UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 27, 2016

Mr. Bryan C. Hanson
Senior Vice President
Exelon Generation Company, LLC
President and Chief Nuclear Officer (CNO)
Exelon Nuclear
4300 Winfield Road
Warrenville, IL 60555

SUBJECT: BYRON STATION, UNIT NOS. 1 AND 2, AND BRAIDWOOD STATION, UNITS 1 AND 2 – RELIEF FROM THE REQUIREMENTS OF THE ASME CODE (CAC NOS. MF6715, MF6716, MF6717, AND MF6718)

Dear Mr. Hanson:

By letter dated September 11, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15259A048), as supplemented by letters dated February 11, 2016 (ADAMS Accession No. ML16043A148), March 22, 2016 (ADAMS Accession No. ML16082A435), and April 4, 2016 (ADAMS Accession No. ML16095A291), Exelon Generation Company, LLC, (the licensee) requested relief from the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) specifically related to repair of degraded reactor vessel closure head (RVCH) penetrations nozzles and their associated partial penetration J-groove attachment welds at Braidwood, Units 1 and 2, and Byron, Unit Nos. 1 and 2.

Pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.55a(z)(1), the licensee proposed alternative repair activities for the RVCH nozzle penetrations on the basis that the alternatives provide an acceptable level of quality and safety.

The U.S. Nuclear Regulatory Commission staff has reviewed the subject request and concludes, as set forth in the enclosed safety evaluation, that the licensee has adequately addressed all of the regulatory requirements set forth in 10 CFR 50.55a(z)(1).

Therefore, the NRC staff authorizes the proposed alternative for the remainder of the third 10-year ISI interval at Byron Station, Unit Nos. 1 and 2, and for the remainder of the third 10-year inservice inspection interval at Braidwood, Units 1 and 2.

Should you have any questions, please contact Joel S. Wiebe, Senior Project Manager, at 301-415-6606 or via email at joel.wiebe@nrc.gov.

Sincerely,

Justin C. Poole, Acting Chief
Plant Licensing Branch III-2
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. STN 50-456, STN 50-457,
STN 50-454 and STN 50-455

Enclosure:
Safety Evaluation

cc w/encl: Distribution via Listserv

UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELIEF REQUEST NOS. I3R-16 AND I3R-28

REGARDING REACTOR VESSEL CLOSURE HEAD PENETRATION NOZZLE REPAIR

EXELON GENERATION COMPANY, LLC

BYRON STATION, UNIT NOS. 1 AND 2,

AND BRAIDWOOD STATION, UNITS 1 AND 2

DOCKET NOS. STN 50-454, STN 50-455,

STN 50-456 AND STN 50-457

1.0 INTRODUCTION

By letter dated September 11, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15259A048), as supplemented by letters dated February 11, 2016 (ADAMS Accession No. ML16043A148), March 22, 2016 (ADAMS Accession No. ML16082A435), and April 4, 2016 (ADAMS Accession No. ML16095A291), Exelon Generation Company, LLC, (the licensee) requested relief from the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) specifically related to repair of degraded reactor vessel closure head (RVCH) penetrations nozzles and their associated partial penetration J-groove attachment welds at Braidwood, Units 1 and 2, and Byron, Unit Nos. 1 and 2.

Pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.55a(z)(1), the licensee proposed alternative repair activities for the RVCH nozzle penetrations on the basis that the alternatives provide an acceptable level of quality and safety.

2.0 REGULATORY EVALUATION

Pursuant to 10 CFR 50.55a(g)(4), the ASME Code Class 1, 2, and 3 components (including supports) must meet the requirements, except the design and access provisions and the preservice examination requirements, set forth in the ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," to the extent practical within the limitations of design, geometry, and materials of construction of the components.

Enclosure

Pursuant to 10 CFR 50.55a(g)(4)(ii), inservice inspection (ISI) examination of components during successive 120-month inspection intervals must comply with the requirements of the latest edition and addenda of the ASME Code incorporated by reference in paragraph (a) of 50.55a 12 months before the start of the 120-month inspection interval (or the optional ASME Code Cases listed in NRC Regulatory Guide (RG) 1.147, Revision 17, when using Section XI, that are incorporated by reference in paragraphs (a)(3)(ii) and (iii) of 10 CFR 50.55a), subject to the conditions listed in paragraph (b) of 10 CFR 50.55a.

Pursuant to 10 CFR 50.55a(g)(6)(ii)(D), Augmented ISI requirements: Reactor vessel head inspections - All licensees of pressurized water reactors (PWR) must augment their inservice inspection program with ASME Code Case N–729–1 "Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds, Section XI, Division 1," subject to the conditions specified in paragraphs (g)(6)(ii)(D)(2) through (6) of 50.55a.

Pursuant to 10 CFR 50.55a(z), alternatives to the requirements of paragraph (g) of 10 CFR 50.55a may be used when authorized by the Director, Office of Nuclear Reactor Regulation. A proposed alternative must be submitted and authorized prior to implementation. The licensee must demonstrate: (1) the proposed alternative would provide an acceptable level of quality and safety; or (2) compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Based on the above, and subject to the following technical evaluation, the U.S. Nuclear Regulatory Commission (NRC) staff finds that regulatory authority exists for the licensee to request and the NRC to authorize the alternative requested by the licensee.

3.0 TECHNICAL EVALUATION

3.1 ASME Code Components Affected

The ASME Code Class 1 RVCH penetration nozzles and their associated partial penetration J-groove attachment welds are affected. In accordance with ASME Code Case N-729-1 (Table 1), the RVCH penetration nozzles and their associated attachment welds are classified as Item No. 4.20. Pursuant to 10 CFR 50.55a(g)(6)(ii)(D), Augmented ISI requirements: Reactor vessel head inspections - (1) All licensees of pressurized water reactors must augment their ISI program with ASME Code Case N-729-1 "Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds, Section XI, Division 1," subject to the conditions specified in paragraphs (g)(6)(ii)(D)(2) through (6) of 10 CFR 50.55a.

The licensee provided the following information about the RVCH penetration nozzles for which relief is requested.

Braidwood, Unit 1:

Relief request I3R-16 applies to 77 RVCH penetration nozzles (Nos. P-1 through P-68 and P-70 through P78). This request does not apply to the previously repaired nozzle No. P-69.

Braidwood, Unit 2:

Relief request I3R-16 applies to 78 RVCH penetration nozzles (Nos. P-1 through P-78 There was no nozzle repaired previously in Braidwood, Unit 2.

Byron, Unit 1:

Relief request I3R-28 applies to 74 RVCH penetration nozzles (Nos. P-1 through P-30, P-32 through P-42, P-44 through P-63, P65 through P75, and P-77 through P78). This request does not apply to the previously repaired nozzle Nos. P-31, P-43, P-64, and P-76.

Byron, Unit 2:

Relief request I3R-28 applies to 76 RVCH penetration nozzles (Nos. P-1 through P-5, P-7 through P-67, and P-69 through P-78). This request does not apply to the previously repaired nozzle Nos. Nos. P-6 and P-68.

The construction materials of the existing RVCH penetration nozzles in Braidwood and Byron are Alloy 600, attachment welds are Alloy 82/182, and the RVCHs base materials are ferritic low alloy steel (LAS). The nominal outside diameter (OD) of these nozzles is 4 inches. The nickel based alloy materials are known to be susceptible to degradation by the primary water stress corrosion cracking (PWSCC) mechanism.

3.2 Applicable Code Edition and Addenda

The code of record for the third 10-year ISI interval (Braidwood, Units 1 and 2, and Byron, Unit Nos. 1 and 2) is the 2001 Edition through 2003 Addenda of the ASME Code.

The licensee stated that the Construction Code (Braidwood, Units 1 and 2, and Byron, Units 1 and 2) is the 1971 Edition through summer 1973 Addenda of the ASME Code.

3.3 Duration of Relief Request

The licensee submitted I3R-16 for the remainder of the third 10-year ISI interval of Braidwood, Unit 1, which commenced on July 29, 2008, and is scheduled to end on July 28, 2018, and Braidwood, Unit 2, which commenced on October 17, 2008, and is scheduled to end on October 16, 2018.

The licensee submitted I3R-28 for the remainder of the third 10-year ISI interval of Byron, Units 1 and 2, which commenced on July 16, 2006, and is scheduled to end on July 15, 2016.

The licensee stated that the repaired RVCH penetration nozzles that are the subject of I3R-16 and I3R-28 shall remain in service for the design life of the repair.

- The licensee stated that the IDTB [AREVA (Inside Diameter Temper Bead)] weld repair would be intended to support the remaining life of the original 40 calendar year plant design basis (40 calendar year operating license) plus license renewal extension (20 calendar year additional operating license) or 60 calendar year plant design basis life overall. At the time an IDTB weld repair would be performed (if applicable) for each individual unit (Byron, Unit Nos. 1 and 2, and Braidwood, Units 1 and 2), there would be approximately 10 to 11 calendar years of life remaining from the original 40 calendar year plant life on any of the units. Therefore, the overall design life the IDTB weld repair would be approximately the 33 calendar year remaining plant life.

- The licensee stated that a conservative estimate is to use effective full power years (EFPY) for the design life the IDTB weld repair. EFPY refers to a duration which takes into account plant down time due to refueling outages that typically occur over a 26 day period when the plant is not at full reactor power. The duration of 33 calendar years of plant life is approximately 12,045 days, whereas considering EFPY for this same duration is approximately 11,473 days (22 outages at approximately 572 days not at full power in a 33 calendar year span). Therefore, the licensee proposes the overall design life for the IDTB weld repair to be approximately 33 EFPY.

3.4 Applicable Code Requirement

Article IWA-4000 of Section XI, the ASME Code, states that for repair/replacement activities, the requirements of this article apply regardless of the reason for the repair/replacement activity or the method that detected the condition requiring the repair/replacement activity.

In accordance with IWA-4220 of Section XI, any repair/replacement activity shall meet the Construction Code and the owner's requirements. The licensee may also use all or portions of later editions and addenda of the Construction Code, Section III, when the Construction Code was not Section III, or applicable ASME Code cases provided that the applicable requirements in IWA-4222 through IWA-4226 are met.

The ASME Code, Section XI, IWA-4600, requires preheat and post weld heat treatment (PWHT) for temper bead welding applications on reactor pressure vessel and related components. The extent of preheat and PWHT during temper bead welding are reduced by ASME Code Case N-638-4 "Similar and Dissimilar Metal Welding Using Ambient Temperature Machine Gas Tungsten Arc Welding (GTAW) Temper Bead Technique, Section XI, Division 1," paragraph 1(g), to ambient temperature without a need for the PWHT of LAS. This code case has been incorporated by reference into 10 CFR 50.55a by inclusion in RG 1.147, Revision 17, with conditions that are:

1. Demonstration for [ultrasonic testing] UT examination of the repaired volume is required using representative samples which contain construction type flaws; and

2. The provisions of 3(e)(2) or 3(e)(3) may only be used when it is impractical to use the interpass temperature measurement methods described in 3(e)(1), such as in situations where the weldment area is inaccessible (e.g., internal bore welding) or when there are extenuating radiological conditions.

The ASME Code, Section III, NB-5245, "Partial Penetration Welded Joints," specifies progressive surface examination of partial penetration welds.

The ASME Code, Section XI, IWB-3420, states that each detected flaw or group of flaws shall be characterized by the rules of IWA-3300 to establish the dimensions of the flaws. These dimensions shall be used in conjunction with the acceptance standards of IWB-3500.

The ASME Code, Section XI, IWB-3132.3, states that a component whose volumetric or surface examination detects flaws that exceed the acceptance standards of Table IWB-3410-1 is acceptable for continued service without a repair/replacement activity if an analytical evaluation, as described in IWB-3600, meets the acceptance criteria of IWB-3600. The area containing the flaw shall be subsequently reexamined in accordance with IWB-2420(b) and (c).

The ASME Code, Section III, NB-5331(b), states that indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

The preservice inspection (PSI) after repair/replacement activities and subsequent ISI of the RVCH penetration nozzles are governed by ASME Code Case N-729-1 as mandated by 10 CFR 50.55a(g)(6)(ii)(D) with conditions.

3.5 Reason for Relief

The licensee stated that it submitted I3R-16 and I3R-28 to propose alternative requirements for repair of the degraded RVCH penetration nozzles if flaws requiring repair are discovered in the penetration nozzles in the remainder of the third 10-year ISI interval. The proposed alternatives are discussed in the next section.

3.6 Proposed Alternative

The licensee proposed the following alternatives if repair is required as a result of discovery of unacceptable flaws in the RVCH penetration nozzles and their attachment welds during ISI.

a. The licensee proposed to apply rotary peening to the surface of the final layer of the repair (i.e., new) weld installed by the IDTB welding technique. Rotary peening is a form of surface stress improvement that only affects a shallow surface layer of metal to reduce PWSCC initiation. The licensee proposed this alternative in lieu of the requirement in 1(g) of ASME Code Case N-638-4.

The licensee stated that the extent of peening includes the new IDTB weld surface, the heat affected zone (HAZ) of Alloy 600 surface, and the roll expanded (or machined extent) inside diameter (ID) surface of nozzle. The minimum length of peened surface (or also referred as remediation or remediated surface) on the ID of the nozzle is 3.72 inches long. The surface on the ID of the nozzle to be peened starts at the lower edge of the IDTB weld and continues upward to include the roll expanded surface and 1.75 inches above the upper extent of the roll expanded surface.

The licensee proposed to perform surface examination of the remediated or peened surface by the penetrant testing (PT) method following completion of peening.

The licensee stated that application of the rotary peening will not affect the ASME Code Case N-729-1 required PSI, subsequent ISI, and the frequency of inspection as mandated by 10 CFR 50.55a(g)(6)(ii)(D) with conditions.

b. The licensee proposed that the new weld and its immediate surrounding area within the bore, as identified in Figures A-3 and A-12 of Attachment 1 to the licensee's submittal dated September 11, 2015, will receive a combination of surface examination by the PT method and volumetric examination by the UT testing method. The licensee proposed this alternative in lieu of the requirement in NB-5245 of Section III.

c. Inherent to the IDTB welding method for repair of penetrating nozzle is an anomaly (or artifact) created in the new weld at the "triple point" location during welding. The "triple point" is the location in the new weld where the Alloy 52 weld metal, the RVCH ferritic LAS base metal, and the remnant of original Alloy 600 nozzle or the replacement Alloy 690 nozzle intersect. Mockup testing has verified that the "triple point" anomaly resembles a crack-like indication. In order to justify operating with a crack-like fabrication indications in the new weld, the licensee performed a flaw analysis in accordance with IWB-3600. The licensee proposed this alternative in lieu of the requirement in NB-5331(b) of Section III.

d. The proposed repair methods leave a remnant of the original Alloy 82/182 J-groove weld in service. There are no qualified volumetric examination methods available to characterize J-groove weld flaws. In order to justify operating with potential flaws in the remnant of the original J-groove weld, the licensee proposed a flaw analysis in accordance with IWB-3600. The flaw analysis will demonstrate that a postulated worst case flaw left in the remnant of the original J-groove weld will not grow to the ASME Code allowable flaw size until the end of service lifetime of the component. The licensee proposed this alternative in lieu of the requirements in IWB-3420 (i.e., characterizing the flaw identified in the J-groove weld), IWB-2420(b) and (c) (i.e., subsequent reexamination of area containing the identified flaw).

3.7 <u>Licensee Basis for Use of Alternative</u>

The licensee stated that the repair/replacement activities, PSI, and ISI including subsequent ISI following repair will be performed in accordance with applicable requirements in the

Construction Code, the 2001 Edition through 2003 Addenda of the ASME Code, Section XI and Section III, ASME Code Case N-638-4 with conditions contained in RG 1.147, Revision 17, and ASME Code Case N-729-1 as mandated by 10 CFR 50.55a(g)(6)(ii)(D) with conditions.

Repair of the CRDM, RVLIS, and CETC nozzles by the IDTB welding technique

The licensee stated that the ASME Code required high temperature PWHT in LAS following repairs of RVCH nozzles may pose a risk of damaging the RVCH base material properties or dimensions. The repair welds installed with the IDTB welding technique using a remotely operated machine GTAW process at ambient temperature does not require a high temperature PWHT in LAS. The licensee plans to repair the degraded nozzles by installing a repair (new) weld using the IDTB welding technique with the GTAW process in accordance with ASME Code Case N-638-4 including the conditions in RG 1.147, Revision 17. Section 4.0 of the relief requests describe the licensee's repair procedures in detail.

Rotary peening

The licensee stated that the prohibition imposed by the ASME Code on peening of the final layer of a temper bead weld is the high cold-work peening which is traditionally used for configuration distortion control during welding. This is not applicable to the proposed rotary peening process. Rotary peening imparts highly controlled and uniform compressive stresses on the surface that only affect a shallow surface layer of metal. The ASME Code, Section III, Appendix W, W-2140, describes the beneficial nature of compressive stresses for the mitigation of stress corrosion cracking (SCC) susceptibility. It states that shot peening, as a form of stress improvement, can be used to place the inside diameter of piping in a compressive residual stress state to resist SCC.

The licensee stated that corrosion testing was performed for rotary peened samples that underwent U-bend testing. After 2000 hours of primary water exposure at 360 degree Celsius (°C), none of the rotary peened samples tested showed cracking at the surface, demonstrating that rotary peening mitigates the effects of PWSCC.

The licensee stated that the proposed rotary peening is performed on the final IDTB weld surface and the roll expanded surface to alleviate tensile stress introduced by both the new IDTB weld and the mechanical roll expansion process. The peened surface (remediation surface) consist of the new IDTB weld surface, Alloy 600 HAZ, and the roll expanded ID surface. The roll expanded surface is located on the upper portion of the nozzle inside the RVCH above the IDTB weld. Prior to cutting the lower portion of the nozzle, the upper portion of the nozzle inside the RVCH is slightly roll expanded to secure the upper portion of the nozzle to the RVCH and maintain it in place. Total length of the peened (remediation) surface on the ID of the nozzle is a minimum of 3.72 inches long. The ID surface to be peened (3.72 inches minimum) starts at the lower edge of the IDTB weld and continues upward to include the roll expanded (or machining extent) surface and 1.75 inches above the upper extent of the roll expanded surface. This peened (remediation) surface is subjected to the PT after completion of peening.

The licensee stated that the proposed rotary peening will not affect the applicable ASME Code Case N-729-1 required PSI, ISI, subsequent ISI, and the frequency of inspections.

Examinations

The licensee stated that the original Construction Code (NB-5245 of the ASME Code, Section III), requires progressive surface examination of the partial penetration welds because the volumetric examination is not practical for the conventional partial penetration welded joint configurations. However, the licensee stated that the IDTB repair weld joint (in the subject CRDM, RVLIS, and CETC nozzles) is determined to be suitable for volumetric examinations by the UT. Therefore, the UT of IDTB repair weld and the associated HAZ of nozzle base metal will be performed following the IDTB welding. The extent of volume required to be examined (as established by ASME Code Case N-729-1) is shown in Figures A-3 and A-12 of Attachment 1 to the licensee's September 11, 2015, submittal.

The licensee stated that for inspection of the IDTB repair weld by the UT, the longitudinal (L)-wave search units with nominal angles of 0 and 45 degrees are utilized to scan the new weld in two circumferential directions. The L-wave search units with nominal angles of 70 and 45 degrees are utilized to scan the new weld in two axial directions. Figures A-4 through A-8 and A-13 through A-17 of the licensee's September 11, 2015, submittal show sketches of anticipated volume that could be scanned. Additionally, the volume extending to ¼ inch beneath the new weld into the LAS base material (Figures A-3 and A-12 of Attachment 1) will be examined using the 0 degree L-wave transducer looking for evidence of under bead cracking and lack of fusion in the HAZ. The examinations will be performed to the extent practical.

The licensee stated that it anticipates the UT of the CETC nozzles will achieve essentially 100 percent coverage of the required examination volume. The actual coverage of the required examination volume of the CRDM and RVLIS nozzles will be calculated after the as-built dimensions of the new weld are known and the examination is performed. The licensee anticipates that the examination coverage of the CRDM or RVLIS nozzle will be greater than 80 percent of the required examination volume. The weld taper transition geometry would limit achieving essentially 100 percent coverage. There is no portion of the CRDM or RVLIS nozzle required weld volume that does not receive at least single direction UT coverage. The examinations will be performed to the extent practical.

For the subject CRDM, RVLIS, and CETC nozzles, the licensee stated that the repair weld joint is determined to be suitable for surface examinations by the PT. The extent of surface area required to be examined (as established by ASME Code Case N-729-1) is shown in Figures A-3 and A-12 of Attachment 1 to the licensee's September 11, 2015, submittal. A final (or post welding) surface examination by the PT will be performed on the entire surface area of the new weld and HAZ of base metal as shown in Figure A-3 of Attachment 1 for the CRDM and RVLIS nozzles and Figure A-12 of Attachment 1 for the CETC nozzles. The licensee expects that the final PT will achieve essentially 100 percent coverage of the required examination area.

The licensee stated that the surface and volumetric examinations performed on the new welds and their immediate surrounding area and volume will be sufficient to verify that defects have not been induced due to welding.

Furthermore, the licensee stated that the surface examination by the PT will be repeated after completion of rotary peening. The extent of area subjected to the PT after peening will be the length of the peened (remediation) surface on the ID of the nozzle (i.e., 3.72 inches minimum). Specifically, the ID surface to be peened (remediated) starts at the lower edge of the IDTB weld and continues upward to include the roll expanded (or machining extent) surface and 1.75 inches above the upper extent of the roll expanded surface. The PT performed after peening does not include the entire ID of the remnant Alloy 600 nozzle. The licensee expects that the PT will achieve essentially 100 percent coverage of the peened area. The licensee stated that the surface examinations performed on the peened area will be sufficient to verify that defects have not been induced due to peening.

The licensee stated that the acceptance criteria for disposition of the flaws detected by PT is in accordance with NB-2546 of Section III, the 2001 Edition through 2003 Addenda of the ASME Code.

UT demonstration

In accordance with N-638-4 and the conditions in RG 1.147, Revision 17, the UT procedure for repair weld inspection shall be demonstrated on representative mockups containing construction type flaws. The UT procedure demonstration is intended to show the ability of the UT to detect a weld fabrication "triple point" anomaly extending 0.10 inch into the new weld, which could be an under weld bead cracking, a lack of bond, and/or a lack of fusion.

The licensee stated that mockups have been fabricated with the IDTB weld containing construction type flaws representative of the repair weld volume. The fabricated mockups replicate the expected configuration with a series of electrical discharge machining (EDM) notches at the "triple point" location to simulate (a) the "triple point" anomaly at various depths into the nozzle wall and (b) cracking at the IDTB weld to LAS interface. The mockup also contains flat bottom holes to simulate under bead cracking, lack of bond, and lack of fusion. The licensee stated that its UT procedure has demonstrated the ability to detect the aforementioned fabrication flaws in the new weld and HAZ of base materials. Details of the licensee's UT procedure demonstrations on the RVCH penetrations weld repairs are described in Sections 7.1 and 7.2 of Attachment 1 to the licensee's September 11, 2015, submittal.

"Triple point" anomaly evaluation

The licensee stated that an artifact of ambient temperature temper bead welding is an anomaly in the weld, known as the "triple point" anomaly, where three materials intersect (i.e., the Alloy 52 weld metal, the RVCH ferritic low alloy steel base metal, and the remnant of original Alloy 600 nozzle or the Alloy 690 replacement nozzle). The "triple point" anomaly and its location is shown in Figure A-2 of Attachment 1 to the licensee's September 11, 2015, submittal for the CRDM and RVLIS nozzles and Figure A-11 for the CETC nozzle. Due to nozzle geometry and repair configuration, the CETC nozzle repair weld contains two "triple point" anomalies (i.e., an upper "triple point" anomaly and a lower "triple point" anomaly) and the CRDM and RVLIS nozzles have one "triple point" anomaly. The "triple point" anomaly is assumed to exist and consists of an irregularly shaped very small void. Mockup testing has verified both the existence of the "triple point" anomaly and the anomaly's depth and length. The anomaly's depth has been verified not to exceed 0.10 inch and its length may extend around the entire bore circumference at the "triple point" location.

The licensee stated that it performed a flaw analysis in accordance with Section XI of the ASME Code to provide justification for operating with an anomaly or a crack like flaw in the new weld at the "triple point" location. In the analysis, the licensee has postulated an initial planar flaw with depth of 0.10 inch located at the "triple point" location and considered the most susceptible material for propagation. The postulated initial flaw at the "triple point" location could be oriented such that there are two possible flaw propagation paths:

(1) A flaw propagation path that could extend across the nozzle's wall thickness from the OD surface to the ID surface. This path is determined to be the shortest path through the new weld material.

    In this path, the licensee postulated two planar flaws. A continuous 360-degree circumferentially oriented flaw that could lie in a plane normal to the axial stresses. A semicircular axially oriented flaw that could lie in a plane normal to the circumferential stresses. Both planar flaws would propagate toward the ID surface of nozzle.

(2) A flaw propagation path that could extend down the outside surface of the repair weld between the weld and the RVCH LAS interface.

    In this path, the licensee postulated one planar flaw. A cylindrically oriented flaw that could lie along the interface between the weld and the RVCH LAS and subject to the radial stresses with respect to the nozzle. This flaw may propagate through either the new weld material or the RVCH ferritic LAS base material.

In the first flaw propagation path, the licensee stated that it has postulated two cracks: a circumferential flaw and an axial flaw at the OD surface of the new weld would both propagate in the horizontal direction toward the ID surface of the new weld. The cylindrically oriented flaws along the interface between the weld and RVCH would propagate in vertical direction between the two components. For both of the propagation paths, the licensee assumed the worst-case flaws and the most susceptible material for propagation. The linear elastic fracture mechanics (LEFM) and limit load analysis are used. Crack growth for each flaw is calculated due to all transients. The growth of each postulated flaw is calculated until the end of service lifetime of the IDTB weld repair (40 years). The criteria of IWB-3612 and IWB-3642 are used to assess acceptability of the postulated axial and circumferential flaws in the new weld to remain in service for the duration of the service lifetime of the IDTB weld repair. The licensee stated that acceptability of the postulated cylindrical flaw in the new weld is assessed against criteria in NB-3227.2 because there is no limit load solution in the ASME Code, Section XI, for such a flaw. Details of the licensee's fracture mechanics analysis for the "triple point" anomaly are provided in Attachments 1 and 3 to the licensee's September 11, 2015, submittal. The licensee's flaw analysis showed that the "triple point" weld anomaly is acceptable for a 40 year design life of the IDTB weld repair.

Evaluation of as-left flaws in the J-groove weld

The licensee stated that because there are no qualified UT exams to characterize flaws in the original J-groove Alloy 82/182 attachment weld in accordance with IWB-3600, it is assumed that the original J-groove weld contains flaws. The licensee performed a flaw analysis of the original J-groove weld using a worst-case postulated flaw. It is postulated that the entire J-groove weld metal including buttering material are cracked. It is further postulated that the dominant hoop stresses in the J-groove weld would create a situation where the preferential direction for cracking would be radial. A radial crack in the J-groove weld metal would propagate by the PWSCC through the weld and buttering to the interface with the RVCH LAS base material. Any growth of the postulated "as-left" flaw into the low alloy steel would be by fatigue crack growth under cyclic loading conditions. A combination of LEFM analysis and elastic-plastic fracture mechanics (EPFM) analysis is utilized. The licensee calculated the fatigue crack growth for cyclic loading conditions using operational stresses from pressure and thermal loads and crack growth rates from Article A-4300 of Appendix A to the ASME Code, Section XI for ferritic material in the primary water environment. The EPFM analysis is performed using a J-integral/tearing modulus (J-T) diagram to evaluate flaw stability under ductile tearing. Additionally, the crack driving force (applied J-integral) is checked against the lower bound J-R curve from Regulatory Guide 1.161 (ADAMS Accession No. ML003740038). The results of this evaluation show that a postulated worst-case as-left flaw in the original J- groove weld is acceptable for 33 EFPY remaining life of the plant. Details of the licensee's fracture mechanics evaluation are provided in Attachments 1 and 5 to the licensee's September 11, 2015, submittal.

Debris from remnant of J-groove weld

The licensee stated that it has considered the potential for debris from a cracking of a remnant of Alloy 82/182 J-groove weld metal. Radial cracks were postulated to occur in the J-groove weld due to the dominance of hoop stresses. The possibility of occurrence of transverse cracks that could intersect the radial cracks is considered remote because there are no forces that could drive a transverse crack. The radial cracks would relieve the potential transverse crack driving forces. There are also no known service conditions that could drive radial cracks and transverse cracks to intersect to produce a loose part. Therefore, the licensee determines that the potential for flaws in the J-groove weld to create debris would be low.

General corrosion of low alloy steel

As a result of the IDTB nozzle repair, a portion of the RVCH LAS base metal between the IDTB (new) weld and the remnant of the J-groove weld is exposed to primary coolant. The licensee evaluated potential corrosion of the RVCH LAS wetted surface (i.e., the exposed RVCH LAS base metal in the area between the IDTB weld and the J-groove weld) due to galvanic corrosion, hydrogen embrittlement, stress corrosion cracking, and crevice corrosion.

- The licensee determined that the galvanic difference among the RVCH LAS, Alloy 600, Alloy 690, the weld metals, and stainless steel vessel head cladding is not significant enough to consider galvanic corrosion as a strong contributor to the overall boric acid corrosion process.

- The licensee determined that the average hydrogen concentration in the RVCH is less than the maximum hydrogen concentrations for hydrogen embrittlement.

- From review of the light-water reactor operating experience related to LAS being exposed to the reactor coolant, the licensee determined that there are no known occurrences of stress corrosion cracking of LAS reactor vessel material in which the depth of the crack was of significant concern.

- The licensee determined that crevice corrosion is not expected to be an issue due to the open geometry of the final repair configuration. The final repair configuration for CETC will create crevice conditions between the LAS in the RVCH and portions of the new Alloy 690 nozzle. However, crevice corrosion is not expected to be of a concern for this repaired configuration because any corrosion deposits will likely plug the crevice path causing corrosion in the crevice to cease.

The licensee stated that it estimated the general corrosion rate to be 0.0036 inch per year, which has negligible impact on the RVCH and is acceptable for 40 years following an IDTB weld repair.

Therefore, the licensee stated that the repairs installed in accordance with provisions of relief requests I3R-16 and I3R-28 shall remain in place for 33 EFPY or until the RVCH is replaced, whichever occurs first.

3.8 EVALUATION

The NRC staff has evaluated I3R-16 and I3R-28 pursuant to 10 CFR 50.55a(z)(1). The NRC staff focused on whether the proposed alternative provides an acceptable level of quality and safety. In evaluating the technical sufficiency of the licensee's proposed alternative, the NRC staff considered the following aspects of the licensee's basis: (1) Evaluation of the IDTB weld repair technique; (2) Evaluation of rotary peening; (3) Evaluation of alternative examinations and coverage; (4) Evaluation of leaving potential flaws in service; (5) Evaluation of LAS corrosion; and (6) Evaluation of dislodged debris from cracking.

Evaluation of the IDTB weld repair technique

In reviewing the license's repair process, the NRC staff notes that the lower portion of each original penetration nozzle will be machined and removed to an elevation above the original J-groove attachment weld. This eliminates portions of the original nozzle and the J-groove weld that may contain unacceptable flaws. The proposed repair is contingent on discovery of an unacceptable flaw in the RVCH penetration CRDM, RVLIS, and CETC nozzles and their associated J-groove attachment welds. Repair design specific to the CRDM, RVLIS, and CETC nozzles is described by the licensee as follows:

- For repair of the CRDM or RVLIS nozzles, the lower portion of the original nozzle is removed; the remaining upper portion of the original nozzle is welded (Alloy 52) to the RVCH by the IDTB welding technique.

- For repair of the CETC nozzles, the lower portion of the original nozzle is removed and replaced with a new nozzle (Alloy 690); the new nozzle and the remaining upper portion of the original nozzle is welded (Alloy 52) to the RVCH by the IDTB welding technique.

The new weld (Alloy 52) installed by the IDTB welding technique establishes a new pressure boundary above the original J-groove weld. Steps involved in the repair procedure are summarized as follows:

- Removal of thermal sleeve assembly, as applicable.
- Roll expansion of nozzle above J-groove weld to prevent nozzle movement.
- Machining and removal of nozzle to an elevation above the J-groove weld – Machining operation to prepare area for IDTB welding – Nondestructive examination (NDE) of machined area.
- Performing IDTB welding.
- Machining or grinding to prepare weld surface – NDE of new weld, HAZ, and roll expansion area.
- Performing rotary peening – NDE of new weld, HAZ, and roll expansion area
- Installation of thermal sleeve assembly, as applicable.

In reviewing the license's welding process, the NRC staff notes that the IDTB welding is performed using the ambient temperature machine GTAW process in accordance with ASME Code Case N-638-4 and the conditions specified in RG 1.147, Revision 17. Utilizing the GTAW process to install IDTB welds does not need preheat treatment and PWHT of LAS. The licensee's welding procedure is qualified in accordance with N-638-4 and the ASME Code, Section XI. The licensee has used a heat flow calculation to determine the interpass temperature instead of measuring the interpass temperature by direct methods during welding (e.g., thermocouples). The heat flow calculation is used because the licensee determined that the internal bore welding creates a physical constraint and limits access to the weldment area. From the heat flow calculation, it is estimated the increase in interpass temperature from the heat flow calculation to be 183.6 degree Fahrenheit (°F) over the course of the entire welding process. The NRC staff determines that the licensee's estimated increase in interpass temperature is less than 350 °F, thus, meets N-638-4 and the conditions in RG 1.147, Revision 17. Furthermore, the licensee has successfully performed the Charpy V-notch impact tests to determine the impact properties of metals without a temperature adjustment, which meets N-638-4. Therefore, the NRC staff finds that the licensee's repair technique is acceptable because (a) the welding will be performed in accordance with ASME Code Case N-638-4 and (b) all the conditions in RG 1.147, Revision 17, for use of this ASME Code case will be met.

Evaluation of rotary peening

The licensee's proposed alternative involves performing rotary peening on the final weld layer. The NRC staff notes paragraph 1(g) of ASME Code Case N-638-4 states that peening may be used except on the initial and final layers. The restriction most likely has originated from the ASME Code, Section XI, IWA-4621, which contains the general requirements for the temper bead welding of similar materials and states that peening may be used except on the initial and final weld layers. The ASME Code, Section III, contains similar language in NB-4422, which states, "Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, or on the final layer unless the weld is postweld heat treated."

The NRC staff also notes that the peening restrictions referenced in ASME Code Case N-638-4, IWA-4621, and NB-4622, although not specifically stated, are only intended to be used when performing peening to minimize distortion. This form of peening involves the application of manual or pneumatic hammer blows to the weld that results in plastic flow of the weld metal and severe deformation of the peened surface. The weld metal is spread laterally by peening, thus counteracting the inward pull of each weld bead as it cools. This process of counteracting the inward pull of weld passes can be used to minimize and/or control distortion. Severe distortion can lead to weld metal cracking. Peening for the purpose of controlling distortion can result in embrittlement as a result of a substantial amount of cold-work applied to a deposited weld metal layer. However, this adverse condition is eliminated by the subsequent layer of weld metal that is deposited over the peened area. This provides the basis for not permitting peening of the final weld surface unless the weld receives a PWHT. Furthermore, the root pass, or first weld layer, of a welded joint is relatively thin, and heavy deformation from peening of the first layer can result in cracking. This also provides the basis for the prohibition of peening on the first weld layer.

Therefore, based on the above, the NRC staff finds that the licensee's use of rotary peening is not intended to control distortion but is to impart a uniform compressive stress layer on the final weld surface which is in contact with the reactor coolant. Imparting a compressive stress layer on the final weld surface can assist in the mitigation of PWSCC by reducing or eliminating surface tensile stresses. Tensile stress, or the tensile weld residual stress in particular, is one of the key components to PWSCC initiation and growth.

In reviewing the licensee's proposed examination following peening, the NRC staff notes that the remediated or peened surface on the ID of the nozzle (i.e., 3.72 inches minimum) will be subjected to the PT to ensure the remediated surface is free of cracks. The licensee has stated that the ASME Code Case N-729-1 required ISI and frequency of inspection will not be affected by the proposed peening and no credit is requested. Therefore, the NRC staff finds that the licensee's proposed peening is acceptable because this peening provides the stress improvement of metal surface and significantly relieves the surface tensile stresses and the primary mechanical driving force for the PWSCC, and increases assurance of the structural integrity of the repaired reactor pressure vessel head penetration nozzles.

Evaluation of alternative examinations and coverage

The NRC staff notes that due to joint configuration of the conventional partial penetration weld, the bases for the ASME Code required progressive surface examination have been: (a) the potential cold cracking, should it occur during welding, would be detected by the PT; and (b) the volumetric examination has been ineffective in detecting cracks in the weld. However, the licensee has demonstrated in mockup testing that the subject IDTB repair welds have joint designs or configurations that are suitable for the UT. Furthermore, the IDTB repair welds installed by the GTWA process at ambient temperature is less susceptible to cold cracking. The extent of the volume and area to be examined by the UT and PT are shown in Figure A-4, for the CRDM and RVLIS, and Figure A-12, for the CETC in the licensee's September 11, 2015, submittal. The examination coverage is consistent with ASME Code Case N-729-1. Therefore, the NRC staff finds the alternative examinations following completion of repair weld by the UT and PT are acceptable because this examination will provide reasonable assurance that the IDTB repair welds are free of both surface-connected and subsurface fabrication flaws.

From review of Section 5.1 and the sketches in Attachment 1 to the licensee's September 11, 2015, submittal, the NRC staff verified that the licensee obtained the maximum coverage achievable (i.e., percentage of the required examination volume covered by the UT using applicable ultrasonic modes of propagation, probe angles, and scanning directions). The achievable coverage represents the aggregate coverage of the required UT performed (axial and circumferential scanning directions combined). The NRC staff verified that the weld taper transition geometry in the CRDM and RVLIS nozzles would limit achieving the full coverage of the examination volume. For the CRDM and RVLIS nozzles, the licensee has demonstrated that (a) all portions of required weld volume including the weld taper transition will receive at least single-direction UT coverage; (b) the aggregate coverage is expected to be greater than 80 percent, and (c) the actual coverage of the required examination volume will be calculated after the as-built dimensions of the new weld are known and the examination is performed. For the CETC nozzles, the licensee has demonstrated that essentially 100 percent coverage is achievable. For all nozzles, the volume extending to ¼ inch beneath the new weld into the LAS base material will also be volumetrically examined. Therefore, the NRC staff finds that the alternative volumetric examination is acceptable because any potential cracks or fabrication flaws in the repair weld and surrounding HAZ would be detected by the UT and the licensee would take appropriate corrective actions.

In reviewing the license's UT procedures demonstration and personnel qualification discussed in Section 7.0 of Attachment 1 to the licensee's September 11, 2015, submittal, the NRC staff finds that the licensee has used representative mockups containing certain fabrication or construction flaws for the IDTB repair weld technique and GTWA process. The mockups contained EDM notches at various depth to simulate the "triple point" cracks oriented in the axial and circumferential directions, and drilled flat bottom holes to simulate under bead cracking, lack of bond, and lack of fusion. Mockup testing is intended to demonstrate that the UT procedures and personnel are capable in detecting certain construction flaws specific to this welding. Therefore, the NRC staff finds that the licensee's UT procedures demonstration is adequate because the licensee has met ASME Code Case N-638-4 and the condition in RG 1.147, Revision 17.

Furthermore, the NRC staff finds that the proposed PT of the final layer of repair weld is acceptable because (a) the potential for cold cracking in LAS is considerably minimized by the IDTB repair weld technique that utilizes the ambient temperature machine GTAW process; and (b) the licensee has achieved 100 percent coverage of the Code Case N-729-1 required examination area.

Based on the above, the NRC staff finds that the alternative UT and PT will provided reasonable assurance of structural integrity of the CRDM, RVLIS, and CETC nozzles because both surface-connected flaw and/or subsurface flaw, should it occur during welding, will be detected prior to returning to service and the licensee will take appropriate correction actions.

Evaluation of leaving potential flaws in service

As part of technical basis to demonstrate assurance of RVCH structural integrity while operating with as-left flaws, the licensee preformed a plant specific flaw analysis in accordance with IWB-3600. The NRC staff's evaluation of the licensee's flaw analysis is discussed below.

The first flaw analysis discussed below is for the "triple point" anomaly in the new weld. Inherent to the ambient temperature IDTB welding technique, an anomaly may be formed in the root of new partial penetration weld at the "triple point" location during welding. The "triple point" location is the junction of three dissimilar metals: the remnant of Alloy 600 nozzle or the replacement Alloy 690 nozzle, the RVCH LAS, and the new Alloy 52 weld. Mockup tests have verified that (a) the "triple point" anomaly is an irregularly shaped very small void that resembles a crack-like indication with depth not exceeding 0.1 inch and the length may extend 360 degrees around the entire bore circumference; and (b) the existence of the "triple point" anomaly is unavoidable under the best welding fabrication process. Since the "triple point" anomaly resembles a crack, it is unacceptable regardless of size in accordance with NB-5331(b). Therefore, the NRC staff determines that a plant specific flaw analysis in accordance with IWB-3600 is required to justify operating with a 0.1 inch deep flaw in the new weld.

The second flaw analysis discussed below is for a potential flaw left in the remnant of the original partial penetration J-groove weld. Any flaw that may exist in the remnant of the original J-groove welds shall be fully characterized to establish the dimensions in order to compare with the acceptance standards of IWB-3500. The current UT techniques are not capable and qualified to characterize the flaws in the original J-groove weld with reasonable accuracy and confidence. Therefore, the NRC staff determines that a plant-specific flaw analysis in accordance with IWB-3600 is required to justify operating with a potential as-left flaw in the remnant of the original J-groove weld.

In its review, the NRC staff has assessed whether the licensee has used appropriate ASME Code analytical procedures and criteria, industry guidance, assumptions, and inputs as applicable to the "triple point" weld anomaly or the as-left flaw in the original J-groove weld during performance of plant specific flaw analysis.

1) Flaw analysis of new weld

Inherent to the ambient temperature IDTB welding technique, a "triple point" anomaly may be formed in the root of new partial penetration weld during welding and its existence is unavoidable under the best welding fabrication process. The NRC staff's review of the licensee's plant specific flaw analysis of the "triple point" anomaly is as follows.

- The NRC staff notes that the licensee's flaw analysis is limited to only the CETC nozzles. The licensee has determined that the flaw analysis for CETC nozzles bounds the CRDM and RVLIS nozzles, because (a) the RVCH design and load conditions are identical across all four units, (b) the CETC nozzles are located farther from the RVCH centerline and experience larger stresses due to greater hillside angle, (c) the CETC nozzles have the smaller nominal weld length fused to the RVCH base metal, and (d) the CETC nozzles contain a lower nozzle (Alloy 690) which imparts additional loading to the new weld. Therefore, the NRC staff finds that the licensee's flaw analysis of the CETC nozzle with the largest hillside angle is adequate and bounding.

- In reviewing the license's flaw characterization, the NRC staff notes that licensee postulated three planar flaws within the "triple point" anomaly and two propagation paths to simulate the worst-case flaws and directions for propagation. The postulated flaws include a circumferentially oriented planar flaw, an axially oriented planar flaw, and a cylindrically oriented planar flaw located in the new weld at the "triple point" location on the nozzle OD surface.

    - The circumferentially oriented flaw is postulated as a continuous OD surface flaw extending 360 degrees around the nozzle's circumference and subjected to the axial stresses. The axially oriented flaw is postulated as semicircular OD surface flaw and subjected to the circumferential stresses. Both circumferential and axial flaws propagate from the nozzle's OD toward the ID surface through the new weld (horizontal path). This is the shortest path for the postulated circumferential and axial flaws to propagate. To ensure another potential path through the HAZ between the new weld and the Alloy 600 nozzle material is bounded, the licensee used the Alloy 600 nozzle material properties.

    - A cylindrically oriented flaw is postulated to lie along the interface between the new weld and the RVCH LAS base material and subjected to the radial stresses with respect to the nozzle. The cylindrical flaw propagates down the outside surface of the repair weld between the new weld and the RVCH LAS interface (vertical path).

Based on the above, the NRC staff finds that the licensee's postulated flaw orientations are appropriate representations of crack-like defects that may exist in the "triple point" anomaly because each postulated flaw lies on a plane perpendicular to higher stresses. Furthermore, the paths identified for the flaws to propagate are the shortest and are in the most susceptible materials.

- In its review, the NRC staff notes the licensee has followed the evaluation procedures and the flaw acceptance criteria of the ASME Code (e.g., IWB-3641, Appendix A, Appendix C, IWB-3612, and IWB-3642 of Section XI). The licensee has conducted the LEFM and the limit load evaluation to address non-ductile and ductile materials behavior.

- For a flaw growth calculation due to fatigue, the licensee used the ASME Code, Appendix A, and NUREG/CR-6907 "Crack Growth Rates of Nickel Alloy Welds in a PWR Environment" fatigue crack growth model. The fatigue crack growth rates for the RVCH LAS material exposed to air and reactor coolant environments are obtained from the ASME Code, Section XI, Appendix A. The fatigue crack growth rates for the new weld and the nozzle materials exposed to air and reactor coolant environments are obtained from NUREG/CR-6907. The NRC staff determines that the licensee used appropriate analytical procedures and fatigue crack growth rates because the new weld, RVCH LAS, and new replacement nozzle may be exposed to air and reactor coolant environments.

- In its review, the NRC staff notes that the stress intensity factors for the postulated axial and circumferential flaws were determined from the weight function solutions. The stress intensity factors for the cylindrical flaw were determined from the flat plate solutions discussed in Appendix A of Section XI of the ASME Code. The NRC staff finds that the licensee's approach is acceptable because the above solutions are routinely used for this application and are considered adequate. The licensee utilized a finite element analysis to obtain operating stresses. The analysis considered stresses from all plant transients for normal, upset, and emergency conditions (service levels A, B, and C). Since the nozzles are encased in the RVCH, the bending loads and external loads are transmitted to the head and their effect on the nozzles are insignificant. The residual stresses from machining and IDTB welding are calculated and linearly added to the applied stresses for all transients. The NRC staff finds that the licensee has considered the necessary applied stresses for the IDTB repair configuration to determine crack driving forces, therefore, they are acceptable.

- The NRC staff notes for every postulated initial flaw size of 0.1 inch at the "triple point" location, the licensee has conducted flaw growth analysis and determined the final flaw size after 40 years of plant life. Once the licensee has determined the final flaw size, each flaw is assessed to determine the safety margins and compliance with the required margins in the ASME Code. The licensee demonstrated that the calculated safety margins are greater than the required margins of the ASME Code (IWB-3612 and Appendix C).

Based on the above evaluation, the NRC staff finds the licensee adequately demonstrated by the analytical methods in accordance with criteria of the ASME Code, Section XI, IWB-3600, that the triple point weld anomaly remains stable for the intended service life of the repair and operating with a relevant condition at weld triple point is justified.

2) Flaw analysis of the remnant of the original J-groove weld

The NRC staff notes that the currently available volumetric inspection techniques are unable to characterize the flaws that may exist in the original J-groove weld of RVCH nozzle penetration. It is also noted that the original J-groove weld is no longer considered the pressure boundary. However, a potential crack in the original J-groove weld may grow into LAS of RVCH base metal. The NRC staff's review of the licensee's plant specific flaw analysis of the J-groove weld is as follows.

- For this analysis, the licensee has assumed a worst-case crack in the J-groove weld. The entire Alloy 82/182 J-groove weld and butter are assumed to be cracked by the PWSCC and a fatigue crack is initiated in the LAS head and the interface of Alloy 82/182 and LAS. A three dimensional finite element analysis (FEA) model of the penetration nozzles, RVCH, and associated components is created. The stress analysis has revealed the nozzle penetration location with the most limiting stresses (i.e., the nozzle with the largest hillside angle and the nozzle's uphill side experience the highest stresses). Since the hoop stresses are also determined to be the dominant stresses in the J-groove weld, the licensee has postulated the initial crack to be axially (or radially) oriented relative to the penetration bore. Furthermore, because the CETC nozzle location has the largest hillside angle and experience the highest stresses, the licensee has determined that the flaw analysis of only the CETC nozzle is adequate and bounding. Therefore, the NRC staff determines that the licensee's assumptions are acceptable because the worst-case (or most limiting) conditions are assessed.

- For this analysis, the licensee has utilized combinations of the LEFM, EPFM, and limit load principles and the acceptable criteria in IWB-3610 based on Appendix A of Section XI and IWB-3612. The flaw calculations were based on the stress intensity factor to demonstrate that the postulated worst-case crack in the as-left J-groove weld at the worst-case penetration location is acceptable for the remaining life of plant for all transient loading conditions. The licensee has evaluated fatigue crack growth of the worst-case crack for the estimated 33 EFPY remaining design life of the plant.

- To calculate the stress intensity factors or crack driving forces at the J-groove weld crack, the licensee has utilized the FEA because there are no closed-form solutions available. The stress intensity factors are calculated using applied loads which includes the residual stresses and operational stresses from the applicable transient loading conditions. The residual stresses are obtained from a separate three dimensional FEA model. The calculated stresses are directly mapped to the crack face in the FEA crack model. Utilizing the stress intensity factors from FEA, the fatigue crack growth is calculated from the fatigue crack growth rate model given in Article A-4300 of ASME Code, Section XI. Therefore, the NRC staff finds that licensee flaw evaluation is consistent with the IWB-3600 and Appendix A of the ASME Code, Section XI.

- The results of the licensee flaw evaluation showed that the calculated safety margins for the worst-case flaw postulated in the J-groove weld and subjected to highest stresses are greater than the ASME Code required margins. Therefore, the NRC staff finds that the RVCH nozzle repair design configuration is acceptable for the estimated 33 EFPH remaining design life of the plant following an IDTB weld repair.

Based on the above evaluation, the NRC staff finds the licensee has adequately demonstrated by the analytical methods in accordance with criteria of the ASME Code, Section XI, and IWB-3600 that the J-groove partial penetration weld flaw remains stable for the intended service life of the repair and operating with a relevant condition at J-groove weld is justified.

Evaluation of PWSCC

As a result of the IDTB weld repairs, the remnant of Alloy 600 penetration nozzle left in service could be possibly affected by the PWSCC due to exposure to the reactor coolant. The licensee performed a plant specific PWSCC flaw evaluation of the remediated surfaces and determined that the estimated minimum time for a PWSCC flaw to reach the ASME Code allowable size of 75 percent of the original nozzle wall thickness is over 100 EFPY.

Therefore, the NRC staff finds that the licensee has adequately demonstrated that a significant margin exists for a potential PWSCC flaw in the remnant of the original nozzle to reach the ASME Code allowable size during the design life the RVCH penetration nozzle IDTB weld repairs.

Remnant of J-groove weld dislodged debris evaluation

If the remnant J-groove partial penetration weld cracks, the debris (loose parts) may dislodge from the cracked weld and fall into the reactor core region potentially affecting the safe operation of the plant. This scenario could occur if the radial and transverse cracks intersect. The NRC staff notes that the licensee has evaluated the potential for fragments dislodged if the remnant J-groove partial penetration weld would crack radially and transversely. The licensee determined that the possibility of occurrence of transverse cracks that could intersect the radial cracks is remote because there are no forces that would drive a transverse crack. The potential for existence of radial cracks due to the high hoop stress have been evaluated. These radial cracks would relieve the potential transverse crack driving forces. Hence, it is unlikely that a series of transverse cracks could intersect a series of radial cracks resulting in any fragments becoming dislodged from the remnant J-groove weld. Furthermore, industry operating experience has not shown any occurrence of loose part scenario in the RVCH penetration nozzle IDTB weld repairs.

Therefore, the NRC staff finds that the licensee has adequately demonstrated that the possibility of potential debris from the remnant of the J-groove weld to become dislodged and affect the safe operation of the plant is insignificant.

General corrosion evaluation of LAS penetration bore region

As a result of the IDTB nozzle repair, a portion of the RVCH LAS base metal between the IDTB (new) weld and the remnant of the J-groove weld is exposed to primary coolant. The licensee has evaluated potential corrosion of the RVCH LAS wetted surface (i.e., the exposed RVCH LAS base metal in the area between the IDTB weld and the J-groove weld) due to galvanic corrosion, hydrogen embrittlement, stress corrosion cracking, and crevice corrosion. The licensee estimated the general corrosion rate to be 0.0036 inch per year at the exposed locations based on a 90 percent capacity factor. The capacity factor is estimated to be equivalent to 18 months of operation followed by 2 months shutdown which is the most limiting. The corrosion evaluation determined that the total surface (radial) corrosion in the penetration bore for 40 years would be 0.144 inch. Based on a 40-year design life of the RVCH penetration nozzle IDTB weld repairs, the anticipated material loss of RVCH LAS base metal is insignificant.

Therefore, the NRC staff finds that the licensee has adequately demonstrated that the corrosion of the RVCH LAS penetration bore of the repaired nozzles is insignificant. Therefore, the RVCH nozzle penetration IDTB weld repairs will not affect the structural integrity of the reactor vessel penetration bore of the repaired nozzles.

Evaluation of design life of repair

On the basis of the above evaluation, the NRC staff finds that the licensee has performed flaw analyses of the triple point anomaly in the new weld, the worst-case "as-left" flaw in the remnant of original J-groove weld, and the PWSCC evaluation of remaining portion of Alloy 600 nozzle to estimate an acceptable design life of the repair. The NRC staff finds the licensee's proposed life expectancy of 33 EFPY for the repair design acceptable because it is based on the most limiting life predicted amongst all flaw analyses.

4.0 CONCLUSION

Based on the above evaluation, the NRC staff finds that the proposed alternative provides an acceptable level of quality and safety. Accordingly, the NRC staff concludes that the licensee has adequately addressed all of the regulatory requirements set forth in 10 CFR 50.55a(z)(1). Therefore, the NRC staff authorizes the use of the proposed alternative in I3R-16 for the remainder of the third 10-year ISI interval of Braidwood, Unit 1, which commenced on July 29, 2008, and is scheduled to end on July 28, 2018; and Braidwood, Unit 2, which commenced on October 17, 2008, and is scheduled to end on October 16, 2018. The NRC staff also authorizes the use of the proposed alternative in I3R-28 for remainder of the third 10-year ISI interval of Byron, Unit Nos. 1 and 2, which commenced on July 16, 2006, and is scheduled to end on July 15, 2016. The repaired RVCH penetration nozzles that are the subject of I3R-16 and I3R-28 shall remain in service for the design life of the repair or until the RVCH is replaced, whichever occurs first.

All other ASME Code, Section XI, requirements for which relief was not specifically requested and authorized herein by the NRC staff remain applicable, including the third-party review by the Authorized Nuclear Inservice Inspector.

Reviewer: A Rezai
Date: April 27, 2016

Should you have any questions, please contact Joel S. Wiebe, Senior Project Manager, at 301-415-6606 or via email at joel.wiebe@nrc.gov.

Sincerely,

/RA/

Justin C. Poole, Acting Chief
Plant Licensing Branch III-2
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

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