June 14, 2001

Mr. Alex Marion, Director
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Nuclear Energy Institute
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Washington, D.C. 20006-3708

SUBJECT: STAFF FINDINGS REGARDING “PWR MATERIALS RELIABILITY PROJECT INTERIM ALLOY 600 SAFETY ASSESSMENT FOR US PWR PLANTS (MRP-44), PART 1: ALLOY 82/182 PIPE BUTT WELDS"

Dear Mr. Marion:

By letter dated April 27, 2001, the Nuclear Energy Institute (NEI), as the regulatory interface for the EPRI Materials Reliability Project (MRP), submitted the proprietary (TP-1001491, Part 1) and non-proprietary (TP-1001491-NP, Part 1) versions of the EPRI report, "PWR Materials Reliability Project Interim Alloy 600 Safety Assessment for US PWR Plants (MRP-44), Part 1: Alloy 82/182 Pipe Butt Welds," for staff information.

The NRC staff has reviewed this report to evaluate the MRP's assessment of the generic implications of cracking in Alloy 82/182 pipe butt welds. The staff has concluded, based on the information provided in the MRP-44 Part 1 report, that the results of this interim safety assessment are sufficient to justify the continued operation of pressurized water reactors (PWRs) while the industry completes the development of the final version of the MRP-44 Part 1 report. It is important to recognize that, in order to minimize the potential regulatory impact on the industry's fall 2001 outages, submission of the final MRP-44 Part 1 report should be made in sufficient time to allow staff review of the susceptibility rankings and planned inspections and subsequent feedback to industry.

The specific MRP conclusions that support the staff's conclusion are:

(1) cracking observed to date has been predominantly axial;

(2) pipe weld axial crack growth is bounded by the low-alloy steel or stainless steel materials at either end of the weld;

(3) the critical flaw size for axial rupture is several times greater than the width of the welds; and,

(4) there is expected to be no significant concern arising from boric acid corrosion as a result of the relatively low leakage rates from the high temperatures of the affected components and the cracks seen to date.

The above conclusions indicate that there is a low probability of near-term failure of these welds. Therefore, the staff agrees that PWRs may continue to operate safely while the industry performs additional analyses and inspections.

While the operating experience and evaluations performed to date indicate cracking in these welds would be predominately axial, additional work is necessary to further understand the potential for significant circumferential cracking and to define long term actions to address this issue.

It is the staff's expectation, based on the discussions during previous public meetings on this issue, that the final MRP-44 report will address:

(1) the potential of multiple initiation sites in a single weld, like that found at Summer;

(2) the need for PWR licensees to augment their visual inspection of these welds, or employ augmented leak detection capabilities that will be able to detect leakage at a level that maintains appropriate safety margins;

(3) the need to develop a licensee- or generic-susceptibility ranking for the fall 2001 refueling outages of the Alloy 82/182 pipe butt welds and a proposed inspection scope and schedule that will examine, using best available technology, a significant percentage of the most susceptible and the most risk-significant of these pipe joints; and,

(4) the other items discussed by the MRP and the NRC during the public meetings (see Meeting Summarys on the NRC's "Generic Activities on PWR Alloy-600 Weld Cracking" at http://www.nrc.gov/NRC/REACTOR/ALLOY-600/index.html).

The staff agrees that there is a demonstrated need for improvements to non-destructive examination (NDE) technology. The NRC staff has previously stated in several public meetings with the MRP, industry representatives and NEI that the presently required in-service inspection (ISI) examinations need to be augmented in the near term. It is important to recognize that the licensing basis philosophy for plants, consistent with the philosophy of the ASME Code as referenced in 10 CFR 50.55a, is to detect cracking and other forms of degradation and to limit its extent so that primary system leakage does not occur, and that appropriate margin to failure is maintained. Thus, effective NDE methods and programs should be developed to achieve this objective. Leak-Before-Break (LBB) is an element of defense-in-depth, but it should not be relied upon as the principal long-term method for identifying and managing service-related degradation. Inspections utilizing effective technologies also are necessary to confirm the results of analytic studies.

Based on the results presented in this report, the staff understands there is an industry commitment to develop NDE technologies that can adequately examine and evaluate these welds in the near term. This commitment reinforces the staff's conclusions that the additional short term operation proposed in this interim report is justified and precludes the need for any regulatory action regarding inspection at this time. Should the industry not be timely in resolving inspection capabilities to identify PWSCC in Alloy 600 welds regulatory action may result.

The enclosure to this letter contains a listing of issues that the final report should address.

If you have any question regarding this letter, please contact Mr. Jack Strosnider of my staff at 301-415-3298.

Sincerely,

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Brian W. Sheron, Associate Director
for Project Licensing and Technical Analysis
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Project No. 689

Enclosure

cc: See next page

cc:


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NRC STAFF REVIEW OF MRP-44

"PWR MATERIALS RELIABILITY PROJECT INTERIM ALLOY 600 SAFETY ASSESSMENT FOR US PWR PLANTS (MRP-44), PART 1: ALLOY 82/182 PIPE BUTT WELDS," TP-1001491, PART 1, INTERIM REPORT, APRIL 2001

By letter dated April 27, 2001, the Nuclear Energy Institute (NEI), as the regulatory interface for the EPRI Materials Reliability Project (MRP), submitted the proprietary (TP-1001491, Part 1) and non-proprietary (TP-1001491-NP, Part 1) versions of the EPRI report, "PWR Materials Reliability Project Interim Alloy 600 Safety Assessment for US PWR Plants (MRP-44), Part 1: Alloy 82/182 Pipe Butt Welds," for staff information.

The NRC staff has reviewed this report to evaluate the MRP's assessment of the generic implications of cracking in Alloy 82/182 pipe butt welds. The staff has concluded, based on the information provided in the MRP-44 report, that the results of this interim safety assessment are sufficient to justify the continued operation of pressurized water reactors (PWRs) while the industry completes the development of the final version of the MRP-44 report. The specific MRP-44 conclusions that support the staff's conclusions are:

(1) cracking observed to date has been predominantly axial;

(2) that pipe weld axial crack growth is bounded by the low-alloy steel or stainless steel materials at either end of the weld;

(3) that the critical flaw size for axial rupture is several times greater than the width of the welds; and,

(4) there is expected to be no significant concern arising from boric acid corrosion as a result of the relatively low leakage rates from the high temperatures of the affected components and the cracks seen to date.

The above conclusions indicate that there is a low probability of near-term failure of these welds. Therefore, the staff agrees that PWRs may continue to operate safely while the industry performs additional analyses and inspections.

While the operating experience and evaluations performed to date indicate cracking in these welds would be predominately axial, additional work is necessary to further understand the potential for significant circumferential cracking and to define long term actions to address this issue.

It is the staff's expectation, based on the discussions during previous public meetings on this issue, that the final MRP-44 report will address:

(1) the potential of multiple initiation sites in a single weld, like that found at Summer;

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(2) the need for PWR licensees to augment their visual inspection of these welds, or employ augmented leak detection capabilities that will be able to detect leakage at a level that maintains appropriate margins;

(3) the need to develop a licensee- or generic-susceptibility ranking for the Fall 2001 refueling outages of the Alloy 82/182 pipe butt welds and a proposed inspection scope and schedule that will examine, using best available technology, a significant percentage of the most susceptible and the most risk-significant of these pipe joints; and,

(4) the other items discussed by the MRP and the NRC during the public meetings (see Meeting Summarys on the NRC's "Generic Activities on PWR Alloy-600 Weld Cracking" at http://www.nrc.gov/NRC/REACTOR/ALLOY-600/index.html).

The staff agrees that there is a demonstrated need for improvements to non-destructive examination (NDE) technology. The NRC staff has previously stated in several public meetings with the MRP, industry representatives and NEI that the presently required in-service inspection (ISI) examinations need to be augmented in the near term. Inspections utilizing effective technologies are necessary to confirm the results of analytic studies. Based on the results presented in this report, the staff agrees that the industry should develop NDE technologies that can adequately examine and evaluate these welds in the near term. Further, the staff agrees that the above need to be completed in a timely manner in order to provide for continued confidence in the long-term safe operation of PWRs.

The following general comments regarding the MRP-44 report is meant to serve as recommendations to strengthen the final report. The staff encourages the MRP to review the following and, based on these comments, to evaluate its proposed approach to assessing the generic implications of cracking in Alloy 82/182 pipe butt welds in the final version of the MRP-44 report. This final, revised report should provide technical justifications for any proposed generic actions to address this significant issue in a timely manner to allow for continued safe operation of PWRs.

Cracking Phenomenon

In several places, the report states that "most cracks" or the predominant cracking will be axially oriented, based on field experience and consideration of finite element stress analysis results. Based on the circumferential cracking found at V. C. Summer, and the small embedded circumferential defects found at a foreign PWR, the staff finds that the development of circumferential cracking cannot be precluded. The staff notes that the circumferential cracking at Summer was arrested by the low alloy steel nozzle. The potential for a circumferential crack developing at a location where the entire pipe cross section is composed of Alloy 82/182 metal instead of one similar to that at Summer, where the crack initiated at a site bounded by adjacent low alloy steel and thus was contained, needs to be further addressed.

Section 5 of the report states that through-wall circumferential cracks will produce leaks that can be detected in service before exceeding available structural margins. This is based on statements in Section 4.3 that deep 360-degree part-depth circumferential cracks are "a very low probability" without a through-wall indication being detected. With the finding from the Summer and foreign PWR experiences that circumferential cracking can occur and multiple sites can initiate along the pipe inside circumference, the development of deep 360-degree part-depth circumferential cracks cannot be precluded. Further discussion on the ability to detect and size this type of cracking is provided below under "ISI Capability."

The type (axial vs. circumferential) and nature (through-wall vs. 360 degree part-depth) of flaws that could develop in these weld joints will be affected by many factors, including the stresses (e.g., residual stress and operating stress orientations and magnitudes), the extent and nature of weld repairs, the structure (micro- and macro) of the welds, and the operating conditions (temperature and time). Given the complex interaction of these parameters and the field experience to date, additional information is required in order to characterize predicted cracking.

Page A-44 of the report describes use of a stress corrosion crack growth rate on the order of 50 percent of that for intergranular stress corrosion cracking (IGSCC) of fully sensitized 304 stainless steel in a BWR environment, without providing any details on the relationship used to evaluate crack growth. By letter dated February 20, 2001, from K. R. Cotton (NRC) to S. Byrne (Southern Carolina Electric & Gas Company), the NRC staff's safety evaluation of WCAP-15615 indicated that a crack growth rate (CGR) given by CGR = $2.1 \times 10^{-11} (K - 9)^{1.16}$ m/sec provides a conservative bound to the limited CGR data for Alloy 182 weld material. The final version of report MRP-44 should provide specific information regarding the CGR values and the bases for the values assumed in the report.

Visual Inspection for Leakage

The MRP-44 report cites visual inspection for boric acid leakage, as requested by Generic Letter (GL) 88-05, "Boric Acid Corrosion of Carbon Steel Reactor Pressure Boundary Components in PWR Plants," dated March 17, 1988, as providing an opportunity to discover leaks in Alloy 600 components before a significant safety risk developed. Two issues that should be addressed in the report are the expected leakage levels from postulated cracks and the effectiveness of visual examination (e.g., boric acid deposits) and leakage detection instrumentation and procedures to detect the available leakage.

The issue of the expected leakage levels from postulated cracks arises from the experience at Summer and overseas PWRs that have demonstrated tight surface-breaking PWSCC cracks. An evaluation of the cracking at the overseas PWR found that the cracks had very tight tips and were very tight at the ID surface of the pipe. The tightness of these cracks, in combination with the dendritic nature of the PWSCC cracks, could tend to limit the leakage available for detection. The (potentially) resultant limited leakage could make early detection of the cracking difficult. The report should be revised to indicate that MRP will address the adequacy and reliability of reliable implementation of existing leakage regulatory requirements, i.e., inventory balance, radiation monitoring, sumps, etc. The staff has concerns with the plant-specific accessibility to perform an effective visual examination for boric acid deposits at all of the locations of interest. Of particular concern is insulation or other obstructions limiting the effectiveness of the visual boric acid inspections, and any procedures to promote reliable detection of boric acid deposits. The revised final MRP-44 report should address these visual inspection issues. Additional discussion of this issue is found under "Fracture Evaluation and Leak-Before-Break Assessment."

ISI Capability

The staff has previously stated in several public meetings with the MRP, industry representatives and the Nuclear Energy Institute (NEI), that the presently required ISI examinations need to be augmented in the near term. Specifically, the ultrasonic (UT) examinations performed in accordance with the minimum ASME Code requirements do not appear to be effective in detecting all cases of PWSCC in these welds.

In the recent UT inspection of the Summer "A" hot leg nozzle weld, a number of small PWSCC cracks, up to a depth of 0.615-inches into the weld thickness, were missed. However, these crack indications were detected by eddy current testing (ET), and confirmed by the destructive metallographic analysis. Similarly, in PWRs, Inconel 82/182 pipe butt welds were not considered to be susceptible to PWSCC until the recently reported event of the Summer "A" hot leg nozzle weld cracking. This was due, in part, to the UT inspection performed during the 10-year Section XI ISI program that did not identify such cracking. The cracking was discovered only when the affected component started leaking.

The MRP-44 report concluded that there are no wide spread problems with these Alloy 82/182 pipe butt welds based on the absence of findings from these 10-year Section XI ISI programs. The MRP's conclusion appears to be based on inspections using UT procedures and techniques that may not reliably detect cracking, particularly in its early stages, or utilized methods that were not focused on detection of the type of cracking experienced at Summer. Furthermore, PWSCC is a time dependent phenomenon. It takes time for the crack to initiate and propagate to a size that is detectable by UT. Since PWSCC is a complex degradation process, its mechanism is not yet completely understood. Therefore, it is not presently possible to evaluate crack incubation time and the time it takes to grow to a detectable size at each affected pipe weld. Therefore, to ensure the integrity of components that are susceptible to PWSCC, early and frequent inspections using the best available NDE techniques and procedures for potential PWSCC is warranted.

For the NDE inspections performed at Summer, the UT examinations missed several short PWSCC cracks. These short cracks were detected by ET and confirmed by the destructive failure analysis. This is attributed to the problems associated with decoupling of the UT probe because of adverse inside diameter (ID) surface conditions (irregular surfaces due to ID grinding, counterbore, weld root and offset between the nozzle and the pipe). To ensure a more reliable examination for small cracks, the NDE examination techniques and procedures should be enhanced to accommodate these adverse ID surface conditions.

The staff also notes that the EPRI mock-up used for UT demonstration at Summer does not contain PWSCC cracks, which are typically very tight and branching. Because of these characteristics, PWSCC cracks are much more difficult to detect and size. Therefore, efforts should be made to implant PWSCC-type cracks into future demonstration mock-ups, so that more realistic demonstrations of NDE examination capability for PWSCC can be achieved.

Fracture Evaluation and Leak-Before-Break Assessment

The staff has the following comments resulting from our review of the fracture evaluation and Leak-Before-Break (LBB) assessment in Sections 5 and 6 of Appendix A to the MRP-44 report.

Regarding the analysis of axially-oriented flaws, the staff agrees with the conclusion in the MRP-44 report that these cracks are not expected to be of sufficient size to challenge the structural integrity of the primary system piping. This conclusion can be made based on the expectation that the growth of PWSCC axially-oriented flaws initiating in Alloy 82/182 materials would arrest when they reach the associated stainless steel or ferritic steel materials. This would limit the size of an axial-oriented PWSCC flaw to approximately 2 to 3 inches, well below the critical through-wall flaw size which could lead to piping rupture.

The staff has was not able to independently evaluate the results of the MRP-44 report's analysis of circumferentially-oriented part through-wall flaws due to the lack of detail in the report regarding assumptions made in the fracture analysis. However, the conclusion that an inside diameter, 360-degree flaw would need to be approximately 50 percent through-wall prior to the onset of projected failure under safe shutdown earthquake (SSE) loading conditions (or startup/shutdown bending stresses for the surge line analysis) appears to be reasonable. The staff requests that additional detail regarding the bases for material properties and loadings assumed in the analysis be included in the final MRP-44 report for the staff's review.

The MRP-44 report does not adequately substantiate that such large part through-wall flaws may not develop in-service. This concern reflects the staff's position that ISI examinations conducted to date may not provide reliable information regrading the occurrence of PWSCC in Alloy 82/182 welds prior to the onset of leakage. Further, reliable crack growth information was not presented to evaluate what size flaw (or flaws, if multiple initiation sites are assumed) could grow to the critical part through-wall flaw size in one operating cycle. Therefore, even if the conclusion that the material can withstand a 360-degree, 50-percent though-wall is valid, the issues identified above need to be addressed before the level of safety offered by this conclusion can be fully understood.

Regarding the analysis of leakage from circumferentially-oriented through-wall flaws, critical details of the analysis were not included in the MRP-44 report. Although the report states that the calculations (in the Westinghouse analysis) were "performed using the same methodology used by Westinghouse for all LBB applications which have been reviewed and approved by the NRC," the staff has found discrepancies between NRC and industry results for flaw leakage calculations in licensee LBB submittals. No information regarding significant input parameters (e.g., crack surface roughness, number of 45-degree and 90-degree turns, etc.) was included for any of the leakage analyses. Given the cracking mechanism in question, it is not clear that the same assumptions for these parameters should be made in this evaluation as were made in LBB evaluations. Further, although it is stated in the report that the calculations carried out were intended to compare a "best-estimate" critical flaw size to a one gallon per minute "best-estimate" leakage flaw size, the NRC staff's position is that there are large uncertainties in evaluating and detecting leaks of this size. The staff notes that licensing basis calculations for approving LBB for piping systems include a factor of safety of 10 on the leakage when establishing a flaw size which would be reliably detected based on its leakage.

The NRC staff requests that additional detail regarding the bases for both the leakage flaw size and critical through-wall flaw size analyses (assumed material properties, loadings, etc.) be included in the final MRP-44 report for the staff's review.

Weld Residual Stress Evaluation

The NRC staff has reviewed Appendix C to the MRP-44 report regarding the evaluation of weld residual stresses and operating stresses as they pertain to Alloy 82/182 welds. The staff noted that, although the information summarized in Appendix C was helpful in understanding specific issues associated with the Summer and foreign PWR cracking events, detailed information necessary for the staff to complete its review of Appendix C was omitted. Some of this information would include:

(1) through-wall thickness profiles showing welding/repair residual stresses and superimposed operating conditions induced stresses,

(2) an investigation of the adequacy of the axi-symmetric modeling and elastic-perfectly plastic material properties assumptions, and

(3) details of the ANSYS thermal and residual stress analysis models such as a mesh-size convergence/refinement study for the 4-node quad (linear) elements used and a description of how the constitutive properties of previous weld passes were changed during re-melting and solidification due to the new weld passes being laid down.

The models presented in Appendix C were observed to be specific to the Summer and foreign PWR events. In order to more fully understand the potential for axial or circumferential cracking in welds at other facilities, it appears to the NRC staff that a review of welding records would be necessary to identify the spectrum of weld types (as characterized by their general fabrication processes, prevalence of weld repairs, etc.) which exist in operating facilities. Based upon this survey, finite element modeling of typical weld types and potential outliers could be undertaken. Such efforts would provide a more balanced assessment of weld residual and operating stresses for all PWRs and provide a better understanding of PWSCC potential throughout the PWR fleet.

Risk Assessment

The staff has reviewed Appendix A, Section 7, “Risk Evaluation,” which provides an analysis of PWRs designed by Westinghouse and Combustion Engineering. The risk evaluation concludes that “[although] the risk of core damage due to PWSCC related large leaks in the RPV outlet nozzle weld is expected to remain insignificant, there are a number of potential actions available to reduce uncertainty and manage the PWSCC degradation of the Alloy 82/182 welds.” The staff requests that you give further technical justification for the core damage risk conclusion based on realistic initiating event frequencies, bounded by technically-justified uncertainty bands for all three NSSS types of PWRs. These risk-informed assessments should provide sufficient technical details so that the staff can verify the risk-informed results.