UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

ACRSR-2272

October 19, 2007

Mr. Luis A. Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: NRC STAFF'S SAFETY ASSESSMENT OF THE INDUSTRY STUDY RELATED TO DISSIMILAR METAL WELD ISSUES IN PRESSURIZER NOZZLES

Dear Mr. Reyes:

During the 546th meeting of the Advisory Committee on Reactor Safeguards, October 4-5, 2007, we discussed the NRC staff's safety assessment of the industry's advanced finite element analysis of primary water stress corrosion cracking (PWSCC) in pressurizer nozzle dissimilar metal butt welds, and other related activities. Preliminary results of this analysis were presented to us at our meeting on July 11-13, 2007. During these meetings, we had the benefit of discussions with representatives of the NRC staff and the industry, and of the documents referenced. We previously provided a report on the dissimilar metal weld issues on March 22, 2007.

CONCLUSION AND RECOMMENDATION

1. The studies undertaken by the industry and the staff have been timely and improved significantly the technical basis for the assessment of circumferential flaws in dissimilar metal welds in pressurizer nozzles.

2. We support the efforts of the staff to pursue further work on residual stresses including additional efforts to obtain more experimental confirmation of the welding residual stresses.

BACKGROUND AND DISCUSSION

In October 2006, ultrasonic examination revealed five indications in three nickel-based dissimilar metal welds joining the ferritic steel nozzles to the austenitic stainless steel coolant piping at the Wolf Creek Generating Plant. These indications were interpreted as large circumferential cracks.

The nickel-based alloys (Alloy 82 and 182) used for these welds are known to be susceptible to PWSCC in the primary coolant environment of pressurized water reactors (PWRs). Only about 15 percent of the dissimilar metal pressurizer nozzle welds in PWRs have been inspected. Since the adjoining base metals are resistant to PWSCC, axial cracks will be limited to a length no greater than the width of the weld. Such cracks may lead to leakage, but are unlikely to lead to rupture or significant loss of coolant. However, circumferential cracks can potentially grow to sizes that could lead to rupture.

Prior to the Wolf Creek findings, the staff and industry had recognized the potential for cracking in such dissimilar metal welds, and the industry had instituted a program to inspect these welds or apply weld overlays similar to those used at Wolf Creek. Most licensees of PWRs with susceptible nozzle welds will complete inspections or apply weld overlays during 2007. However, nine plants plan to perform these activities during outages in the spring of 2008. The plants that have not yet completed inspections or mitigation activities have committed to enhanced leakage detection as a compensatory action until these activities are completed.

After the Wolf Creek findings, the staff took the position that mitigation activities should be completed by the end of 2007 rather than the spring of 2008. The industry presented analyses that suggested the likelihood that nozzles can rupture without prior warning is low, and that the increased risk associated with a schedule for completing inspection and mitigation activities in the spring of 2008 is acceptably small. The industry undertook a program to develop more rigorous analyses. The affected licensees also committed to accelerate the schedule for inspection and mitigation and complete the work by the end of 2007, if the results of the analysis did not demonstrate adequate margin for leak-before-break.

Prior to the initiation of this effort, most fracture mechanics analyses have assumed that the crack shape is either elliptical or constant depth. The improved analysis developed by the industry considers crack growth at each point along the crack front and allows the crack to change shape as dictated by the stress distribution and appropriate crack growth correlations. Even with this increased capability to model the growth of cracks, there are large uncertainties in important variables, such as the welding residual stresses and the applied loads on the welds, that affect the results. In conjunction with the development of the advanced fracture mechanics analysis, the industry also undertook a large study to characterize the range of weld residual stresses and applied loads associated with dissimilar metal welds on pressurizer nozzles. Extensive sensitivity analyses were performed to assess the effects of weld residual stress profile, nozzle dimensions and geometry, initial crack shape, initial crack dimensions, multiple cracks, operational loads, PWSCC crack growth rates, and plastic redistribution of loads.

As part of its review of the industry results, the NRC staff established a substantial, essentially real time, independent confirmatory study to review, benchmark, and verify the results of the industry's advanced fracture mechanics analysis, estimates of the weld residual stresses, and choice of failure criteria. In general, there was excellent agreement between the results of the industry study and the staff's confirmatory study.

The studies performed by the staff and industry show that the assumption that the crack shape remains elliptical or constant depth is conservative compared to the more realistic analysis in which the shape of the crack is not artificially constrained. The sensitivity studies showed that the behavior of the cracks is highly dependent on the weld residual stress profiles. In particular, inner diameter weld repairs create high local tensile stresses, which would cause a postulated crack to grow faster radially than circumferentially and eventually grow throughwall at the location of the repair. As a result, leakage will occur before rupture. Welds without repairs can promote the development of cracks that can grow around a large fraction of the circumference before growing throughwall.

The work performed by the staff and industry has provided a significant increase in the capability to realistically model the growth of flaws in reactor components and will be useful in a variety of applications. Although it has been recognized for many years that the most significant stresses associated with stress corrosion cracks are welding residual stresses, the work done here is the most comprehensive study of welding residual stresses performed to date. The work has helped to characterize the effects of weld repairs and highlight the importance of correctly accounting for interactions between the weld region and the remainder of the piping system.

Despite this improved understanding, there are still significant uncertainties in the state of knowledge regarding cracks that could exist in uninspected welds. The staff and industry have addressed these uncertainties through the selection of initial crack profiles for the analyses. The staff has judged that a 360°/10% throughwall crack and a 21:1 aspect ratio/ 26% throughwall crack are conservative choices. We agree with these choices in light of experience with intergranular stress corrosion cracking, the nature of the indications at Wolf Creek, and the likelihood that, if cracking were extensive, leaks would have appeared at high-stress locations associated with weld repairs.

With these postulated flaws, the analyses show large margins against rupture prior to the occurrence of detectable leakage for the spray, safety, and relief nozzle geometries. The margins for the surge nozzles are significantly smaller, but still adequate unless additional conservatisms are added to the analyses such as an increase in the crack growth rate by a factor of 10. Therefore, the staff has concluded that the advanced finite element analysis provides reasonable assurance that the nine affected plants can operate safely until scheduled outages in spring 2008.

The staff and industry have accomplished a large amount of work under a very demanding schedule to address this problem. The work has led to important advances in fracture mechanics capability and understanding of weld residual stresses. We support the efforts of the staff to pursue further work on residual stresses including experimental confirmation.

Sincerely,

/RA/

William J. Shack
Chairman

References:

1. Memorandum from Michele G. Evans, Director, Division of Component Integrity, Office of Nuclear Reactor Regulation, to Catherine Haney, Director, Division of Operating Reactor Licensing, Office of Nuclear Reactor Regulation, “Safety Assessment on the Advanced Finite Element Analysis Related to Growth of Postulated Primary Water Stress Corrosion Cracking in Pressurizer Nozzle Dissimilar Metal Butt Welds,” dated September 7, 2007 (ML072430091 and ML072400199).
2. Engineering Mechanics Corporation of Columbus, “Final Report on Implication of Wolf Creek Indications,” August 2007 (ML072470394).

3. Electric Power Research Institute, “Materials Reliability Program: Advanced FEA Evaluation of Growth of Postulated Circumferential PWSCC Flaws in Pressurizer Nozzle Dissimilar Metal Welds (MRP-216, Revision 1): Evaluation Specific to Nine Subject Plants,” August 2007 (ML072410235).

4. Letter from William J. Shack, Chairman, Advisory Committee on Reactor Safeguards, to Luis A. Reyes, Executive Director for Operations, U.S. Nuclear Regulatory Commission, dated March 22, 2007, “Proposed NRC Staff and Industry Activities for Addressing Dissimilar Metal Weld Issues Resulting From the Wolf Creek Pressurizer Nozzle Weld Inspection Results” (ML070810710).

3. Electric Power Research Institute, "Materials Reliability Program: Advanced FEA Evaluation of Growth of Postulated Circumferential PWSCC Flaws in Pressurizer Nozzle Dissimilar Metal Welds (MRP-216, Revision 1): Evaluation Specific to Nine Subject Plants," August 2007 (ML072410235).

4. Letter from William J. Shack, Chairman, Advisory Committee on Reactor Safeguards, to Luis A. Reyes, Executive Director for Operations, U.S. Nuclear Regulatory Commission, dated March 22, 2007, "Proposed NRC Staff and Industry Activities for Addressing Dissimilar Metal Weld Issues Resulting From the Wolf Creek Pressurizer Nozzle Weld Inspection Results" (ML070810710).

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