Two of the new steam generators arriving by barge at Diablo Canyon's intake cove (Photos: PG&E)

A four-steam-generator outage at Diablo Canyon-2

BY RICK MICHAL

A special delivery system had to be designed and implemented to move steam generators in and out of Diablo Canyon-2's containment building.

THE 14TH REFUELING outage at Diablo Canyon's Unit 2 proved to be the plant site's largest and most challenging undertaking. The outage, referred to as 2R14, encompassed the task of replacing all four steam generators, along with thousands of other jobs and the refueling itself. The other jobs included the replacement of the containment recirculation sump screens, a volumetric inspection of the reactor head, pressurizer weld overlays, and a containment integrated leak rate test.

The outage, which ran from February 4, 2008, to April 12, 2008, brought more than 3000 workers to the site at peak work time. The outage was so successful that it received an honorable mention for "Project of the Year" by *Power Engineering* magazine in its January 2009 issue.

The two-unit Diablo Canyon nuclear power plant, located in Avila Beach, Calif., is operated by Pacific Gas & Electric Company (PG&E). Diablo Canyon-1 was in the midst of its own steam generator replacement and refueling outage—its 15th outage, referred to as 1R15—in March, when this article was written.

The two Diablo Canyon units are Westinghouse pressurized water reactors. Unit 1, rated at 1138 MWe, started commercial operation in May 1985, and Unit 2, rated at 1151 MWe, went commercial in March 1986. The steam generators replaced at both units were original plant components.

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New steam generators in on-site temporary storage

A failure-proof, seismically qualified single-point lift system (left photo) was used to pick up each steam generator and place it on a heavy transporter (right photo).

Preliminary work

The process for obtaining regulatory approvals for the Unit 2 outage at the local and state levels and from the Nuclear Regulatory Commission began in 2004, but significant planning started earlier, according to Bob Exner, project manager for the steam generator replacement. It also took a number of years to secure other necessary permits and contracts for plant components and personnel to work the outage.

The contract for the fabrication of the steam generators was signed in August 2004. The four large components arrived together in the United States from the Equipos Nucleares S.A. factory located in Santander, Spain, and were then delivered, two per barge, at the plant's intake cove in November 2007. The components were then stored in temporary buildings for about three months before being installed during 2R14.

Travel path

Although Diablo Canyon has containment equipment hatches big enough to accommodate a 350-ton, 16-ft by 70-ft steam generator, there were several unique challenges with the travel path for the large components. A hatch transfer system with a turntable had to be designed to allow a steam generator to clear a cubicle wall while going through the hatch, which opens onto the roof of the auxiliary building that houses safety-related operating equipment.

A hatch transfer design utilizing a failure-proof, seismically qualified single-point lift system was used outside the hatch to pick up each old steam generator. The lift system placed the steam generator on a heavy transporter for the short trip through the fuel-handling building to a temporary outside lift system, where it was lowered to another transporter for the trip to an on-site facility for long-term storage.

"This was a very challenging travel path," Exner said. "It was much more complicated than an average steam generator replacement project. Our contractors designed a unique and innovative system to accommodate the path. The entire team rose to the challenge and moved the steam generators safely and efficiently to storage."

At its peak, the steam generator project employed about 1600 people, including PG&E project management and staff, subcontracted craft workers, radiation protection technicians, and additional security forces. Other outage activities employed about 1500 additional staff.

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"The temporary workers are critical to the outage work we do at the plant," said Jim Becker, Diablo Canyon site vice president. "They are also important to our local economy. About half of the outage workers

Each old steam generator was delivered by a truck transporter to a railcar, then carted by rail line uphill to the on-site storage building.

are from out of the area—that means over 1000 individuals are living, eating, and shopping along the central coast of California during what is normally a relatively quiet tourism period."

Outage goals

Goals established for outage duration, project cost, and total personnel radiation dose were bettered or within target. Financial goals included a duration of 66 days or less, at a cost of $52.3 million or less, not including the cost of the steam generator replacement project. The actual outage duration was 68 days, 22 hours, and the cost was $50 million. (Costs for Unit 2's steam generator project, including installation, totaled $157 million.)

"Although the business goal for outage duration was not met, Diablo Canyon was only the fourth plant in the U.S. industry to perform a first-unit steam generator outage in fewer than 70 days," said Jeff Knisley, Diablo Canyon outage manager. "All in all, 2R14 was a very successful steam generator replacement outage, and we expect even greater success for 1R15."

The overall exposure for 2R14 was 226 person-rem, which was considerably lower than the original goal of less than 257 person-rem. The personal contamination event (PCE) rate for 2R14 was 0.20 PCE per 1000 person-hours, the lowest on record for a steam generator replacement outage in the U.S. industry, according to Knisley.

In addition, there were no nuclear safety challenges, significant human performance events (site-level clock reset), or disabling injuries.

Preparation work

Long before the outage started, an optimization plan identified five major cross-cutting issues deemed to have a significant impact on the outage's success. Teams were assigned to each of the five issue areas: craft and labor resources, in-processing and training, radiation protection and decontamination planning, security, and work management.

The steam generator replacement project team worked with the contractor and the plant staff to develop working agreements and to schedule development and integration reviews and task reviews. A year prior to the start of the outage, integration meetings and "vertical slice" schedule reviews closely examined the many activities that would occur simultaneously. The purpose of vertical slice meetings was to integrate the steam generator work and outage activities that could affect both work teams. Outage schedulers, site managers, task managers, lead field engineers, health physics technicians, and other key organizations were asked to participate. The idea behind these meetings was for both job teams to go through a structured schedule review to identify conflicts and resolve all issues prior to the start of the outage.

Diablo Canyon also implemented safety and human performance training for all personnel on-site who would be working the outage, including contractors and temporary additional hires. This "breakthrough training," according to Exner, included hands-on practice and engaging workers in activities designed to lock in human performance tools such as three-way communication, the "two-minute rule" (for identifying unanticipated job-site conditions

before work begins), and place-keeping (a technique used to mark the steps in a procedure, which aids in the prevention of skipping or repeating steps), among others. The training had "a very positive impact on personnel and industrial safety" during 2R14, Exner said.

In other pre-outage work, representatives from the radiation protection team visited vendors and inspected their component mockups in order to gain a better understanding of how work would be done and how radiation dose could be reduced. The RP team also installed additional portal monitors that had faster, more accurate counts for more efficient worker processing through containment. A temporary containment access facility was established on the turbine deck for personnel to prepare for entering containment.

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Critical path

The basic critical path started with the reactor's shutdown in February 2008 and its subsequent defueling and continued through the removal of the four original steam generators, the installation of the four replacement steam generators, and the welding of the primary and secondary piping. The critical path also included the completion of instrumentation and other systems that had been removed and modified, refueling and plant testing, an integrated containment leak rate test, and plant startup.

Challenges

As with any outage, there were challenges, some of which were technical. The mechanical systems that support the steam generators had to be reworked to accommodate the new steam generators. That, in turn, created challenges for the installation of the replacement steam generators. In addition, when the foot bolts on the steam generators were stuck during the removal phase, management realized that a contingency plan was needed that was more efficient than the one that had been developed for the outage. Instrumentation restoration issues also ended up being more complex than anticipated.

Other issues—such as a transportation program that brought workers on site from off-site parking lots (more on this later) and a flu outbreak that affected many people in the area—put unexpected demands on labor resources.

Site security

Art Wells, security supervisor for the steam generator replacement project, said that early expectations about site security were ratcheted up following discussions with personnel from other nuclear plants that had been involved in large outages. "While we initially expected 200 truckloads of deliveries, real-world experience from other plants reported up to 500," he said. "As a result, additional security personnel were added at the plant's main gate and at the plant's vehicle inspection station, where vehicles enter a more secure perimeter around the plant."

A dispatch office was established to coordinate all on-site deliveries. For daily in-processing of materials and personnel, the security instrumentation and control staff provided around-the-clock technical coverage to address any issues with security computers or other security equipment. In addition, more security search trains were monitored during peak personnel traffic times to ease the congestion that resulted from more workers being on site.

Inside the plant, additional temporary card readers were installed to expedite traffic flow and eliminate hand-logged entries, and additional security personnel and protective measures were installed at key locations.

Because of limited on-site parking, the steam generator project team established a busing program to transport about 1000 craft workers per day from off-site temporary PG&E parking lots to the plant, as well as a shuttle service to and from on-site parking lots.

"Planning well in advance and performing readiness reviews, along with lots of teamwork, made this one of Diablo Canyon's best outages in the history of the plant," Wells said. By the end of the outage, loggable security events amounted to only half the established goal, making it the lowest on record for a Diablo Canyon outage.

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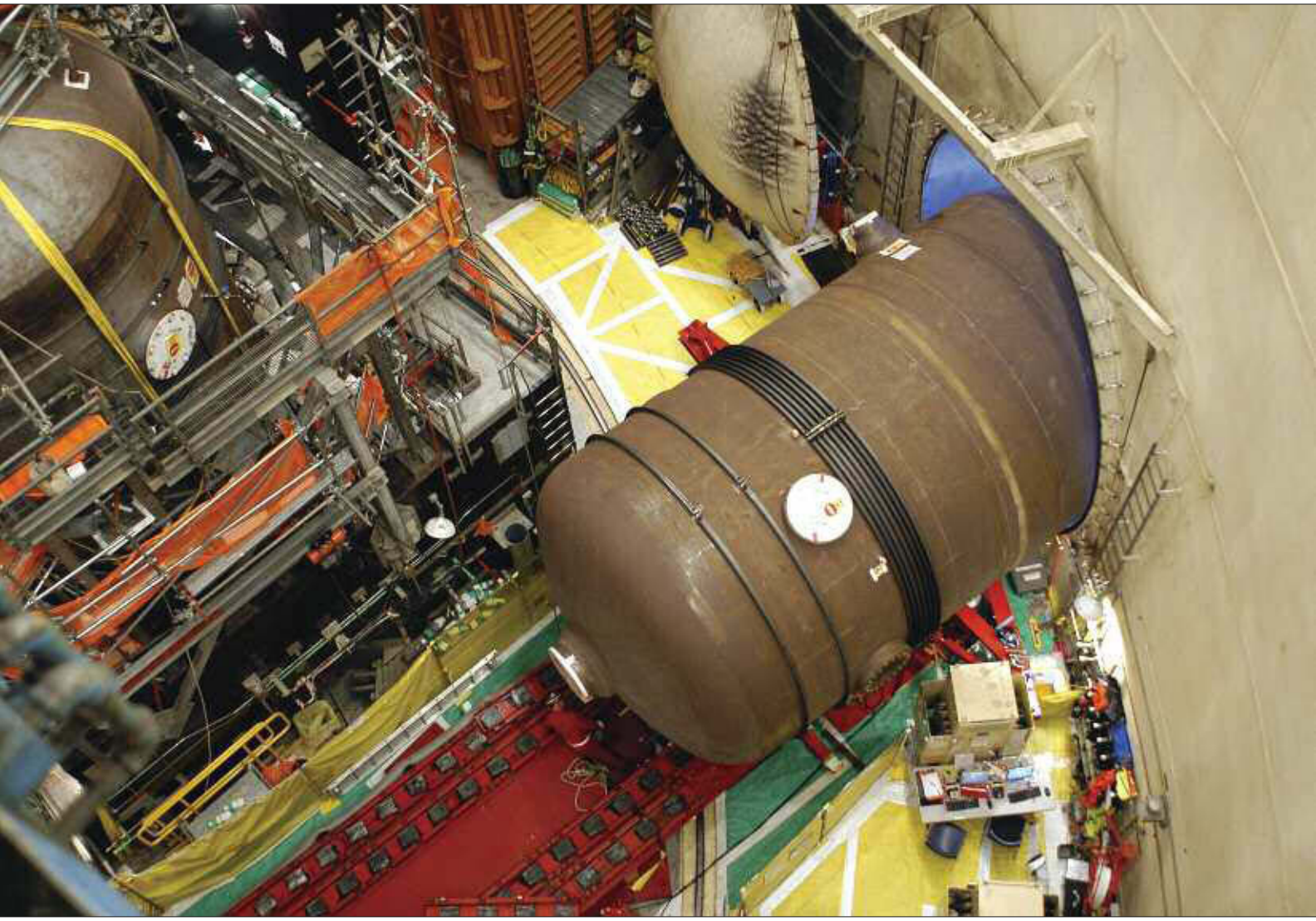

A steam generator passes through the Diablo Canyon-2 containment equipment hatch.

Lessons learned

"Diablo Canyon is a learning organization," Exner said. "We are always looking for ways to improve processes, gain efficiencies, and better allocate resources. Part of that process is to capture lessons learned."

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Some of the more notable lessons learned—implemented even as Unit 1's outage was in progress—are the following:

- Because tasks such as instrumentation, steam generator supports, structural modification, and restoration were more complicated than anticipated, focus teams made up of PG&E and contract construction management, engineering, planning, and project management personnel were implemented to perform detailed task planning and integration with other work.
- Construction management teams were brought on site earlier to begin work on the project.
- Additional cutting and welding equipment and craft resources were provided to allow for parallel work on the steam generators.
- Specialized tooling was developed for rethreading and reusing stuck foot bolts during the removal of the old steam generators, along with special tooling for resurfacing lateral support bumpers in place to save time and radiation dose.
- Effective management systems were developed for work package closure.

Closing comments

Becker, who was also the station director at the time of 2R14, said, "Our Unit 2 steam generator replacement outage was our biggest refueling outage to date. The organization's success with this project was directly attributed to the team's dedication and commitment."

Outage director Tim King added, "2R14 was a pivotal event in Diablo Canyon history. Replacing the steam generators will help ensure that Unit 2 is able to safely and reliably generate low-cost electricity for the duration of its license." King concluded by saying that with the knowledge and experience gained in 2R14, "we are looking forward to improved personnel safety and outage duration during the steam generator replacement in Unit 1." NN