BN-350 reactor building; photo was taken during United Kingdom-Kazakhstan meeting, October 2010.

The Benefits of International Cooperation on Decommissioning

U.S. and U.K. Contributions to the Decommissioning of Kazakhstan's BN-350 Reactor

U.S. and U.K. assistance at BN-350 was aimed at reducing potential threats from the presence of nuclear and radioactive materials and at putting the reactor beyond economic reuse.

By D. Wells, J. Michelbacher, and T. Hayward

The BN-350 sodium-cooled fast reactor was an industrial-scale plant designed and built by the Soviet Union in the 1960s and sited in what is now Kazakhstan's port city of Aktau on the Caspian Sea. The reactor operated successfully from 1973, producing electricity and process steam for desalination. BN-350 was finally shut down in 1999, when it became uneconomic to continue the annual revalidation of its unique systems, and decommissioning commenced.

U.S. assistance with decommissioning and with management of the substantial quantity of spent nuclear fuel at BN-350 had already been sought by Kazakhstan before reactor shutdown. Rather later, the United Kingdom joined in the assistance program, initially under the aegis of International Atomic Energy Agency's (IAEA's) international coordination group for BN-350 decommissioning, contributing funding and technical assistance in the

same manner as the United States. Soon thereafter, it became clear that there would be benefits from closer collaboration between U.S. and U.K. activities in support of BN-350; thus, from 2003, this became a recognized way of working on decommissioning activities. (It should be noted that in parallel with the decommissioning assistance work, there is a major and separate U.S.-Kazakhstan bilateral collaboration project to package and transfer spent nuclear fuel from BN-350.)

This article summarizes the achievements of the United States and the United Kingdom in providing assistance with the BN-350 decommissioning project.

BN-350 Reactor Design and Operation

The BN-350 reactor was a loop-type sodium-cooled, enriched uranium oxide–fueled fast neutron reactor with an original design thermal output of 1000 MW. In practice, the maximum output achieved was restricted to 750 MWt and 260 MWe. The reactor had six primary and six secondary sodium loop circuits supplying heat to steam generators that produced steam fed to an adjacent electricity generation plant that remains operational using conventional steam boilers. The six primary circuit loops each include valves, an intermediate heat exchanger, a main circulation pump, and a leak catch tank. Each primary loop is linked to one of the secondary sodium loops via an intermediate heat exchanger. Each secondary loop incorporates a single mechanical circulating pump and leak catch tank feeding sodium to a heat exchanger. Four of the six steam generators are to the original installed design; the other two were replaced by modular-type units after several years of operation.

The reactor building also contains facilities for introducing new fuel into the reactor and for removing and storing irradiated fuel. Sodium was removed from irradiated fuel assemblies as a routine operation, allowing spent fuel to be stored in a large covered water-filled pond in another part of the reactor building.

Objective of U.S. and U.K. Assistance with BN-350 Decommissioning

The rationale behind the U.S. and U.K. assistance at BN-350 is to reduce potential threats from the presence of nuclear and radioactive materials and to put the reactor beyond economic reuse, achieving the so-called irreversible shutdown criterion. This focus has the result that certain standard aspects of decommissioning, such as waste management, environmental remediation, or dismantling, are essentially excluded from the assistance offered and are undertaken by Kazakhstan with assistance from other international collaborators as appropriate. The U.S. and U.K. assistance with BN-350 decommissioning is implemented via Nuvia Limited, acting as the technical collaborator on behalf of the responsible U.K. government department. Idaho National Laboratory (INL) is the technical collaborator on behalf of the U.S. government.

The areas of assistance covered can be summarized under three main headings:

- Decommissioning planning.
- Decommissioning projects.
- Training and technical assistance.

Decommissioning Planning

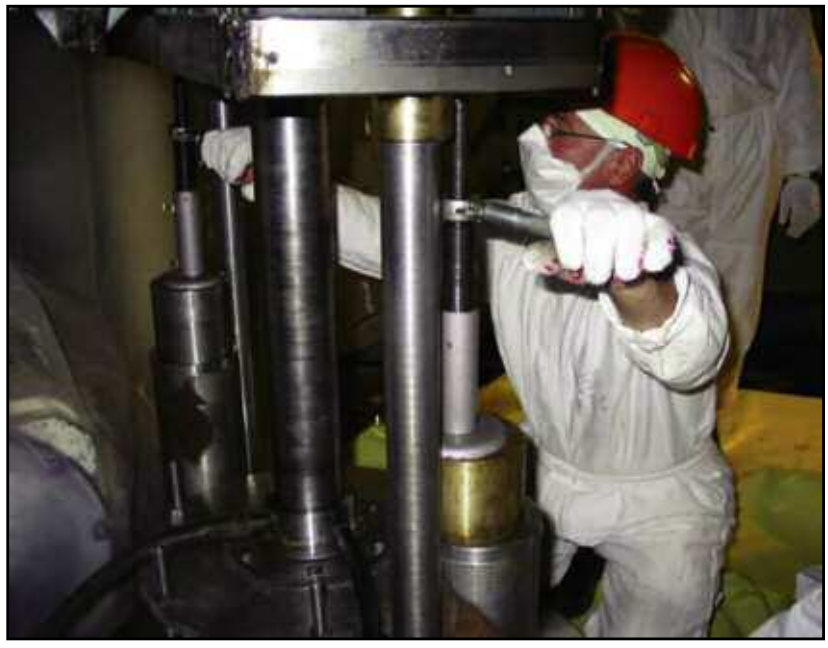
The preparation of a "Top-Level Decommissioning Plan," meeting IAEA standards and requirements, was originally funded by the United States through the intermediary organization, the Moscow-based International Science and Technology Center (ISTC) under project number K-513.[1] The Decommissioning Plan was prepared by personnel from Kazakhstan and underwent international reviews followed by final editing with the assistance of U.K. experts. This version of the Decommissioning Plan was submitted to IAEA in 2003. The plan continues to be updated by Kazakhstan as a living document enshrining the strategy for the overall decommissioning of the reactor, with the initial phase preparing the plant for an extended period of SAFSTOR to allow radioactive decay before final dismantling.

Decommissioning Projects

Sodium Processing

The strategy developed under the U.S.-Kazakhstan bilateral collaboration from around 2000 was based on the following stages:

1. Initial radioactive decontamination of the primary sodium by cesium trapping.
2. Draining of primary sodium into the installed storage tanks.



Sodium draining operations on BN-350 reactor top.

3. Design and construction of a sodium processing facility (SPF) to react the sodium with aqueous caustic.

4. Development of a solid storage medium to immobilize the consequential sodium hydroxide product of the SPF in a geocement matrix.

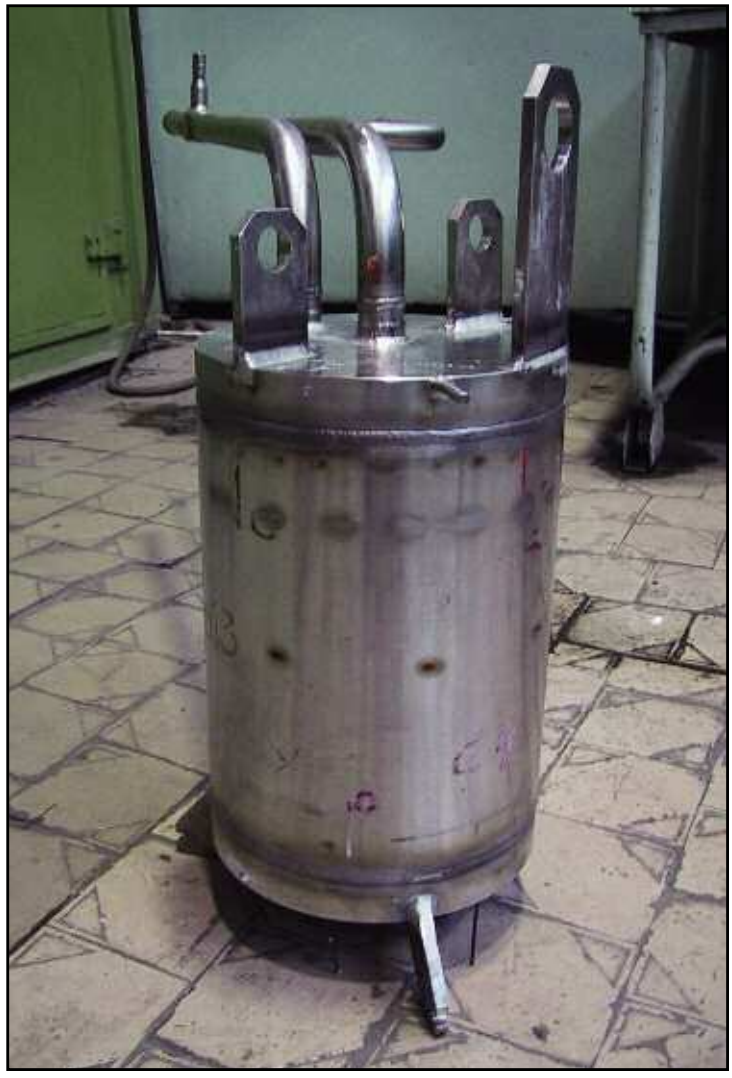
Subsequently, Kazakhstan was able to identify a route for direct industrial reuse of the secondary sodium in the refining of specialist metals, avoiding the need to process this material in the SPF with the associated generation of solid waste.

Cesium Trapping and Sodium Draining

The current status is that cesium trapping was completed in 2003,[2] followed closely by draining of the sodium from the reactor and primary coolant loops. Consequential activities from this phase of work that are continuing include processing of the primary sodium and immobilization of the cesium traps (see section following).

Construction and Commissioning of Sodium Processing Facility

The U.S.-funded design, construction, and commissioning of a sodium processing facility modeled closely on the plant successfully operated between 1998 and 2001 to process sodium from EBR-II. Construction and initial setting to work of the BN-350 processing facility was completed in late 2008 at an approximate cost of $6 million. Unfortunately, to date the unavailability of the downstream waste immobilization plant has meant that it has not been possible to



U.S.-Kazakhstan design cesium trap (shown without shielding).

BN-350 Sodium Processing Facility building.

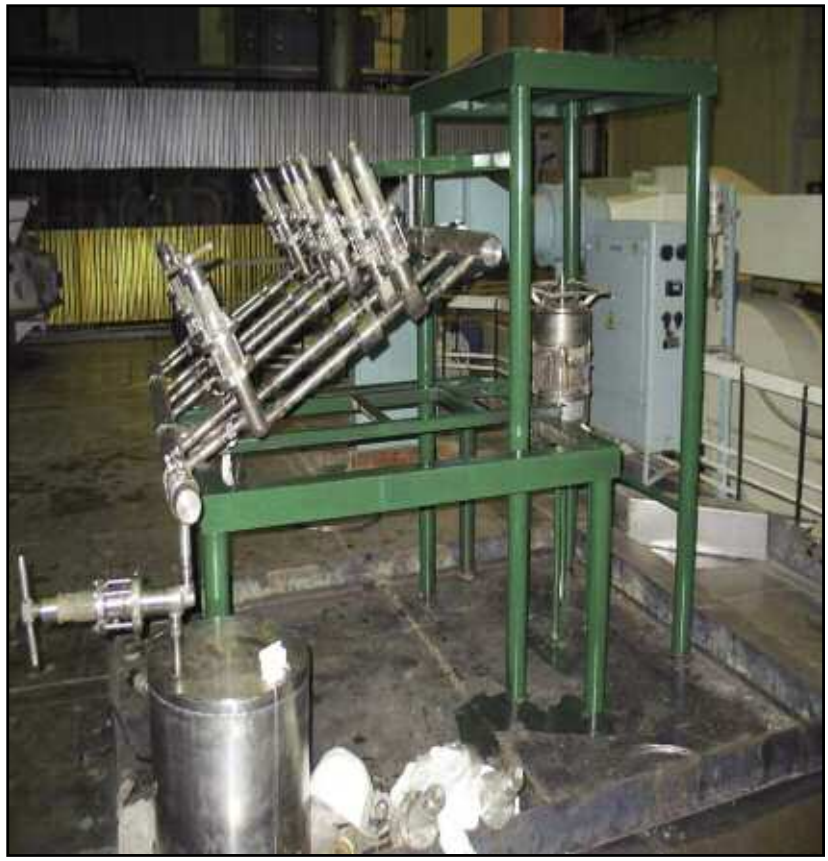
start active sodium processing. An option to modify the plant to produce high-concentration sodium hydroxide for interim storage onsite is thus under development.

Development of Geocement

The U.S. and U.K. cofunded development, including a series of full-scale trials, of a geocement-type waste form for immobilization of 35 percent concentration sodium hydroxide produced by the processing facility. This work has resulted in a design for the process plant being made available for construction by Kazakhstan.

Treatment of Residual Sodium

A key aspect of attaining suitable conditions for the SAFSTOR period is the passivation of the residual sodium and NaK remaining within the coolant circuits. Development work for BN-350 residual sodium processing concentrated on the in-situ cleaning of the circuits using moist carbon dioxide. Development of the process for BN-350 was initially funded by the United States, with technical input from INL specialists.



Cesium Trap lead filling test rig.

Implementation of residual sodium processing was set up as a project under the auspices of ISTC with funding from the British government. The project began in early 2006 and was completed at the end of 2009. A companion paper[3] describes the achievements of this project in more detail. Passivation of residual sodium eliminates the need to maintain a high-purity inert gas atmosphere within the circuits, with major safety and cost benefits over a 50-year SAFSTOR period. In addition, passivation effectively renders future reactor operation impossible due to the production of sodium carbonate/bicarbonate.

Immobilization of Cesium Traps

Two different types of cesium trap were used at BN-350 to remove cesium-137 contamination from the primary sodium coolant. The first were Russian-designed in-core devices—the "MAVR" series, which used low-ash granulated graphite (LAG)—configured in a holder simulating a fuel assembly. The second type, termed trap accumulators, were devices connected into an external loop, using reticulated vitreous carbon (RVC) to decontaminate the primary sodium after final reactor shutdown. These traps were designed by Kazakhstan, in collaboration with INL and MAEC Kazatomprom, the operator of BN-350. At present, four spent cesium traps of the MAVR series and seven spent trap accumulators are stored at BN-350. The filled cesium traps have high specific activity and are contaminated with varying amounts of sodium; therefore, they are not suitable for long-term storage or disposal due to the mobility of radioactivity and chemical reactivity.

Characterization of the traps and optioneering for handling of BN-350 spent cesium traps was accomplished between 2004 and 2006. Conditioning of all cesium traps by filling with lead or lead-bismuth (Pb-Bi) alloy, based on Russian technology, was proposed as the preferred technology, recognizing that additional experimental verification was required. Experimental work[4] was undertaken from 2007 to 2008 and substantiated the use of lead filling. The actual immobilization project is now in progress, funded by the United Kingdom, with completion planned this year.

Survey of Hot Cell Waste Vault, Fuel Transfer, and Washing Cells

BN-350 was equipped from the outset with remote handling facilities to handle and examine fuel and materials irradiated in the reactor. The Hot Cell was designed to allow the removal of pins from irradiated fuel assemblies for destructive and nondestructive examination and included an adjoining waste vault or repository for storage of beta-gamma active scrap removed in the course of examinations. This vault was identified as a possible "sink" for fissile material losses during historical operations. A remote visual and internal radiation survey of the vault was undertaken in 2009, with data analysis continuing into early 2010. The U.K.-funded survey has helped to establish confidence that nothing more than minor amounts of nuclear material remain in the vault. The survey will be extended to the fuel route from reactor to the fuel storage

pond and eventually to the pond itself, once all spent nuclear fuel has been loaded into casks.

Training and Technical Assistance

The United States and United Kingdom have collaborated since 2003 in providing project management and technical training. Several courses, from introductory[5] to specialist level, have been delivered in Kazakhstan: introduction to project management; project scheduling, estimating, and procurement; risk management; and optioneering techniques. Technical training workshops have included specialist sessions in the United States, United Kingdom, or Kazakhstan covering experience with liquid metals, radiation protection, decommissioning techniques, radioactive waste immobilization, and cementation technology.

Future Plans

With Kazakhstan looking to restart its own nuclear power generation program[6] and hence able to take responsibility for remaining liabilities at BN-350, the U.S./U.K. assistance is currently reducing in scope and is expected to end by around 2012. Activities continuing through 2010 included modifications to the sodium processing facility, cesium trap lead filling preparations, and the fuel route survey.

Lessons Learned

The U.S. and U.K. assistance to Kazakhstan with the decommissioning of BN-350 has made a contribution to global threat reduction by bringing about irreversible shutdown of the reactor and working to immobilize certain key wastes. Besides the technological objectives, some "soft" objectives associated with the transfer of decommissioning technology and methodologies have been achieved. Working together has allowed the U.S. and U.K. participants in the assistance to Kazakhstan to add value over and above what would be achieved from separate bilateral assistance programs.

Other lessons learned from the BN-350 assistance work include the fact that the discipline of project management (budgeting, scheduling, and managing risks) is not yet fully embraced by all engineering organizations in Kazakhstan. Even with a substantial amount of training in these techniques, it remains that the wider industrial infrastructure (equipment suppliers and contractors) has difficulty in supplying on time or at the right quality.

References

1. "Project K-513, Preparation of a Decommissioning Plan for International Review to Place the BN-350 Reactor in a SAFSTOR Condition," International Science and Technology Center; www.istc.ru.
2. O. Romanenko et al., "Cleaning Cesium Radionuclides from BN-350 Primary Sodium," *Nucl. Technology,* **150**, 79 (2005).
3. O. Romanenko et al., "Processing of Residual Sodium in the BN-350 Reactor Coolant Circuits," Summary 1749, *Proc. DD&R Topl. Mtg.,* Idaho Falls, Idaho (2010).
4. O. Romanenko et al., "Experiments Performed in Substantiation of the Conditioning of BN-350 Spent Cesium Traps Using Lead or Lead-Bismuth Alloy Filling Technology," 33rd Int. Symp. Scientific Basis for Nuclear Waste Management, St. Petersburg (2009).
5. N. Organ et al., "International Collaboration with the Decommissioning of the BN-350 Reactor," *Proc. DD&R Topl. Mtg.,* Denver, Colorado, pp. 191–194 (2005).
6. K. Kadyrzhanov, "Supplier Turns Consumer," *Nuclear Engineering International* (2009). ■

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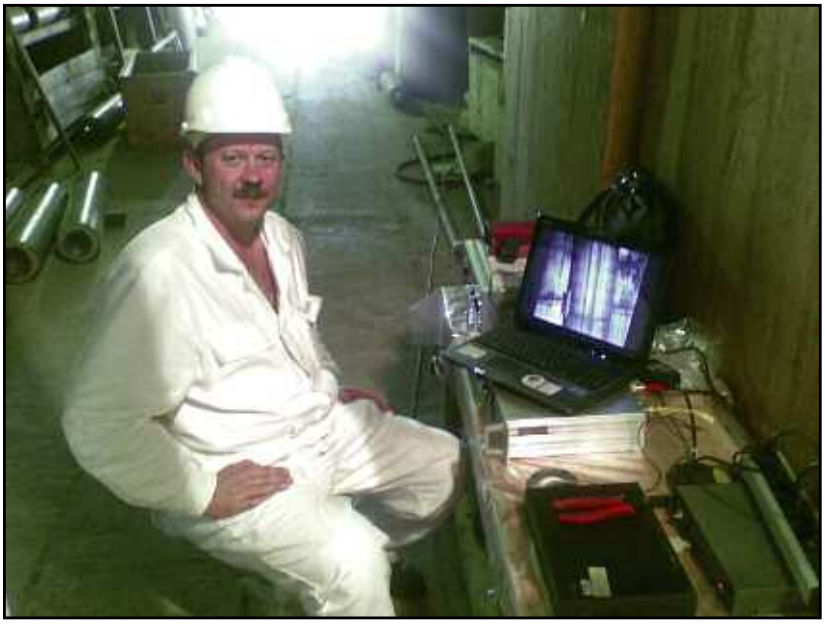
This article reports work funded by the U.S. Department of State and Department of Energy and by the U.K. Department of Energy and Climate Change. Permission to publish is gratefully acknowledged.

This article is based on a presentation made at the American Nuclear Society's 2010 Topical Meeting on Decommissioning, Decontamination, and Reutilization, held August 29–September 2, 2010, in Idaho Falls, Idaho.



Hot Cell waste vault remote survey control point.