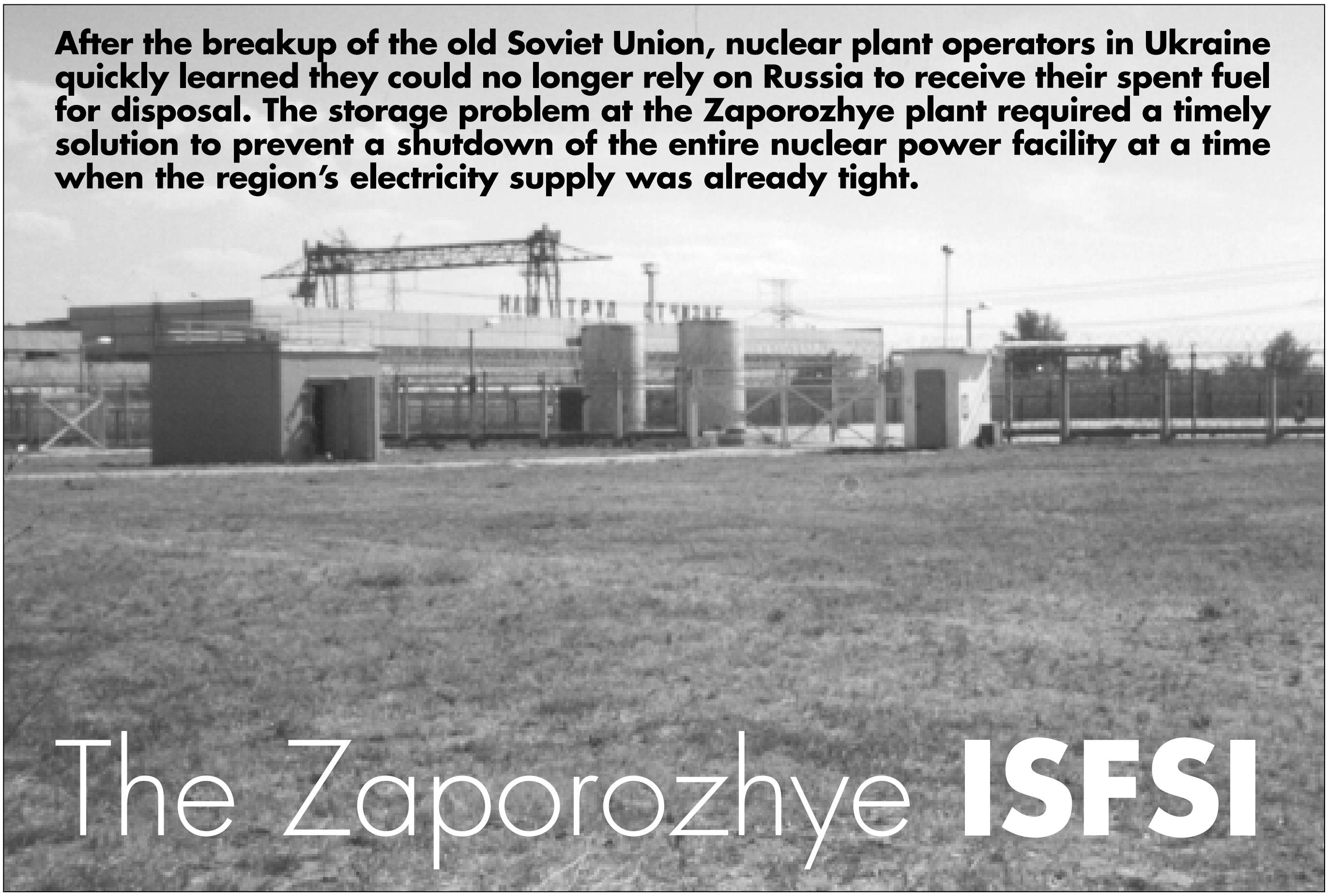
After the breakup of the old Soviet Union, nuclear plant operators in Ukraine quickly learned they could no longer rely on Russia to receive their spent fuel for disposal. The storage problem at the Zaporozhye plant required a timely solution to prevent a shutdown of the entire nuclear power facility at a time when the region's electricity supply was already tight.

The Zaporozhye **ISFSI**



VCS spent-fuel containers sit empty on the ISFSI concrete pad waiting for the loading operation to begin.

By David G. Marcelli and Tommy B. Smith

In April 1986, the Chornobyl nuclear power plant disaster would bring together the technical and political worlds of the United States and the Soviet Union. Duke Power Co.'s chairman and CEO at the time was the late William S. "Bill" Lee. Lee had become well known around the world for his industry leadership after the 1979 nuclear plant accident at Three Mile Island and for managing one of the most successful fleets of nuclear plants in the United States. The Institute of Nuclear Power Operations was formed under Lee's leadership. As a highly regarded industry leader, Lee was summoned to Ukraine to help plan the Chernobyl recovery effort. This is where he first met and became friends with Vladimir K. Bronnikov, who would later become general director of the Zaporozhye nuclear power plant (ZNPP).

The 1991 collapse of the Soviet Union created some unforeseen problems for nuclear power in Ukraine. Ukraine was now an independent state, and nuclear plant operators there soon learned they could no longer rely on Russia to receive the country's spent fuel for disposal. Political confusion among the former Soviet republics essentially created an impassable roadblock for the shipment of spent fuel from Ukraine to Russia. It was unclear how long this problem would last, and Bronnikov realized he

Forming the storage casks. The steel forms have been removed to reveal the concrete cask.

needed to find alternative solutions for disposing of spent fuel from his reactor pools.

The ZNPP, Europe's largest nuclear power facility, with six 1000-MW reactors, was not designed with significant spent-fuel storage capacity. By the summer of 1993, several of the facility's fuel pools were completely full—in some cases consuming the core off-load space. ZNPP-6, at the time under construction but nearly complete, was pressed into service as an emergency storage facility for spent fuel. The spent-fuel problem required immediate attention to avoid a shutdown of the entire nuclear power facility at a time when the region's electricity supply was already tight.

TURNING TO AN OLD FRIEND

Bronnikov once again turned to his trusted friend in the United States. Lee agreed to help, and a team of Duke Engineering & Services engineers was deployed to Ukraine in late August 1993. Duke Power Co. and Duke Engineering had been developing alternative spent-fuel storage concepts since 1987. These included a spent-fuel storage facility for Duke Power's Oconee nuclear station and conceptual designs for the U.S. Department of Energy's civilian radioactive waste program.

The Duke Engineering project team met with ZNPP engineers and the plant's designer, Kharkov Design Institute, who provided the team with a design basis document that included fuel parameters and other technical requirements. After an intense three-day discussion, the group determined that it would be possible to modify an existing spent-fuel storage system design for U.S. pressurized water reactor (PWR) fuel that would meet the technical and commercial requirements for ZNPP's Russian-designed VVER fuel. The project team returned to the United States to study the problem and develop a technical and commercial proposal by October.

The project team realized that although it had significant experience with PWR fuel, there were many differences between PWR work in the United States and Russian VVER work. Among these differences were the following:

- Minimal preexisting information was available to provide guidance to the designers on fuel or equipment adaptation.

Zaporozhye Nuclear Power Plant Spent Nuclear Fuel Storage Facility

The Zaporozhye Nuclear Power Plant (ZNPP) is the largest nuclear power plant in Europe.

Number of employees: 15 000
Units: Six
Total megawatts: 6000 (1000 per unit)
Location: Energodar, Ukraine; Population: 65 000

Dates of initial operation:
Unit 1—April 1985
Unit 2—October 1985
Unit 3—January 1987
Unit 4—January 1988
Unit 5—October 1989
Unit 6—October 1995

OPERATING HISTORY

The ZNPP has generated more than 300 billion kilowatt-hours of electricity, not only for homes, businesses, and industry in Ukraine, but also for sale to other countries. ZNPP and other Ukrainian nuclear power plants generate about 40 percent of the nation's electricity.

WHAT TYPE OF NUCLEAR STATION IS ZNPP?

ZNPP is designed only for the generation of electricity. All six reactors are Soviet-designed VVER-1000 pressurized water reactors.

SPENT NUCLEAR FUEL STORAGE FACILITY

Project Objectives

- Provide safe and environmentally friendly onsite storage for spent nuclear fuel (SNF).
- Transfer technology to Ukraine to support SNF storage efforts in the region.

Spent Fuel Discharge

300 spent fuel assemblies are unloaded from the six reactor units per year.

Components of the Ventilate Storage Cask (VSC) System

- Multiassembly sealed basket: Coated carbon steel containment vessel, with shielding lid, structural lid, and hexagonal steel tubes to receive the spent fuel assemblies.
- VSC: Reinforced concrete cask with an inner steel liner, including steel air inlet and outlet penetrations for natural cooling and ventilation.

Cask Transferring and Handling Systems Provided to ZNPP

- Transfer cask: A steel and lead cylinder with hydraulically actuated doors at the bottom, a lid-like restraint ring, and a steel lifting yoke.
- Storage cask transporter: A U-shaped steel frame vehicle and self-contained hydraulic system for lifting and moving the heavy concrete cask.
- Vacuum drying system: Skid-mounted pumping station with water pump, water vapor–compatible vacuum pump, helium-compatible vacuum pump, and assorted pressure gauges and valves.
- Welding system: Semiautomatic welding rig with power supply, controller, drive carriage, and wire feeder.

SNF Storage Cask Designer: British Nuclear Fuel Solutions

SNF Storage Capacity: One VSC cask holds 24 fuel assemblies. Onsite facility is designed to hold 380 casks.

- Uncertainty existed on validating information, since the VVER design basis information was not readily available.

Ukraine did not have any practical regulatory experience in dealing with development of licensing documents for a spent-fuel facility or policies and procedures for their review and approval.

- There were difficulties implementing an NQA-1-type quality assurance program on foreign equipment and design.

Furthermore, Ukraine did not have any practical regulatory experience in dealing with development of licensing documents for a spent-fuel facility or policies and procedures for their review and approval. And while the language barrier was obviously going to present a challenge, the team did not envision the difficulties caused by local social customs, local requirements, and general economic questions.

The project team overcame these challenges and prepared a comprehensive proposal to address the immediate problem of managing spent nuclear fuel (SNF) with the added dimension of future self-sufficiency for ZNPP. The following principal factors guided the proposed solution:

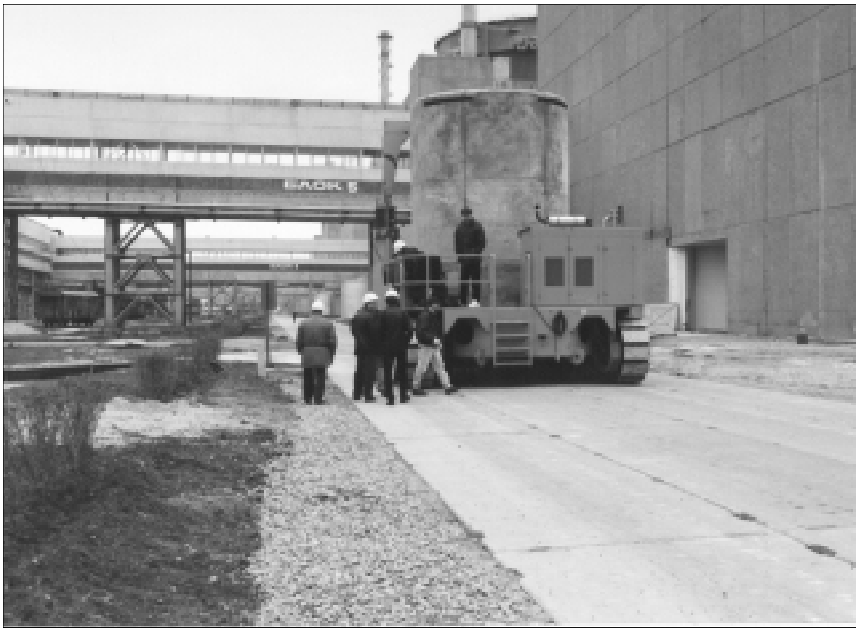
- The selected system must be licensed for use and proven in applications to the extent possible.
- The selected system had to be modular in concept—sufficiently modular to meet uncertain storage needs and financial conditions.
- The selected system had to be capable of being designed to meet Ukrainian requirements and be constructed in not more than 30 months.
- The selected system components had to be readily constructable in Ukraine now or in the near future using available local materials and labor.

The project team proposed a turnkey solution to the near-term problem of unloading fuel from the pools to an independent spent-fuel storage installation (ISFSI) within the shortest time frame possible. Between September and December 1993, Duke Engineering and ZNPP negotiated a contract to perform the work, and a contract was signed in December 1993. The contract included the following activities: storage system component design, equipment fabrication and delivery, construction oversight, licensing assistance, quality assurance program development and implementation, onsite technical support, operator training, public relations support, and project management.

The Ventilated Storage Cask System

Storage system selection is a critical decision in the design process because this decision drives fulfillment of the licensing requirements, construction requirements, materials selection and qualification, and operational issues. The project team's experience in analyzing and custom designing storage systems for the DOE proved to be invaluable in selecting an appropriate system to use at ZNPP.

Because team engineers had previously evaluated many existing and proposed systems to store spent fuel in a variety of applications, they were in a unique posi-



An empty VCS container is moved to the reactor building to be loaded with spent i

Decontamination and radiation protection workers assemble prior to entering the radiation control zone at ZNPP before fuel loading begins in the reactor building.

tion to select an existing storage system for this application. The project team selected the ventilated storage cask (VSC) system developed by Sierra Nuclear Corp. (SNC) as the basic storage system component. The VSC storage system uses a carbon steel basket to house the fuel assemblies meeting 10 CFR 72 licensing requirements. The basket design is simple and quite efficient. The basket is housed in a concrete cylinder that provides radiation shielding and protection from external hazards. The VSC system turned out to be the correct choice in balancing cost, adaptability, and flexibility for this application.

Although the contract was signed in late 1993, engineering work on the storage system was delayed until summer 1994. Because of continuing political and economic turmoil in the former Soviet Union, ZNPP was unable to meet the financial reserve requirements of the contract. The interim period was used to seek funding from government and private sources to enable work on the project to begin. Funding was secured in June, and work began in July 1994. SNC engineers began converting the VSC-24 (PWR) design to a VVER-24 design for the Russian hexagonal fuel.

That same month, Duke Engineering established a project office in Energodar, Ukraine. Significant volumes of information passed back and forth between the Ukraine project office and Duke Engineering and SNC offices in the United States. The language problem in the field was overcome as translation and interpretation support was initially provided by ZNPP. For the personnel who were stationed in Ukraine or made frequent visits, this assistance proved to be invaluable in adapting to Ukrainian life in a small remote town in Southern Ukraine.

Redesigns, More Redesigns, and a Complicated Licensing Process

One of the biggest challenges was designing the storage basket and cask to meet more stringent radiation shielding requirements imposed by the Ukrainian legislature. The strict shielding requirement required a significant increase in the thickness of the interior concrete liner and walls of the storage cask. Redesigns optimized the liner thickness at 3 inches (compared to the usual 1.5-in.-thick liner) and concrete cask diameter of 133 in. These final dimensions also required changes to the minimum acceptable concrete density; the designers imposed rigid controls on the concrete mix. The final design resulted in only 3 in. of clearance between the reactor hall door and the top of the cask and less than 5 in. of clearance on each side of the door.

Except for the transfer cask, the rest of the equipment was designed without significant question or incident. The transfer cask is used to move the loaded fuel basket from the fuel pool into the concrete cask. This heavy, lead-shielded component protects utility workers from unnecessary radioactive exposure when the fuel assemblies are lifted out of the water.

In the United States, the transfer cask is typically lowered into the fuel pool, which normally has adequate space to accommodate the VSC–24 transfer cask and door actuators. In a VVER-1000, fuel movement occurs in the reactor building in a combined reactor pool/spent-fuel pool/transfer pool. The VVER-1000 system was designed to interface with a Russian-designed TK-13 cask for shipping spent fuel to a centralized storage area in Siberia. The designated (and only) location for transferring fuel in the VVER-1000 is in the "universal seat," a small cavity integral to the spent-fuel pool. The universal seat did not have sufficient space to accommodate the complete VSC transfer cask, requiring a redesign of the door actuators and supporting structures. Furthermore, to meet Ukrainian heavy-lift hoisting requirements, an additional set of lifting trunnions was added to the transfer cask, resulting in two pairs of totally redundant lifting points—each trunnion pair matched to the lifting beam attached to the polar crane.

The redesign of the VSC system to meet ZNPP design requirements and Ukrainian safety analysis report (SAR) requirements took place in slightly less than eight months—not long considering the difficulty with document translation and the long distance data gathering and verification process. After lengthy discussions with ZNPP representatives and the Ukrainian Nuclear Regulatory Authority, Duke Engineering set out to develop the SAR for the licensing phase of the project.

The ZNPP license review and approval process was complicated by a lack of a defined and proven licensing process. Another challenge involved demonstrating the applicability of American Society of Mechanical Engineers Code relative to design codes used in the former Soviet Union. After nearly four years of discussion between U.S. and Ukrainian engineers, the technical issues governing the design and operation of the storage system components were finally agreed upon and approved by the Ukrainian Nuclear Regulatory Authority.

As the licensing work progressed in Ukraine, the decision was made to begin the equipment fabrication in the United States prior to final technical approval of the SAR. Senior management involved in the project agreed that accepting this unusual risk was necessary to meet a now extremely demanding operational schedule. With one exception, the development and fabrication of the storage equipment components occurred without significant incident or problems.

The most critical component in the storage system is the fuel basket. The design requirements are typically stringent, and in the case of VVER refueling technology, the fabrication tolerances for equipment are extremely tight. Precise fabrication is required to permit the fuel basket to mate up with the computer-controlled refueling bridge. Halfway through the fabrication schedule, the client asked the project team to significantly improve the typical U.S. fabrication tolerances to more closely match the machined precision found in a Russian TK-13 fuel cask.

Working directly with the manufacturer, fabrication support engineers devised a method to meet the more restrictive tolerances on the basket by improving initial fitup of the internal grid assembly and establishing a method to accurately predict the postwelding distortion profile of the individual pieces. The entire basket and internal grid were surveyed during and after assembly using laser surveying equipment. The final product was checked for functionality by testing each cell of the basket using an oversized imitation fuel assembly.

Ukraine's First ISFSI

Following the historic issuance of the first license to operate a SNF storage facility in Ukraine on July 16, 2001, ZNPP made preparations for loading three baskets of spent fuel from the Unit 2 pool. The loading operation began on August 18 and concluded with the loading of the third basket on September 4, just a little more than eight years from the date of initial planning. After a mandatory one-year trial operation, ZNPP plans to move forward with full implementation of the project for all six units. The successful completion of the eight-year, multimillion-dollar project paves the way for the safe and effective management of SNF and the continued operation of Ukraine's largest nuclear power plant. ■

David G. Marcelli served as the Duke Engineering & Services project manager for the Zaporozhye ISFSI. Tommy B. Smith is communications manager for the company.

ZNPP technicians review a videotape of the day's spent-fuel loading operation.