>
<th>Estimated Completion</th>
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<tr>
<td>Khmelnitsky</td>
<td>Full-Scope</td>
<td>S3 Technologies</td>
<td>Hardware Software Control Panel Modification</td>
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<td>Rivno</td>
<td>Full-Scope</td>
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<td>Hardware Software/License Transfer</td>
<td>Control Panels Software</td>
<td>1999</td>
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<td>Hardware Control Panels</td>
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<td>South Ukraine-3</td>
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<td>VNIIAES</td>
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<td>Chornobyl</td>
<td>Analytical</td>
<td>S3 Technologies</td>
<td>Hardware Software</td>
<td></td>
<td>June 1997</td>
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