A unique approach to long-term reactor internals management

PSEG Nuclear’s outage and contingency planning campaign for baffle-former bolt inspections and replacements saved time, reduced worker dose, and will benefit future outage planning.

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During the spring 2017 outage for Unit 2 at the Salem nuclear power plant, PSEG Nuclear instituted a robust outage and contingency planning campaign for baffle-former bolt inspections and replacements. The unique approach saved time in the outage schedule, reduced dose exposure for personnel, and set the stage for the long-term health of the unit’s reactor internals.

Since the mid-1990s, baffle-former bolt cracking has been a known degradation mechanism in the reactor internals of pressurized water reactors. U.S. operating experience in 2016 demonstrated that some of the bolts may be subject to extensive degradation as those plants age. This was the case for Salem-1, where during the spring 2016 outage, PSEG Nuclear found through visual inspection that 18 baffle-former bolts exhibited indications of cracking. Although ultrasonic testing of the baffle-former bolts at Unit 1 wasn’t required until 2019 per the unit’s licensing commitments, PSEG extended the outage to conduct the ultrasonic inspection and replace the bolts as needed. As a result, 189 bolts were replaced, requiring a significant outage extension and additional costs.

Baffle-former bolts are made from stainless steel and are used to attach vertically oriented flat metal panels called baffle plates to horizontally oriented metal panels called former plates. The baffle-former plate assembly serves as a precisely configured support structure for the fuel assemblies, holding them securely inside the round core barrel. The baffle-former plates also direct the flow of coolant water through the reactor.

Baffle-former bolts are located around the core and become highly irradiated due to neutron flux during plant operation. In 1997, the Westinghouse Owners Group (now part of the Pressurized Water Reactor Owners Group) created a task force to evaluate the integrity of baffle-former bolts in PWRs and determined that they are at risk for irradiation-assisted stress corrosion cracking. This and other such plant aging-related concerns are closely monitored by the nuclear energy industry, which has established guidelines through the Electric Power Research Institute’s Materials Reliability Program (MRP), specifically for inspecting and evaluating long-term aging effects on reactor internals. The guidelines are documented in MRP-227, Materials Reliability Program: Pressurized Water Reactor Internals Inspection and Evaluation Guidelines, and MRP-228, Materials Reliability Program: Inspection Standard for PWR Internals.

One possible solution for addressing baffle-former bolt degradation includes modifying the core design from a traditional downward flow—or down-flow—where cooling water is directed between the core barrel and the baffle-former plates in a downward direction, to an up-flow configuration to reduce stresses on the baffle plate and baffle-former bolts. Another mitigation option is replacing original baffle-former bolts with improved design bolts that minimize the concentration of stress between the bolt head and shank. PSEG chose the latter option and applied knowledge acquired through Westinghouse’s predictive analysis model to replace more bolts than had indications.

This was done both to meet PSEG’s future inspection plans and to allow for conversion to an up-flow configuration in the future, if desired.

Outage planning

Anticipating similar baffle-former bolt findings as experienced with Unit 1, PSEG wanted to get ahead of the issue during the spring 2017 outage for Salem-2 and ensure the long-term viability of the unit’s reactor internals. In addition, PSEG wanted to establish an approach that would minimize the variability of baffle-former bolt inspection results and repairs in future outages.

PSEG contracted with Westinghouse, and the two organizations worked together to prepare for the baffle-former bolt ultrasonic inspection and bolt replacements during the outage. With the expectation of having to replace many of the bolts, PSEG created an innovative approach to completing that work while also achieving other outage goals. PSEG’s plan was to pull the core barrel out of the reactor and perform the bolt replacement work with the core barrel in the lower internals stand. This would allow personnel access to the reactor internals to complete other work in parallel with the bolt replacement. Outage planners from the site and Westinghouse engineers also developed a unique approach to long-term reactor internals management.
Westinghouse crafted an innovative plan to achieve PSEG’s goals for the Unit 2 outage.

The planning process included consideration of how to minimize personnel dose exposure with the core barrel removed from the reactor, which elevates radiation levels over the refueling cavity; how to keep personnel dose low when performing the bolt replacements with the core barrel in the lower internals stand; and how to perform maintenance on the polar crane and allow it to be used for other outage tasks while still supporting the bolt replacements. The Westinghouse bafflemformer bolt replacement system typically requires the crane to hold its large tooling.

PSEG’s preparation also included the use of Westinghouse’s predictive analysis model for baffle-former bolts to assist with the utility’s decision-making during the outage. PSEG wanted to pursue this path because the model provides the ability to predict the timing of baffle-former bolt wear, thereby facilitating decision-making regarding the timing of necessary bolt replacements and ultimately allowing the station to establish a long-term multi-outage plan.

Preparation of the model began several months in advance of the outage. Westinghouse, as the original equipment manufacturer, was able to use its knowledge of the detailed inputs and design model for the Westinghouse-design four-loop plant reactor internals in operation at Salem-2. The company developed a finite element analysis model of the unit’s reactor internals, along with a neutron fluence projection, to create the Unit 2-specific predictive analysis model. The model was then ready to receive inspection results as inputs during the outage, allowing PSEG to make informed, timely, and strategic decisions on baffle-former bolt replacements while the outage was under way.

**Inspection**

The baffle-former plate assembly is affixed within the Salem-2 reactor core with 832 bolts. Inspecting these bolts presents a challenge, as their hexagon-shaped socket heads have a locking bar that is inserted into a groove in the head of each bolt to prevent it from loosening and backing out during operation. Working with WestDyne—the wholly owned nondestructive examination subsidiary of Westinghouse and developer of a technique to inspect this style of bolt—Salem planned 3.5 days for the inspection to be completed.

Salem and WestDyne personnel teamed to coordinate the equipment laydown and setup requirements and activities to complete the ultrasonic inspection, which is performed inside the core barrel under water. To reduce the overall inspection time, the outage team implemented a newer approach, deploying two remotely operated mini-submarines, called MIDAS-VI, in parallel to deliver the inspection probes. Each MIDAS-VI engages the bolt head and locking bar so that ultrasonic signals can be projected through the bolts. Each is also equipped with cameras and lights, as well as suction cups for temporary attachment to the core barrel’s walls for stabilization.

The data files resulting from the inspection were reviewed by a minimum of two analysts before each bolt was designated as nondegraded or as having an indication. The team inspected and analyzed each of the 832 bolts, determining that nine had indications. They completed the ultrasonic examinations and evaluations in 2.2 days, which was 1.3 days, or 31.2 hours, ahead of schedule.

**Deciding on the approach**

Following the inspection, the predictive analysis model was employed to assess the results and provide projections of baffle-former bolt degradation for various possible replacement strategies over subsequent operating years.

PSEG made use of the predictive analysis modeling tool to determine a long-term aging management plan based on a realistic prediction of the baffle-former bolts’ integrity based on plant-specific design, up-to-date operating history, and inspection result details. This approach not only lowered the risk of finding future indications unexpectedly, it facilitated proactive decision-making and planning concerning replacement and future inspections.

From the time of inspection to the first bolt installation, Westinghouse was able to evaluate four potential bolt replacement patterns for PSEG’s consideration. PSEG’s first strategic objective for the replacement pattern was that it should provide a reasonable assurance of supporting Unit 2’s operation through four additional cycles without having to perform additional ultrasonic inspections, maximizing the time allowed in the Materials Reliability Program.

With confirmation via the predictive analysis model to support this objective, PSEG decided on an 89-bolt replacement pattern developed for installation by the replacement field teams. Reaching this decision required strong coordination by the PSEG and Westinghouse engineering teams. The decision included the consideration of inputs from the predictive analysis model concerning when additional replacements would provide only diminishing returns, and was made within 72 hours of the completion of the inspection. This prevented the station from unnecessarily spending critical path time replacing bolts that did not appreciably affect aging projections, saving outage time and replacement costs.

A second objective for the replacement bolt pattern was to preemptively replace bolts that would support a cooling water up-flow pattern, should PSEG decide to make up-flow modifications in the future. To take advantage of remaining outage time available following the efficient replacement process of the selected...
89 baffle-former bolts, PSEG requested that the predictive analysis model again be employed. This time, the model was applied to aid in determining which, if any, additional bolts should be replaced to dovetail with a future up-flow pattern. An additional 40 replacement bolts were identified to support this goal, resulting in the installation of a total of 129 replacement bolts during the outage.

**Outage achievements**

PSEG originally had planned a 20-day outage window for the bolt replacement work. This was reduced to 13 days after the inspection results indicated that fewer bolts needed to be replaced than anticipated.

The outage teams pulled the core barrel as planned, and several new techniques were implemented by both teams to shield outage workers from the increased radiation. PSEG super-flooded the reactor cavity and placed a temporary head on the vessel in order to complete work on the steam generator, guide card wear measurement, and the reactor coolant pump and motor in parallel with the baffle-former bolt replacement work—and off the critical path schedule.

Knowing early in the outage planning that PSEG wanted to perform these other outage tasks in parallel with the baffle-former bolt replacement activities, Westinghouse retrofitted and transported to the site a motorized work bridge to hold the 50-foot-long baffle-former bolt replacement system. This freed the polar crane for preventive maintenance and also made it available for the performance of other duties in support of the outage. The teams also installed a shield ring manufactured specifically to shield workers replacing the baffle-former bolts with the core barrel in the lower internals stand, something Westinghouse had not done before. The Salem-2 health physics team also shielded the Westinghouse motorized work bridge, which reduced dose exposure rates even more.

Completing the baffle-former bolt replacements in the lower internals stand proved to be more efficient: The replacement team averaged 10 bolts per day using only one replacement tool.

PSEG’s proactive ideas for completing more work in the outage window resulted in a very efficient outage, as well as reduced dose. The super-flooded reactor cavity condition allowed more water in the cavity to reduce dose in the general area. The installation of the shield ring for completing the baffle-former bolt replacement work in the lower internals stand reduced dose exposure rates from 5 milli-roentgens per hour to 1–2 mR per hour; the shield ring will be a permanent fixture in the plant for future work. Shielding the motorized work bridge reduced dose exposure rates even more.

The team’s approach to the integrated outage planning supported PSEG’s outage maintenance goals as well as its long-term goals for Salem-2’s reactor internals. This has enabled PSEG to establish more predictable outage durations, minimize the cost impact of baffle-former bolt replacements, and consider options for up-flow modifications. PSEG is continuing this approach at Salem-1, which will undergo its first post-baffle-former bolt inspection/replacement outage this fall. The highly successful innovative planning and approach implemented during Salem-2’s spring 2017 outage could serve as a model for other plants as they consider strategic tactics for reactor internals aging management.

Baffle-former bolt replacement at Salem-2, with the core barrel in the lower internals stand and shielding in place, both within the stand and on the motorized work bridge.
With more than 30 years of successfully performing baffle-former bolt services, Westinghouse offers experience and capabilities unmatched in the industry.

Our technical experts meet the challenges of replacing degraded, shifted or galled bolts using fifth-generation tooling with proven field production rates of more than 12 bolts per day. We also offer predictive bolt behavior modeling capabilities, a full range of tailored inspection services and our plant-specific Acceptable Bolting Pattern Analysis – the only such method approved by the U.S. Nuclear Regulatory Commission. Our services are designed to keep your outage on schedule and your plant online.

Discover why Westinghouse is the industry’s most trusted partner for baffle-former bolt solutions. Learn more by visiting us at http://bit.ly/WestinghouseBfB