Development Of Nuclear Power Plant Simulators For Soviet-Designed Nuclear Reactors[1]

P. Kohut, N K. Tutu
Brookhaven National Laboratory, Upton, NY

E. J. Cleary, K.G. Erickson
Pacific Northwest National Laboratory, Richland, WA

J. Yoder
U.S. Department of Energy, Germantown, MD,

A. Kroshilin
GET/VNIIAES, Moscow, Russia

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ABSTRACT

The United States Department of Energy (U.S. DOE), under the U. S. government's International Nuclear Safety Program (INSP), is implementing a program of developing and providing simulators for many of the Russian and Ukrainian Nuclear Power Plants (NPPs). Pacific Northwest National Laboratory (PNNL) and Brookhaven National Laboratory (BNL) manage and provide technical oversight of the various INSP simulator projects for DOE. The program also includes a simulator technology transfer process to simulator design organizations in Russia and Ukraine. Training programs, installation of new simulators, and enhancements in existing simulators, are viewed as providing a relatively fast and cost-effective technology transfer that will result in measurable improvement in the safety culture and operation of NPPs. A review of this program, its present status, and its accomplishments are provided in this paper.

INTRODUCTION

One of the key elements that determines the operational safety of a Nuclear Power Plant (NPP) is the training and technical knowledge of its reactor operators about the behavior of their plant. It is widely recognized that simulators play an essential and extremely important role in establishing viable training programs for NPPs. *Full-scope* and *analytical* simulators provide such training tools for reactor operators

The objective of the International Nuclear Safety Program is a comprehensive improvement in operational safety of Soviet-designed NPPs. This is planned to be accomplished via improvements in: the safety culture of NPP staff and management, power plant operation, physical condition of the power plants and equipment, and infrastructures in countries operating the Soviet-designed reactors. The development and installation of full-scope and analytical simulators help achieve this goal.

SIMULATOR DEVELOPMENT PROGRAM

A summary of simulator programs in Russia and Ukraine is given in Table 1. Altogether nine full-scope simulators and analytical simulators have recently been completed and declared Ready-for-Training, and an additional five projects are underway to be completed in the next few years.

The simulator development program provides the basis for the development and installation of the latest advances in simulation technology at the Russian and Ukrainian NPPs. This includes advanced three-dimensional thermal-hydraulic simulation of the primary system for a VVER-1000 reactor, advanced neutronic models for the reactor core, and complex system malfunction models.

To avoid the occurrence of negative operator training, a very high degree of simulator fidelity (to the reference plant) is required. A key element for the achievement of simulator fidelity is the use of a Verification and Validation (V&V) methodology during the design, development, and testing of the simulator. Training workshops were provided to utility personnel covering a wide range of topics: experience of US Utilities in V&V methodologies, regulatory requirements, human factors connected with simulator fidelity during testing, and evaluation of acceptance test results.

[1] This work was performed under the auspices of the U.S. Department of Energy.

SIMULATOR PROJECTS

In 1994, under the Lisbon Nuclear Safety Initiative, the first full-scope simulator project was started for the Khmelnytskyy Nuclear Power Plant (KhNPP). This project represented the first joint venture of this nature between the United States, Ukraine, and Russia. It was also used as a vehicle for simulator technology transfer to Ukraine. All other simulator projects that have followed used the same project arrangements with a strong technology transfer component.

Host-country simulation development capabilities were utilized to the greatest extent for a variety of reasons. Soviet-designed reactors have many unique features that required technical input and expertise available at host-country design institutes, power plants, and other technical centers. In general, most of the simulator projects were developed using US supplied hardware components together with selected US software products. GSE as the lead US prime contractor utilized VNIIAES (Russian Institute for Nuclear Power Plant Operations, in Russia) and ETC (Engineering Technical Center, in Ukraine) as the prime host-country participants for software model developments.

The hardware components supplied by the US usually consisted of the simulation computer system and its peripheral items, Input-Output (I/O) systems, the power supply system, and communication equipment. The US, through GSE Power System has fostered the development of control panel fabrication capability in Russia and Ukraine through a technology transfer program. It supports the development of design and fabrication capability of control panels, and on certain projects, the development of I/O systems fabricated in the host-countries.

The technology transfer process both in the software and hardware design and development areas is most important in Ukraine due to their lack of initial capability in these areas. Ukraine has more than 11 nuclear power plant installation that will require long term support for simulator installations. This is a sound basis for developing new technical and fabrication capabilities in the host-country.

The simulator software models were developed to satisfy the ANSI/ANS-3.5-1985 standard. Thus, as specified in this standard, the simulator can simulate normal plant evolutions (steady state and transients) and plant malfunctions specific to the VVER design. Among others, the simulated systems include the primary system, main steam, balance-of-plant, reactor core neutronics, turbine thermal-hydraulics, turbine and reactor control system, and logic systems.

In addition to new simulators, a number of other projects were designed to upgrade pre-existing full-scope simulators at the NPPs. These upgrades usually consisted of providing new and more powerful computers, and in some cases, improving the installed I/O system, and developing new specific software models. The software modules have addressed needed improvements in reactor core modeling, implemented changes in turbine control system, and provided flexible malfunction capabilities to improve fidelity and training requirements.

TECHNICAL ISSUES AND PROBLEMS

Many simulator projects proved to have their own technical issues due to the unique design features that many Soviet-designed reactors have. Most initial software models were developed based on Western experience in Pressurized Water Reactors. While most of the technical issues in Soviet-designed reactors are the same, there are many specific features that are unique and require reactor specific model development. For example, in the Novovoronezh VVER-440/270 design the reactor can be cooled down to cold shutdown by a unique turbine by-pass system. During tests some difficulties in plant cool down, specifically oscillations during phase transfer processes, were encountered. These difficulties were, however, successfully resolved.

Three-dimensional thermal-hydraulic model of the primary system was installed in the Kalinin full-scope simulator. The 3-D model is unique and was demonstrated to provide a better technical description of the primary system during asymmetric transient events. The three-dimensional thermal hydraulic and core neutronics models have been integrated with the Balance of the Plant. The three-dimensional effects can clearly be seen in transients like the Reactor Coolant Pump trip. These effects have been indirectly validated by comparison to limited plant data.

One of the most challenging simulator model development efforts was the Bilibino reactor design. The nuclear plant is of a unique design, comprising four identical units, each capable of generating 12 MW of electrical output as well as 20 MW of heat. It is a graphite-moderated natural circulation driven reactor. Its design resembles some elements of the RBMK reactor design and

this was used as the basis for the specific core model development.

A number of lessons were learned from the interaction among the U.S. side, the U.S. simulator vendor, the Russian simulator vendors, the Ukrainian vendors, and the NPPs. The problems encountered were generally a result of cultural differences, or differences in the way things are seen and done (corporate behavior) in Ukraine/Russia versus the United States. In addition, the meager fiscal resources of the NPPs contributed to its own sets of problems. These problems were concentrated mainly in:

1. Data Collection
2. Provision of Panels/Instruments
3. Customs Problems
4. Building Delays

Due to the fact that, in most cases, there is only a single supplier for the instruments for the Soviet-designed reactors, completing the control panels and instrumentation for the simulator is a very difficult task. On the positive side, the technology transfer was quite useful for the power plant personnel who were subsequently able to practice their newly learned skills at the plant and at the simulator.

ACCOMPLISHMENTS AND CONCLUDING REMARKS

The U.S., in coordination with other Western countries, is in the process of providing or supporting training simulators in Russia and Ukraine. It is expected that access to NPP simulators will provide the following benefits:

- Improved training of NPP staff in normal and off-normal operations, and during accident and emergency scenarios.
- Improved overall and system-level understanding of NPP operating characteristics on the part of reactor operators.
- Development and validation of Emergency Operating Instructions (EOIs).
- Improved analytical capabilities of the NPP technical support staff.
- Development and implementation of training programs based on simulators.
- Establishment of host country capabilities to design and manufacture full-scope and analytical simulators for NPPs.

At the completion of these programs all Russian and Ukrainian NPP sites having VVER-type nuclear power plants will have either a full-scope or analytical simulator in place to provide enhanced training capabilities to their operators, thereby resulting in increased plant safety. The future challenge is to ensure that the training facilities in Russia and Ukraine maintain their simulators in a certifiable state and continue to impart the highest standard of training possible, thus ensuring an increased level of safe operation for Soviet-designed NPPs.

Table 1. INSP simulator projects in Russia and Ukraine

NPP	Simulator/Reactor Type	Vendors	Completion Date
Novovoronezh Unit 3	Analytical VVER-440/270	GSE	Sep 98
Balakovo Unit 4	Analytical Full-Scope Upgrade VVER-1000/320	GSE/VNIIAES	Nov 99 Dec 99
Kola Unit 4	Full-Scope VVER-440/213	VNIIAES/GSE	March 00
Bilibino	Analytical LGR	GSE/VNIIAES	Apr 00
Kalinin Unit 2	Full-Scope VVER-1000/302	VNIIAES/GSE	Nov 01
Khmelnytskyy Unit 1	Full-Scope VVER-1000/320	GSE	Dec 97
Chornobyl Unit 3	Analytical RBMK III	GSE/VNIIAES	Feb 98
Zaporizhzhya Unit 5	Full-Scope Upgrade VVER-1000/320	GSE/VNIIAES	Jun 99
South Ukraine Unit 3	Full-Scope VVER-1000/320	GSE/VNIIAES	Apr 00
Rivne Unit 3	Full-Scope VVER-1000/320	GSE	May 01
South Ukraine Unit 1	Full-Scope VVER-1000/302	GSE	Jun 01
Zaporizhzhya Unit 1	Full-Scope VVER-1000/320	GSE/VNIIAES	Apr 02
Rivne Unit 2	Full-Scope VVER-440/213	GSE	Oct 02
Trnava V-2	Upgrade VVER-440/213	SAIC/ORGRESS and others	Sep 01
Kozloduy Modification	Modification VVER-1000	GSE	Nov 00

Notes: GSE: U.S. simulator vendor, VNIIAES: Russian simulator vendor