

Korea Hydro & Nuclear Power Company Implements Stress Corrosion Cracking Assessment Program

Assessment strategies developed from EPRI guidelines and a KHNP-developed software program are expected to avoid leak-related costs of up to \$140 million across the Korean nuclear fleet.

Building on industry experience and EPRI guidance, Korea Hydro & Nuclear Power Company (KHNP) has successfully implemented several strategies to evaluate and mitigate primary water stress corrosion cracking (PWSCC) in components using Alloy 600/82/182 weld metals. With support from EPRI research, KHNP has been able to:

- Develop its own finite element analysis guidelines to assess weld residual stress
- Design the Nickel Alloy Crack Integrity Assessment (NACIA) software program for computerized assessment of PWSCC, which can characterize stress distribution, stress intensity factor, and residual life for any crack location
- Successfully design and execute a PWSCC repair in the reactor vessel head penetration nozzles at the Hanbit Unit 3 nuclear plant using the NACIA system
- Apply the assessment strategies developed with NACIA to prevent PWSCC-related leaks at 14 KHNP units
- Avoid unexpected plant shutdowns and reduce maintenance costs, with an expected benefit of approximately \$140 million

Next-Level Solution to PWSCC

Primary water stress corrosion cracks are a significant, long-term material degradation challenge for pressurized water reactors (PWRs), and PWRs using Alloy 600/82/182 weld metals within the reactor coolant system are particularly susceptible to cracking. Numerous measures have been taken to manage these materials to ensure reliable, economical, and safe operation. Through its Materials Reliability Program (MRP), EPRI is leading efforts to develop analytical methods, inspection techniques and equipment, and mitigation and repair strategies.

KHNP has collaborated with EPRI in the development and deployment of PWSCC management strategies. "The NACIA program is an internal effort by KHNP to apply many generic industry analytical tools in a coordinated manner within a single computational framework to predict crack growth and remaining useful life of degrading components," said Craig Harrington, principal technical leader at EPRI. "Such information can then be used to inform operational decision-making and repair/mitigation planning."

The NACIA program includes information that KHNP staff obtained from nearly a dozen MRP reports that addressed various aspects associated with analyzing remaining life of material components. The NACIA program ultimately adopted the PWSCC assessment methodologies provided in MRP safety assessment reports, workshop presentation materials, and related guidelines.

"PWSCC issues experienced at several U.S. reactors focused KHNP attention on the need for a comprehensive assessment strategy," said Kyoungsoo Lee, chief researcher in the material and component group at KHNP. "EPRI's reports helped prepare countermeasures for PWSCC and provided useful evaluation practices that we have incorporated into the NACIA program."



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KHNP also used EPRI's methodologies and guidance to explain the technical basis for safety assessments and maintenance to the public and to Korea's nuclear regulatory body. KHNP submitted a technical evaluation report for the cracks in head penetration nozzles at Hanbit Unit 3 and Unit 4 using the NACIA program, and the regulatory body accepted this report. EPRI's methodologies also contributed to reducing the outage period at KHNP's plants. "KHNP had established the NACIA program for all the dissimilar metal weld locations before cracks were observed," Lee explained. "Because we were prepared and knew how to evaluate and manage the PWSCC in the head penetration nozzles, we were able to save time for stress analysis, including weld residual stress and structural integrity, and remaining service life. KHNP is also able to make a rapid decision about how to repair the PWSCC."

Current NACIA Applications

According to Lee, KHNP experienced several PWSCC cases in recent years, and each time the utility assessed these cracks with the NACIA system using EPRI's assessment methodology. In fall 2012, KHNP successfully applied the NACIA system, along with technical support from EPRI, to repair a crack in the reactor vessel head penetration nozzles at Hanbit Unit 3. By using NACIA at 14 more units, KHNP believes that these strategies will successfully prevent additional leaks caused by PWSCC and reduce plant downtime, which could ultimately result in \$140 million in savings.

"Remaining service life at Hanbit Unit 3 was calculated through the NACIA program," Lee said. "NACIA includes an algorithm to calculate the stress intensity factor, crack growth velocity, and critical crack size. Therefore, when we get the crack data from inspection results, remaining service life can be calculated within an hour. EPRI provided guidance based on PWSCC repair experience for head penetration nozzles in the United States."

How the NACIA System Works

When PWSCC is detected during in-service plant inspections, flaw data such as depth, length, and location are transferred to the NACIA evaluator. NACIA uses this data to evaluate the remaining service life of the components. This is possible because all the necessary information and processes required to evaluate PWSCC are programmed into the NACIA system, including stress profile data for Alloy 600/82/182.

Finite element stress analyses had been conducted for several years to obtain stress profiles for all the Alloy 600/82/182 locations in KHNP plants. The overall evaluation processes are programmed in accordance with the ASME section XI flaw evaluation procedure. NACIA can generate a stress distribution profile in the cracked location, including stress intensity factor, crack growth velocity, critical crack size and remaining service hours. Each of the calculation procedures complies with ASME guidelines.

A Win-Win Outcome

KHNP used many EPRI reports in performing the detailed stress analyses and developing the PWSCC evaluation algorithm. These reports provided realistic considerations for PWSCC evaluation, along with evaluation examples. The EPRI reports used to develop NACIA include

- MRP-33, Elastic-Plastic Finite Analysis: Single- and Double-J Hot Leg Nozzle-to-Pipe Welds: Welding Residual and Operating Stresses
- MRP-104, Reactor Vessel Head Nozzle and Weld Safety Assessment for Westinghouse and Combustion Engineering Plants
- MRP-106, Welding Residual and Operating Stresses in PWR Alloy 182 Butt Welds
- MRP-107, Analysis of Stress Corrosion Cracks in Alloy 182 Weld Metal after Exposure to PWR Primary Water
- MRP-109, Alloy 82/182 Pipe Butt Weld Safety Assessment for U.S. PWR Plant Designs: Westinghouse and CE Design Plants
- MRP-110, Reactor Vessel Closure Head Penetration Safety Assessment for U.S. Pressurized Water Reactor (PWR) Plants: Evaluations Supporting the MRP Inspection Plan
- MRP-216, Advanced FEA Evaluation of Growth of Postulated Circumferential PWSCC Flaws in Pressurizer Nozzle Dissimilar Metal Welds
- MRP-220, Review of Stress Corrosion Cracking of Alloys 182 and 82 in PWR Primary Water Service
- MRP-271, Validation of Welding Residual Stress Models for PWR Piping Dissimilar Metal Welds
- MRP-282, Weld Residual Stress Measurement and Implications for Stress Corrosion Testing
- MRP-317, Welding Residual Stress Dissimilar Metal Butt-Weld Finite Element Modeling Handbook

"Adapting our research results to international nuclear plants can be challenging," said Harrington. "The regulatory environment and business culture that prevails in the nuclear industry outside of the U.S. is less familiar, so it is a very positive indicator that despite these challenges, KHNP was able to incorporate our research into a successful PWSCC assessment program."

"KHNP hopes to share the NACIA program with other utilities," said Lee. "With a defined set of input data, the program can quickly estimate remaining service life for components, enabling users to make informed decisions regarding mitigation and repair."

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com)

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