February 25, 2016

MEMORANDUM TO: John J. McHale, Chief
Vessels and Internals Integrity Branch
Division of Engineering
Office of Nuclear Reactor Regulation

FROM: Joel G. Jenkins, Materials Engineer ***/RA/***
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SUBJECT: SUMMARY OF THE JANUARY 19, 2016, CATEGORY 2 PUBLIC MEETING WITH INDUSTRY REPRESENTATIVES TO DISCUSS WELDING ON NEUTRON IRRADIATED FERRITIC AND AUSTENITIC MATERIALS

The U.S. Nuclear Regulatory Commission (NRC) hosted a Category 2 public meeting to exchange technical information regarding the guidance and requirements in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Section XI for welding on neutron irradiated austenitic and ferritic materials. This meeting was noticed as a public meeting and the agenda is available in Agencywide Documents Access and Management System (ADAMS) under Accession No. ML16008A081. During this meeting, representatives from the Electric Power Research Institute (EPRI) presented information in the form of slides which are available in ADAMS under Accession No.ML16019A478. The following is a summary of the EPRI presentation:

- Helium (He) generated by neutron transmutation reactions can result in cracking when the irradiated material is welded.
- Guidance should be provided for the consideration of irradiation effects to prevent helium-induced cracking when welding.
- Current rules in ASME Code Section XI for welding on neutron irradiated material are inconsistent.
- Weldability analyses have been performed to determine a suitable threshold of weldability based on the helium concentration within the material.
- Fast neutron fluence is not relevant to evaluating helium-induced cracking of weldments.
- Thermal fluence is only one of several parameters affecting weldability, other important parameters are boron content, material type/grade, heat input.

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- At He concentrations less than 0.1 atomic parts per million (appm), both 304 stainless steel (SS) and 316SS are weldable without consideration of irradiation effects.
- Stainless steel alloys with He concentrations greater than 0.1 appm but less than 10 appm, may be weldable with appropriate evaluation of helium content and application of heat input controls.
- There is insufficient data to develop threshold plots (based on He concentration) for either nickel-based alloys or low-alloy steels.
- Helium generation is significantly affected by initial boron content, in locations with high thermal fluence.
- Based on helium generation mapping, the following components are assumed to be weldable, even with the assumption of high initial boron content.

    - Reactor pressure vessel nozzle to safe end welds
    - Reactor pressure vessel upper and lower head penetrations

During the meeting, NRC staff stated that:

- Having access to industry documents MRP-379 and BWRVIP-97, Rev.1 will be useful in its review of issues related to welding on irradiated materials.
- ASME Code language contained in the Section XI rules for welding on irradiated materials (such as "consideration shall be given") does not appear to be adequate and threshold limits should be defined.

During the meeting and in subsequent communications, EPRI clarified that:

- Industry documents MRP-379 and BWRVIP-97, Rev. 1 are proprietary and have not been submitted to the NRC. PVP2016-64007 paper (discussed in Slide 21 of the public presentation) may be a way to share the technical basis in support of any ASME Code action.
- MRP-379 addresses differences in 316L SS, 304 SS, and low alloy steel, with limited data on nickel based materials.
- Changing the inputs to fluence maps based on different fuel loading conditions does not challenge either the upper head welds or the lower head welds (which are outside the high fluence zones).
- Japanese weldability studies data documented in BWRVIP-151 provided valuable information that better defined weldability thresholds.
- The additional Japanese data clarified the welding thresholds in BWRVIP-97, Rev. 1 and MRP-379:

    - plotted weldability results in terms of effective heat input rather than theoretical heat input to allow a direct comparison of gas tungsten arc welding (GTAW) and laser beam welding data,
    - considered that heat inputs from multipass remelt trials would be higher than heat inputs for single pass welds (as previously assumed), and
    - plotted weldability data for 304 SS and 316L SS separately. The results indicate that 304 SS is somewhat more weldable than 316L SS.

- He generation from iron and chromium transmutation reactions were considered, but the influence of these elements on He generated cracking was orders of magnitude below the influence of nickel and boron.
- Many different heats of SS were tested with a wide range of sulfur and silicon composition, but planned systematic testing of sulfur and silicon was not performed since these elements do not contribute to He generation.
- EPRI considered fast and thermal neutron fluence and observed that appropriate fluence calculations for estimating He generation must include thermal neutron energy groups.
- 50 parts per million by weight (wppm) boron content was assumed within the bounding He calculations to support the study of nickel based materials (based, in part, on BWRVIP-45). There is significant variation in boron content for nickel based alloys. Typical boron contents for nickel based alloys range from 5 to 40 wppm. MRP-241 identifies 50 wppm boron max for nickel based Alloy 690 and notes this as a standard industry practice (which would have similarly applied to Alloy 600).
- Typical boron contents for stainless steels range from 1 to 10 wppm.
- The same boron transmutation reaction drives He generation in nickel based alloys as in SS.
- The data on Slide 8 of the EPRI presentation represents various conditions: SS weld metal furnace sensitized SS, as welded SS, and solution annealed SS.
- The negative slope of the threshold line shown on Slide 8 is conservative, and it is appropriate to extend the horizontal portion of the threshold line to 10 appm since the slope was brought down below the region where grain boundary deterioration was observed. There are no failed test results at heat inputs less than about 0.28 kJ/cm, regardless of He concentration.
- The porosity noted on Slide 9 of the EPRI presentation is not attributed He content in the ferritic material but rather a tenacious oxide that was not removed prior to welding. Proper surface preparation is standard practice and would likely have prevented the porosity. This porosity is not attributable to underwater welding since these tests were performed in air.
- All fluence codes used to produce He generation maps were benchmarked consistent with the requirements of NRC Regulatory Guide 1.190 with acceptable uncertainty.
- Fluence maps have been made for the Westinghouse, Babcock & Wilcox, and Combustion Engineering pressurized water reactor designs, as well as for the US boiling water reactor (BWR) design.
- Some BWRs have nozzles which are near the beltline region. These nozzles may be full penetration welded low alloy steel, or partial penetration welded nozzles consisting of an Alloy 600 tube and Alloy 82/182 partial penetration weld.

    - For the full penetration welded nozzles, the location of concern relative to intergranular stress corrosion cracking mitigation or repair is the nozzle-to-safe end dissimilar metal (DM) weld. All nozzle locations have not been fully investigated. Additional work, if needed, would be performed to support development of ASME Code Rules.
    - For the partial penetration water level instrument nozzles, the location of the weld could require evaluation of irradiation effects due to the potential for significant He generation at the reactor vessel inner diameter.

- Variation in boron contents used in analysis and documented in the presentation is due to work that was performed at different times.
- The most important factors in the He generation mapping are the initial boron content and the cumulative fluence. Upper end initial boron content was assumed. With regard to accumulated neutron fluence, the 40-year, 60-year, and 80-year cases were conservatively evaluated based on true 40 EFPY, 60 EFPY, and 80 EFPY values respectively (rather than assuming typical EFPY values which would be less).
- The intent of the mapping shown on Slide 15 is to provide ASME Code guidance for determination of regions where no consideration of irradiation effects is necessary. The intent is for EPRI documents to provide additional guidance if evaluations or other detailed testing is necessary.
- Below 0.1 appm He, all available data indicate that welding can be performed without consideration of irradiation effects.
- Although both nickel content and boron content influence helium generation during neutron irradiation, boron content dominates the reaction until fluence exceeds 10^{24} n/cm^2. The Trans Ware evaluation performed for BWRs considered reaction sequences capable of generating He for nickel, iron, chromium, and boron with a total He generation line based on these elements, but the data shows that He generation from the reaction sequences of iron and chromium is insignificant at the fluences relevant to light water reactor operation. Further, in most all cases relevant to weld repair of irradiated components, only the boron transmutation reaction is significant.
- BWRVIP-97-A included wording related to supplemental nondestructive examination (NDE) for cases where He induced cracking may occur. Guidance in BWRVIP-97, Rev. 1 and MRP-379 is essentially unchanged from the prior NRC approved guidance in BWRVIP-97-A. Current guidance in BWRVIP-97 Rev. 1 recommends additional nondestructive examination to demonstrate that an acceptable material condition prior to returning the component to service. Since weld repair of irradiated materials may create new helium-induced cracks in the weld heat affected zone region, these regions should be examined after repair weld completion, even if the region contained no cracks prior to welding.
- If He induced cracking occurs despite the Owner adhering to the proposed industry guidelines, the burden would be on the Owner to make adequate repairs and to show that the repaired component is fit for continued operation after such repair. This is no different than any other repair or replacement activity on pressure boundary items.
- Supplemental recommendations that the NRC approved in BWRVIP-97-A provide guidance to perform NDE with special considerations to ensure that there is no He-induced cracking at weld toes or under bead.
- Although there has been no ductility testing of welds made on irradiated material, there has been some tensile and bend testing documented in the Japanese PMT and WIM reports.

- EPRI guidance in BWRVIP-97-A, or future application of proposed industry guidance, for welding on irradiated material is generic in nature and can be applied on ASME Code pressure boundary or non-pressure boundary items. The component to be repaired will define whether ASME Code requirements in addition to guidance for welding on irradiated material is necessary.

The enclosure to this letter provides a list of people who attended the meeting.

Enclosure:
Attendance List

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OFFICE	NRR/DE/EVIB	NRR/DE/EVIB
NAME	JJenkins	JMcHale
DATE	02/22/2016	02/25/2016

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Enclosure to Meeting Summary

Attendance List for the January 19, 2016, Category 2 Public Meeting with Industry Representatives to Discuss Welding on Neutron Irradiated Ferritic and Austenitic Materials

Industry Participants:
Robin Dyle, EPRI
Jeff Enneking, Areva (by phone)
Greg Frederick, EPRI (by phone)
Wayne Lunceford, EPRI
Steve McCracken, EPRI
Jim O'Sullivan, Procon1 (by phone)
Nathan Palm, EPRI
Jon Tatman, EPRI
Dave Waskey, Areva (by phone)
Eric Willis, PG&E (by phone)

NRC Participants:
Bob Davis
Ganesh Cheruvenki
Joel Jenkins
Ken Karwoski
Jeffrey Poehler
Eric Reichelt (by phone)
John Tsao