STP's first-of-a-kind leakage repair

BY EDWARD CONAWAY

More than a dozen industry organizations worldwide pitched in to offer advice for correcting a never-before-seen leakage problem.

BY NOW, THE lessons learned from the nuclear power industry's first-of-a-kind leakage found on the bottom of South Texas Project-1's (STP) reactor vessel have been documented. What may not be as familiar is the safe, effective, and successful manner in which STP corrected that leakage, the details of which follow.

The STP plant has two Westinghouse pressurized water reactors. Unit 1, which started commercial operation in August 1988, is rated at 1268 MWe (net). Unit 2, which started commercial operations in June 1989, is rated at 1268 MWe (net). The plant, in Palacios, Tex., is operated by STP Nuclear Operating Company.

STP-1's reactor vessel bottom leak was discovered during a routine boric acid inspection as part of a scheduled refueling outage in April 2003. During the inspection, a small amount (153 mg) of residue was found on two of the 58 bottom-mounted instrumentation (BMI) tubes that penetrate the underside of the vessel. Tests found boric acid and lithium-7 in the residue, confirming that it came from reactor coolant water. As the industry learned, this was the first time leakage had occurred on the bottom of a reactor vessel.

STP management notified the Nuclear Regulatory Commission, and experts from more than a dozen worldwide industry organizations and companies were asked to visit STP for their advice and recommendations. The experts included representatives of the Electric Power Research Institute, the Institute of Nuclear Power Operations, Altran, Dominion Engineering, Dominion Generation, Duke Power, Electricité de France, Exponent Failure Analysis Associates, Framatome ANP, Performance Improvement International, Progress Energy, Southern Nuclear, Tractabel, Westinghouse PCI, and the following nuclear plants: Arkansas Nuclear One, Comanche Peak, Palo Verde, and V. C. Summer.

Within a week of finding the leak, STP had developed a plan that included scheduled time for the NRC's review of precedent-setting actions. STP also invited vendors to submit bids for proposed testing and repair methods. After comparing the submissions and evaluating demonstrations of tools and techniques at vendor facilities, STP selected Framatome ANP to perform nondestructive examinations and make repairs.

The tests performed included boroscopic, dye penetrant, eddy current, magnetic particle, profilometry, and ultrasonic examinations, as well as stress and fatigue analyses. Extensive tests also were conducted on a metallurgical sample of a nozzle section containing a crack and some weld material. The tests, including some exams devised for this project, located small axial cracks in both BMI nozzles and

A mock-up of the lower half of STP-1's reactor vessel was used on-site by workers to practice various tasks before the real repair job was done. The long pipes descending from the reactor are instrumentation tubes. (Source: STP Nuclear Operating Co.)

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A close-up of a repaired nozzle, which was secured to the outside of the reactor by welding it to a thick, nickel-chromium pad. (Source: STP Nuclear Operating Co.)

a single through-wall crack in each nozzle. The tests were repeated on the other 56 nozzles, and no additional cracks were discovered. The vessel areas around the nozzles were tested ultrasonically and found to be in good condition.

The nozzles were repaired by removing their lower portions and replacing them with new nozzles made of the more corrosion-resistant Alloy 690. The new nozzles were secured by welding them to thick, nickel-chromium pads on the outside of the vessel. This "half-nozzle replacement" method had previously been employed on vessel heads and reactor pressurizers in the United States, and the NRC had reviewed and approved the method's use for those applications.

Before implementation, the STP repairs were practiced and refined using a full-scale mock-up of a reactor vessel bottom. New shielding methods were rehearsed, together with various ways to reduce repair time, resulting in more than a 60 percent reduction in actual radiation exposure for repairs.

Throughout the project, STP kept the NRC informed of plans and developments. These updates included daily briefings with the NRC's on-site inspector, weekly teleconferences with the NRC's regional and national headquarters, and participation in several NRC public meetings. STP also made certain that other key stakeholders—including the plant's owners and employees, the public, and the media—were regularly informed of the project's activities and status.

The reactor was back on line within four months of the residue's discovery. STP's management of the project has provided lessons and experience for the industry. STP did the groundwork and piloted a proven process that other plants with Alloy 600 components can follow to safely and effectively repair reactors and return them to service.

Safety

Reducing radiation exposure to its lowest possible amount was a goal of the BMI project from the start. A number of innovative as well as traditional techniques were used to minimize exposure. One innovation was STP's use of a full-scale mock-up of a reactor vessel bottom, complete with instrument tubes, fabricated in pie-shaped sections that were assembled on site. Workers were able to practice repairs in a dose-free area, and during training they found ways to perform tasks more safely and quickly.

The practice sessions led to a plant design change that significantly reduced exposure rates for removing and replacing reactor vessel insulation. The insulation originally had been secured with screws, placed 2.5 inches apart, that could be quickly removed. Reinstalling the insulation, however, went slowly because each of the hundreds of screws had to be realigned and reinserted. To speed that process, the screws were replaced with snap-clips that could be easily opened and closed. This change dropped the exposure for insulation work from an initially estimated 19.95 rem to an actual total of 4.59 rem, a 76.9 percent reduction.

In other training exercises, scaffolding requirements were matched to those for the actual repairs. Carpenters used the vessel mock-up to practice installing and removing scaffolding and to make modifications so the work could be done faster under the reactor. In addition, scaffolding components were cut and numbered in advance in the training area, to further speed assembly under the vessel. The various measures reduced exposure for scaffolding work from a projected 5.2 rem to an actual 929 mrem.

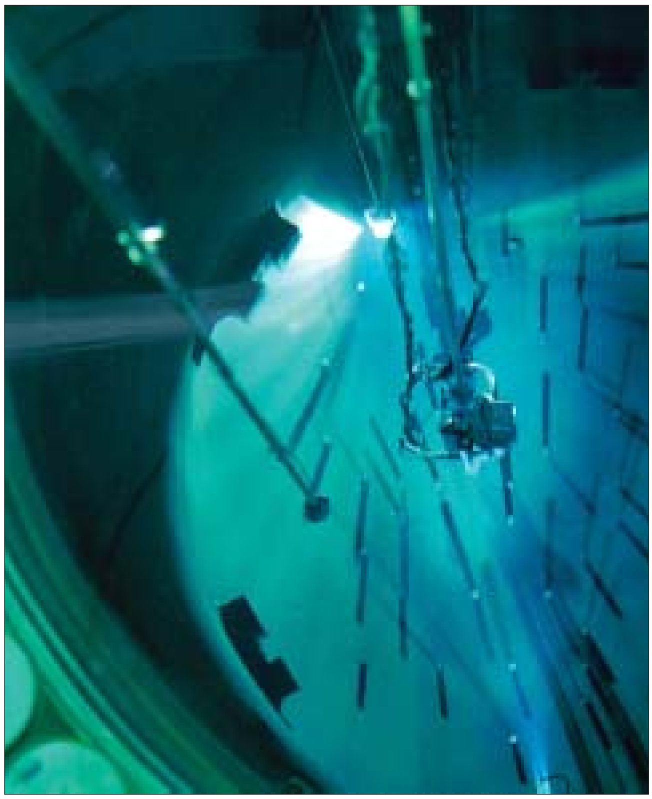
Also, a remotely operated gamma camera imaged hot areas under the reactor vessel. The hot areas varied dramatically, from 300 to 500 mrem/h. The plant's health physics staff used this information to determine the best locations for lead shielding and how to position repair workers to minimize their exposure. Because of this, when the work was actually conducted, the exposure rates for under-vessel work were halved to 150 to 250 mrem/h.

Another first for STP was the ordering and use of special lead blankets from England. The blankets are made from lead-impregnated polyurethane and are about 40 percent lighter and more flexible than standard ones. These blankets, in what turned out to be another innovation, were attached to the vessel using magnets that were quickly placed and removed.

Together, the various work practices reduced exposure for the repairs from an initially estimated 44.52 rem to an actual total of 17.16 rem, a 61.4 percent savings. Exposure for the entire BMI project was lowered 44.3 percent, from a projected 107 rem to the final total of 59.67 rem.

Productivity, efficiency

A decision was made at the start of the project to take as much time as was needed to make sure everything was done safely, correctly, and thoroughly. This was frequently communicated site-wide



Various tests and devices had to be developed or adapted for the BMI repair project, including underwater testing probes attached to a remotely operated, 65-foot-long pole, such as the one shown in photo. (Source: Framatome) through the message, "Think 40 years, not 40 days."

Several weeks were allocated to obtaining the mock-up and conducting extensive training with it. That, in turn, led to substantial exposure reductions and further refinements of the repair technology.

The BMI project schedule also allowed for extensive testing of the cracked nozzles, the other instrument tubes, and the vessel itself. This meant that the industry could learn as much as possible about the cracking, and that STP could make sure no other damage existed.

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Time was also allocated to solving other maintenance issues and to permanently lowering exposure levels near the reactor. For example, a section of a guide tube with a thimble stuck inside was cut out, and a new guide tube section was attached. This single, stuck thimble highlighted a larger issue: a chronic and general thimble-sticking problem. Thimbles by and large were found to be difficult to remove and reinstall during outages at STP, and the problem was traced to the existence of fine metallic shavings in the tubes. The solution was found by simply cleaning the tubes, after which the thimbles moved easily. Related exposure rates dropped to one-tenth of their previous levels.

Innovations

The BMI project posed unique engineering challenges. Although technology existed to inspect and repair penetrations in reactor heads, it had to be substantially modified for use on a vessel bottom. The presence of thimble tubes and the difficulty of working remotely in 65 feet of water presented major obstacles.

The project repeatedly required new tools, techniques, and work practices, most of which had to be developed and implemented within short time frames. Highly specialized devices were designed by STP engineers and fabricated on site by plant mechanics, machinists, and welders, built by vendors using STP specifications, or developed by Framatome.

The inventions included a stainless steel rack to hold thimbles firmly in place inside the reactor vessel without fuel assemblies for support. The rack kept the long, thin rods from bowing and becoming deformed. (Thimbles normally are retracted below a reactor when assemblies are removed for refueling. For the BMI project, the thimbles were reinserted into the empty vessel to reduce dose rates beneath it.) The rack was built in one piece, for quick insertion and removal.

Some tests were conducted for the first time, including phased array ultrasonic examination to check for wastage in the vessel areas around the nozzles. These inspections were done manually in a high dose area under the vessel. However, using the phased array device and refining the tests in the mock-up increased their reliability and substantially cut the time needed to perform them, which reduced worker exposure.

Eddy current inspections of the J-groove welds were done with a specially designed array probe attached to a remotely-operated, 65-ft-long pole. This was the first time this test was done underwater. The probe was a modified version of a prototype being developed for use in a dry vessel, which was adapted and field-tested for underwater application. Also, a delivery system was fabricated that enabled the probe to scan the sharply sloping surfaces around the various BMI locations.

In addition, several other probes were developed and used with the pole to conduct different tests. Underwater nozzle plugs to facilitate the tests were designed and built on site and at a Framatome facility.

STP also designed and developed an essential part for the project. In a previous outage, a specimen plug had been inserted into one of three rotolocks used to lift the core barrel, puncturing a crucial plate on the bottom of the rotolock. The specimen plug had to be removed and the hole had to be blocked before the core barrel could be lifted and project work could proceed. STP engineers designed a rotolock plug that solved the problem. Machinists on site fabricated a mock-up, the actual part, and special tools needed to insert it and lock it in place. The entire process, from initial design to final application, took just three weeks.

In fact, STP Nuclear Operating Company President and Chief Executive Officer Joe Sheppard had noted, "We deployed technology in May that didn't exist in April."

Transferability

The testing and repair techniques, tools, and management methods used in the BMI project can be applied by any plant that encounters Alloy 600 issues. STP is ready to share its relevant experience, knowledge, information, and inventions with the industry. NN