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

June 5, 2019

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: BRAIDWOOD STATION, UNITS 1 AND 2 – RELIEF FROM THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS CODE (EPID L-2018-LLR-0130)

Dear Mr. Hanson:

By letter dated October 4, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18277A149), Exelon Generation Company, LLC (Exelon, the licensee), submitted relief request (RR) I4R-09, which proposes an alternative to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) regarding requirements for the repair and examination of reactor pressure vessel head penetration nozzles (RPVHPNs) at Braidwood Station (Braidwood), Units Nos. 1 and 2, for the fourth inservice inspection (ISI) interval.

Specifically, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.55a(z)(1), the licensee requested to use the proposed alternative on the basis that it provides an acceptable level of quality and safety.

The U.S. Nuclear Regulatory Commission (NRC or Commission) staff has reviewed the subject request and concludes, as set forth in the enclosed safety evaluation, that Exelon has adequately addressed all of the regulatory requirements in 10 CFR 50.55a(z)(1). Therefore, the NRC authorizes the use of RR I4R-09 at Braidwood Station, Units 1 and 2, for the fourth ISI interval, currently scheduled to end on July 28, 2028, and October 16, 2028, respectively.

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

If you have any questions, please contact the Project Manager, Joel Wiebe at 301-415-6606 or via e-mail at Joel.Wiebe@nrc.gov.

Sincerely,

Lisa M. Regner, Acting Chief
Plant Licensing Branch III
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. 50-456 and 50-457

Enclosure:
Safety Evaluation

cc: Listserv

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELIEF REQUEST I4R-09 REGARDING REPAIR OF REACTOR VESSEL HEAD PENETRATION NOZZLES USING INSIDE DIAMETER TEMPER BEAD WELD REPAIR

EXELON GENERATION COMPANY, LLC

BRAIDWOOD STATION, UNITS 1 AND 2

DOCKET NOS. 50-456 AND 50-457

1.0 INTRODUCTION

By letter dated October 4, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18277A149), Exelon Generation Company, LLC (Exelon, the licensee), submitted relief request (RR) I4R-09, which proposes an alternative to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) regarding requirements for the repair and examination of reactor pressure vessel head penetration nozzles (RPVHPNs) at Braidwood Station (Braidwood), Units Nos. 1 and 2, for the fourth inservice inspection (ISI) interval.

Specifically, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(z)(1), the licensee requested to use the proposed alternative on the basis that the alternative provides an acceptable level of quality and safety.

2.0 REGULATORY EVALUATION

Adherence to Section XI of the ASME Code is mandated by 10 CFR 50.55a(g)(4), which states, in part, that ASME Code Class 1, 2, and 3 components will meet the requirements, except the design and access provisions and the pre-service examination requirements, set forth in the ASME Code, Section XI.

Pursuant to 10 CFR 50.55a(g)(6)(ii), the U.S. Nuclear Regulatory Commission (NRC) may require the licensee to follow an augmented ISI program for systems and components for which the NRC deems that added assurance of structural reliability is necessary.

As stated in 10 CFR 50.55a(g)(6)(ii)(D), *Reactor vessel head inspections,* licensees of pressurized-water reactors (PWR) are required to augment their ISI of the reactor vessel head (RVH) with ASME Code Case N-729-4, "Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds, Section XI, Division 1," with conditions.

As stated, in part, in 10 CFR 50.55a(z), alternatives to the requirements of paragraph (g) of 10 CFR 50.55a may be used when authorized by the NRC, if the licensee demonstrates that: (1) the proposed alternative provides an acceptable level of quality and safety, or (2) compliance with the specified requirements 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 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 Relief Request I4R-09

3.1.1 ASME Code Components Affected

The RPVHPNs and their associated partial penetration J-groove attachment welds are ASME Code, Section XI, Class 1, components. 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-729-4, "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 (4) of 10 CFR 50.55a. In accordance with ASME Code Case N-729-4 (Table 1), the RPVHPNs and their associated attachment welds are classified as Item No. 4.20. Each of the Braidwood units have 78 RPVHPNs numbered P-1 through P-78. The RPVHPN No. P-69 for Unit 1 was previously repaired in accordance with RR I3R-09 during the previous inspection interval and was approved for use by NRC letter dated March 29, 2012 (ADAMS Accession No.ML120790647). The RPVHPNs are 4-inch nominal outside diameter and are fabricated with Inconel Alloy 600, SB-167.

3.1.2. Applicable Code Edition and Addenda

The applicable Code of Record for the fourth 10-year ISI interval for Braidwood is the 2013 Edition of the ASME Code, Section XI. Additionally, examinations of the RPVHPNs are performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of Code Case N-729-4, with conditions.

The licensee stated that the applicable Code of Construction (hereafter known as Construction Code) for Braidwood is the 1971 Edition through Summer 1973 Addenda of the ASME Code, Section III.

3.1.3. Applicable Code Requirement

The applicable ASME Code requirements for the removal or mitigation of defects from which relief is requested are as follows:

ASME Code, Section III, 1971 Edition, including through Summer 1973 Addenda

- Table NB-4622.1-1 requires post weld heat treatment (PWHT) for P3 materials.

ASME Code. Section III, 2001 Edition, including Addenda through 2003

- NB-5245 requires progressive surface examination of partial penetration welds for butt-welded nozzles or branch connections.

- NB-5331 (b) requires that indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

ASME Code, Section XI, 2013 Edition

- IWA-3300 specifies requirements for characterization of flaws detected by inservice examination.

- IWA-4221 (b) states:

  An item to be used for repair/replacement activities shall meet the Construction Code specified in accordance with IWA-4221(b)(1), (2) or (3).

- IWA-4221 (c) states in part:

  As an alternative to (b) above, the item may meet all or portions of the requirements of different Editions and Addenda of the Construction Code, or Section III provided the requirements of IWA-4222 through IWA-4226, as applicable, are met.

- IWA-4224.1 states:

  Identical material Procured to a Later Edition or Addenda of the Construction Code, Section III or Material Specification.

  (a) Materials, including welding and brazing materials may meet the requirements of later dates.

  (b) Differences in the specified material tensile and yield strength shall be compared.

- IWA-4400 provides welding, brazing, metal removal, fabrication, and installation requirements related to repair/replacement activities.

- IW A-4411 states:

  Welding, brazing, fabrication, and installation shall be performed in accordance with the Owner's Requirements and, except as modified below, in accordance with the Construction Code of the item.

- IWA-4411 (a) states in part:

  Later editions and addenda of the Construction Code, or a later different Construction Code, either in its entirety or portions thereof, and Code Cases may be used, provided the substitution is as listed in IWA-4221 (c). Filler metal requirements shall be reconciled, as required, in accordance with IWA-4224.

• IW A-4412 states:

Defect removal shall be accomplished in accordance with the requirements of IWA-4420.

• IWA-4421 (a) states:

Defect removal by mechanical processing shall be in accordance with IWA-4462.

• IW A-4462(b) states:

Where welding is to be performed, the cavity shall be ground smooth and clean with beveled sides and edges rounded such that the cavity is suitable for welding.

• IWA-4611.1 (a) states:

Defects shall be removed in accordance with IWA-4422.1. A defect is considered removed when it has been reduced to an acceptable size.

• IWB-3420 states:

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.

• IWB-3132.3 states:

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).

Code Case N-638-6, *Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique,* provides requirements for automatic or machine gas tungsten arc welding (GTAW) of Class 1 components without the use of preheat or post weld heat treatment.

• Paragraph 1 (g) states:

Peening may be used, except on the initial and final layers. The applicable requirements of the following ASME B&PV Construction Codes for the removal or mitigation of defects from which relief is not specifically requested are as follows:

Code Case N-729-4, *Alternative Examination Requirements for PWR Reactor Vessel Upper Heads with Nozzles Having Pressure-Retaining Partial-Penetration Welds,* Section XI, Division 1, Fig. 2, "Examination Volume for Nozzle Base Metal and Examination Area for Weld and Nozzle Base Metal," is applicable to the RPVHPNs.

Code Case N-749, *Alternative Acceptance Criteria for Flaws in Ferritic Steel Components Operating in the Upper Shelf Temperature Range, Section XI, Division 1.*

3.1.4 Reason for Request

The licensee submitted the RR as a contingency to support the required repair of indication(s) that may be discovered in upcoming outages during the fourth ISI interval. The licensee stated that if an indication requiring repair was detected during ultrasonic testing (UT) examination of the RPVHPNs, the affected RPVHPNs will be modified under this request.

The licensee stated that because of the risk of damage to the reactor vessel head material properties or dimensions, it is not feasible to apply the required post-weld heat treatment (PWHT) of the original Construction Code on the RPVHPNs. As an alternative to the requirements of the RVH Code of Construction, the licensee proposed to repair the RPVHPNs using an Inside Diameter Temper Bead (IDTB) welding method to restore the pressure boundary of the degraded nozzle penetration. The IDTB welding method is performed with a remotely operated weld tool using the machine GTAW process and the ambient temperature temper bead method with 50° F (degree Fahrenheit) minimum preheat temperature and no PWHT. The licensee will repair the degraded RPVHPNs in accordance with the 2013 Edition of ASME Code, Section XI, Code Case N-638-6, Code Case N-729-4, and the alternatives discussed in the submittal.

3.1.5 Proposed Alternative

In lieu of performing a repair/replacement of the degraded RPVHPNs in accordance with the ASME Code, Sections III and XI, the licensee proposed to repair the degraded RPVHPNs as discussed in the relief request and is summarized below. In addition, the licensee proposed to deviate from certain requirements of the ASME Code, Sections III and XI, Code Cases N-638-6 and N-729-4, as part of the repair of the RPVHPNs.

The repair is summarized as follows:

(1) Remove a lower portion of the existing thermal sleeve assembly at the applicable RPVHPNs to provide access for IDTB welding.

(2) Roll-expand the nozzle above the region to be modified/repaired to stabilize and prevent any movement when the lower part of the nozzle is separated from the attachment J-groove weld.

(3) Remove the lower nozzle by machining (and Core Exit thermocouple (CETC) nozzle guide at CETC nozzle locations) to an elevation above the J-groove weld to eliminate the portions of the nozzle which may contain the unacceptable indication(s). This machining operation also establishes the weld preparation area (refer to Figures A-1 and A-10 of the licensee's October 4, 2018, letter).

(4) Examine the machined area by liquid penetrant testing (PT) (refer to Figures A-3 and A-12 of the licensee's October 4, 2018, letter).

(5) Weld the remaining portion of the nozzle and replace CETC nozzle extension at the applicable penetration(s), to the RVH using primary water stress corrosion cracking

(PWSCC) resistant Alloy 52/52M/52MSS, hereinafter all referred to as Alloy 52, weld material (refer to Figures A-2 and A-11 of the licensee's October 4, 2018, letter).

(6) Machine the weld and nozzle to provide a surface suitable for nondestructive examination (NDE).

(7) Examine the weld and adjacent region using PT and UT (refer to Figures A-3 and A-12 of the licensee's October 4, 2018, letter).

(8) Rotary peen on the portion of the remaining nozzle most susceptible to PWSCC to impart compressive residual stresses on the nozzle surface.

(9) Examine the peened area by PT.

(10) Weld a new lower thermal sleeve assembly at the applicable penetration(s) and/or installation of a CETC nozzle guide at the CETC nozzle locations.

3.1.6 Basis for Use

Flaw Evaluations

Triple Point Anomaly Calculation

The ASME Code, Section III, 2001 Edition, including Addenda through 2003, NB-5331 (b), requires that indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

The licensee stated that an artifact of ambient temperature temper bead welding is an anomaly in the weld at the triple point. The triple point is the point in the repair weld where the low alloy steel RVH base material, the Alloy 600 nozzle, and the Alloy 52 weld intersect. This anomaly consists of an irregularly shaped very small void. The licensee's mock-up testing has verified that the anomalies are common and do not exceed 0.10-inch in length. The licensee assumed the anomaly to exist, for purposes of analysis, around the entire bore circumference at the triple point elevation. The licensee performed a fracture mechanics analysis for the design configuration to provide justification, in accordance with the ASME Code, Section XI, for operating with the postulated triple point anomaly. The licensee modeled the anomaly as a 0.10-inch deep crack-like defect, initiating at the triple point location, considering the most susceptible material for propagation. The licensee stated that the postulated flaws could be oriented within the anomaly such that there are two possible flaw propagation paths, as discussed below.

Path 1: Flaw propagation is assumed to cross the nozzle wall thickness from the outside surface to the inside surface of the nozzle. This is also the shortest path through the new Alloy 52 weld material. By using a fatigue crack growth rate twice that of the rate of Alloy 600 material, it is ensured that another potential path through the heat affected zone between the new weld and the Alloy 600 nozzle material is also bounded.

For completeness, the licensee postulated two types of flaws at the outside surface of the new IDTB weld. The licensee considered a 360-degree continuous circumferential flaw, lying in a horizontal plane, to be a conservative representation of crack-like defects that may exist in the weld triple point anomaly. This flaw is subjected to axial stresses in the nozzle. The licensee also considered an axially oriented semi-circular outside surface flaw because it would lie in a plane normal to the higher circumferential stresses. Both of these flaws would propagate toward the inside surface of the nozzle when subjected to high cyclic stresses in the nozzle penetration repair.

Path 2: Flaw propagation is assumed to extend down the outside surface of the repair weld between the new IDTB weld and the RVH.

The licensee postulated a cylindrically oriented flaw to lie along this interface subjected to radial stresses with respect to the nozzle. This flaw may propagate through either the new Alloy 52 weld material or the ferritic low alloy steel RVH base material.

The licensee reported that the results of the triple point analyses demonstrate that the 0.10-inch weld anomaly is acceptable for a 40-year design life of the nozzle modification considering the applicable transients and cycles. The licensee indicated that it has demonstrated sufficient design margins for all flaw propagation paths considered in the flaw evaluation. Flaw acceptance is based on criteria for limit load of the ASME Code, Section XI, IWB-3644. The licensee calculated fatigue crack growth along each flaw propagation path for the control rod drive mechanism (CRDM), reactor vessel level indication system (RVLIS) and CETC nozzles. The licensee stated that for the postulated axial and circumferential flaws in the Alloy 52 IDTB weld, the acceptance criteria of IWB-3642 which permits the use of the analytical procedures described in ASME Code, Section XI, Appendix C, will be used. For the CRDM, RVLIS, and CETC nozzle welds, the licensee performed the net section collapse analysis for the postulated circumferential flaw. The licensee explained that cross-sectional bending at the postulated flaw locations is insignificant due to the nozzle being encased in the vessel head penetration. The limit load failure is driven by applied membrane stresses and evaluated. The allowable bending stress is shown to be more than the applied bending stress. Also, the minimum limit load margins for postulated axial and cylindrical flaws are less than the required safety factor of 2.7, as specified in the ASME Code, Section XI, IWB-3644. For the cylindrical flaws, the licensee has shown that the applied shear stress at the remaining ligament is less than the allowable shear stress per the ASME Code, Section III, NB-3227.2.

The licensee prepared these evaluations in accordance with ASME Code, Section XI, and demonstrates for the intended service life of the modification that the fatigue crack growth is acceptable and the crack-like indications remain stable. This satisfies the ASME Code, Section XI, criteria but does not include considerations of stress corrosion cracking (SCC) such as PWSCC. The licensee explained that because the postulated crack-like defects at the top of the CRDM nozzle weld(s), RVLIS nozzle weld(s) and CETC nozzle weld(s) due to the weld anomaly are not exposed to the primary coolant and the air environment is benign for the materials at the triple point, the crack growth rates from PWSCC are not applicable. The licensee requested relief from the acceptance criteria specified in the ASME Code, Section III, NB-5331(b), to permit anomalies at the triple point region to remain in service.

Flaw Evaluation for J-Groove Weld

The ASME Code, Section XI, IWB-3600, assumes that cracks are fully characterized in order to compare the calculated parameters to the acceptable parameters addressed in IWB-3500. The licensee indicated that there are no qualified UT examination techniques for examining the original J-groove welds that attach nozzles to the RVH. The licensee stated that because it is impractical to characterize the flaw geometry that may exist in the J-groove weld, it assumed the remaining J-groove weld includes flaws extending through the entire Alloy 82/182 J-groove weld and buttering. The licensee further postulated that the dominant hoop stresses in the J-groove weld would cause the crack to grow radially. The licensee assumed that a radial crack in the

Alloy 82/182 weld would propagate by PWSCC, through the weld and buttering, to the interface with the low alloy steel RVH material. The licensee stated that any growth of the postulated "as-left" flaw into the low alloy steel would be by fatigue crack growth under cyclic loading conditions.

To calculate flaw growth into the RVH, the licensee applied cyclic loading conditions based on 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 a primary water environment. The licensee stated that the results show that, based on a combination of linear elastic fracture mechanics (LEFM) analysis and elastic-plastic fracture mechanics (EPFM) analysis of a postulated remaining flaw in the original Alloy 82/182 J- groove weld and buttering for the modified RPVHPNs is acceptable for the remaining life of the unit plus a 20-year life extension following an IDTB weld repair.

The licensee stated that although the postulated flaw did not satisfy ASME Code, Section XI, IWB-3612 for all transient loading conditions, the LEFM analysis: (a) determined that the uphill side of the RPVHPNs is the worst-case position for the postulated flaw, (b) calculated the final flaw size by fatigue crack growth, and (c) identified the controlling service conditions for evaluation by EPFM analysis.

The licensee determined the crack stress intensity factors for initial "as-left" flaws using 3-dimensional finite element analysis and applying both residual and operating stresses for each of the applicable transients. The licensee incremented the crack size based on the fatigue crack growth rate equations given in A-4300 of Appendix A to the ASME Code, Section XI, as modified by 10 CFR 50.55a. The licensee calculated the maximum flaw growth of the flaw in the J-groove weld into the RVH low alloy steel on the uphill side and on the downhill side to determine the remaining service life. The licensee stated that crack stress intensity factor, including pressure, thermal, and residual stress effects, for the final maximum flaw size using the acceptance criteria of IWB-3612 indicated insufficient available fracture toughness to provide the specified margins under all conditions.

Therefore, as an alternative, the licensee used EPFM to evaluate the final flaw sizes for all propagation paths. The licensee performed the EPFM analysis using a J-integral/tearing modulus (J-T) diagram to evaluate flaw stability under ductile tearing. Additionally, the licensee checked the crack driving force (applied J-integral) against the J-R curve from Regulatory Guide (RG) 1.161, "Evaluation of Reactor Pressure Vessels with Charpy Upper-Shelf Energy Less Than 50 Ft-Lb," (ADAMS Accession No. ML003740038) at a crack extension of 0.10 inch (J_{01}). The safety factors that are applied to the primary and secondary stresses in the EPFM analysis are tabulated below:

Operating Condition	Evaluation Method	Safety Factors*	
		Primary	Secondary
Normal/Upset	J/T based flaw stability	2.14	1.0
Normal/Upset	J0.1 limited flaw extension	1.5	1.0
Emergency/Faulted	J/T based flaw stability	1.2	1.0
Emergency/Faulted	J0.1 limited flaw extension	1.25	1.0

* EPFM safety factors from Code Case N-749 as modified by the NRC (ADAMS Accession No. ML14330A510).

Loose Parts Evaluation

The licensee considered the potential for debris from a cracking J-groove partial penetration weld. The licensee postulated radial cracks to occur in the weld due to the dominance of hoop stresses at this location. The licensee considered the occurrence of transverse cracks that could intersect the radial cracks is unlikely. The licensee stated that there are no forces that would drive a transverse crack. The radial cracks would relieve the potential transverse crack driving forces. The licensee concluded that there are no known service conditions that could drive radial cracks and transverse cracks to intersect to produce a loose part.

The licensee demonstrated that the postulated flaw in the remaining portion of the J-groove weld is acceptable for 33 years of remaining operation (based on a 60-year plant licensed life).

The licensee stated that successive examinations required by the ASME Code, Section XI, IWB-3132.3, will not be performed because analytical evaluation of the worst-case postulated flaw is performed to demonstrate acceptability. The licensee requested relief from flaw characterization specified in IWB-3420 and subsequent examination requirements specified in IWB-2420(b) and IWB-2420(c).

General Corrosion Evaluation

The licensee stated that the IDTB nozzle modification leaves a small portion of low alloy steel in the RVH exposed to primary coolant. The licensee performed an evaluation for the potential corrosion concerns at the RVH low alloy steel wetted surface. The licensee stated that galvanic corrosion, hydrogen embrittlement, SCC, and crevice corrosion are not expected to be a concern for the exposed low alloy steel base metal. However, general corrosion of the exposed low alloy steel base metal will occur in the area between the IDTB weld and the original J-groove weld. The licensee estimated the general corrosion rate to be 0.0036 inch/year. The licensee indicated that the corrosion of the exposed base metal has negligible impact on the RVH and is acceptable for 40 years from the time the modification is performed.

Rotary Peening

The licensee will perform rotary peening on the final layer to provide further assurance of the modified configuration being resistant to PWSCC. However, peening on the final layer of a temper bead weld is prohibited by ASME Code Case N-638-6, paragraph 1(g). The licensee stated that this prohibition is referring to the high cold-work peening that is traditionally used for configuration distortion control during welding. The licensee stated that this is not considered applicable to the rotary peening process, which is highly controlled, uniform, and only influences a shallow surface layer (approximately 20 mils at the base metal i.e., bounding depth). The licensee indicated that the uniform compressive stress layer created by the rotary peening process does not inhibit subsequent NDE. Furthermore, this residual compressive stress layer has been shown to greatly reduce PWSCC initiation.

The licensee indicated that the ASME Code, Section III, Appendix W, W-2140, clearly describes the beneficial nature of compressive stresses for the mitigation of SCC susceptibility. It states that shot peening as a form of stress improvement can be used to place the inside diameter surface of piping in a compressive residual stress state to resist SCC. The licensee stated that extensive laboratory testing performed as part of topical report "Materials Reliability Program: An

Assessment of the Control Rod Drive Mechanism (CRDM) Alloy 600 RVH Penetration PWSCC Remedial Techniques (MRP-61)," the Electric Power Research Institute (EPRI), Palo Alto, CA, 2003.1008901, indicates that shot peening successfully inhibits PWSCC initiation. With rotary peening, the shot is captured in a flap and regularly spaced such that it uniformly imparts compressive stresses on metal surfaces. However, the additional benefits of rotary peening regarding increased PWSCC resistance will not influence the inspection frequency for the modified nozzles as depicted in ASME Code, Code Case N-729-4. The licensee requested relief from ASME Code, Code Case N-638-6, paragraph 1(g).

Updated Analyses

By letter dated September 11, 2015 (ADAMS Accession No. ML15259A049), the licensee submitted RR I3R-16 and I3R-28 for RPVHPNs repairs during the third ISI interval at Braidwood and Byron Stations, respectively. RR I3R-16 and I3R-28 use the same IDTB weld repair method as is used in the current RR I4R-09.

By letter dated April 27, 2016 (ADAMS Accession No. ML16109A337), the NRC staff approved RRs I3R-16 and I3R-28 for Braidwood and Byron Stations, respectively.

By letter dated November 8, 2016 (ADAMS Accession No. ML16320A035), the licensee submitted RR I4R-11 for RPVHPNs repairs during the fourth ISI interval at Byron Station, Units 1 and 2. In RR I4R-11, the licensee updated analyses that were submitted in RR I3R-16 and I3R-28.

By letter dated February 24, 2017(ADAMS Accession No. ML17047A038), the NRC approved Relief Request I4R-11 for Byron Station, Units 1 and 2.

RR I4R-09 for Braidwood Station is similar to RR I4R-11 for Byron Station.

Byron Station's RR I4R-11 included the updated analyses to incorporate the impact due to the addition of an upset condition transient i.e., excessive feedwater transient (EFT). The updated analyses include updates to the applicable operating stress and weld anomaly flaw analysis based on the inclusion of EFT. The updated analyses in Byron Station's RR I4R-11 are applicable to Braidwood Station's RR I4R-09. The licensee stated that the impact due to EFT was not considered in the analyses submitted with RR I3R-16 for Braidwood Station, Units 1 and 2. However, the upset condition transient stress due to EFT (thermal cold shock) would only occur for a short period of time. The analyses were conservatively updated to include the impact due to EFT in RR I4R-09.

The licensee stated that MRP-335, Revision 3-A, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," November 2016, (ADAMS Accession No. ML16319A282), states that peening applies to steady state stresses during normal operation as SCC initiation is a long-term process and does not apply to transient stresses that occur only for short periods of time. The addition of the analysis of EFT caused a minor change in the results and did not impact the conclusions of the analyses as presented in RR I3R-16 for Braidwood Station, Units 1 and 2. The update due to EFT insignificantly impacted the cumulative usage factor of the operating stress analysis for the nozzle opening. Additionally, there was a minor impact to the weld anomaly flaw analysis minimum fracture toughness margins.

The licensee stated that the calculation of EFT is an upset condition stress and its impact to the analyses supporting Relief Request I4R-09 is limited to those analyses that included the evaluation of operating and transient stresses. The licensee further stated that the EFT issue does not affect the PWSCC evaluation because PWSCC evaluation is a flaw propagation analysis that estimates the minimum time for a PWSCC flaw to reach 75 percent through-wall of the original wall thickness (i.e., not a stress evaluation). The licensee indicated that the EFT issue does not affect the corrosion evaluation of the RVH bore because potential corrosion concerns due to the as-left bored out nozzle configuration is not related to stresses. The licensee explained that the EFT issue does not affect the ambient interpass temperature evaluation because the repair weld does not require performance of direct temperature measurements prior to each weld pass.

Examinations

Acceptance Examination

The 2001 Edition through 2003 Addenda of the ASME Code, Section III, NB-5245, specifies progressive surface examination of partial penetration welds. The licensee stated that the original Construction Code requires progressive surface PT examination in lieu of volumetric examination because volumetric examination is not practical for the conventional partial penetration weld configurations. The licensee proposed the following combination of UT and PT examinations.

The licensee indicated that for the repaired CRDM and RVLIS nozzles, the welds are suitable for UT examination. However, the welds are only accessible from the top side of the nozzle, and, therefore, the UT coverage of the volume within the lower taper transition is limited. For the repaired CETC nozzle, the weld is accessible for UT examination from both the top and bottom sides.

The licensee stated that it will perform volumetric examinations by UT of the repaired/modified configuration as specified in ASME Code, Code Case N-638-6, 4(a)(2) and 4(a)(4). The licensee further stated that it will apply the acceptance criteria of NB-5330 of ASME Code, Section III, 2001 Edition, including Addenda through 2003, to all flaws identified within the repaired/modified volume. RG 1.147, "Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1," Revision 18 (ADAMS Accession No. ML16321A336), has conditionally approved ASME Code Case N-638-6 with the condition that demonstration for UT examination of the repaired volume is required using representative samples which contain construction type flaws.

The licensee stated that the UT transducers and delivery tooling are capable of scanning from cylindrical surfaces with inside diameters of approximately 2.75 inches. The scanning is performed using 0-degree L-wave transducers, 45-degree L-wave transducers in two opposed axial directions, and 70-degree L-wave transducers in two opposed axial directions and 45-degree L-wave transducers in two opposed circumferential directions. Additionally, the licensee will examine the RVH low alloy steel extending to ¼ inch beneath the new weld into the RVH base material wall thickness using the 0-degree L-wave transducers searching for evidence of under bead cracking and lack of fusion in the heat affected zone.

The licensee indicated that the UT equipment is not capable of scanning from the face of the weld taper at CRDM and RVLIS nozzle locations. The 45-degree and 70-degree L-wave axial UT examination scans looking down will interrogate the taper transition volume on the CRDM and RVLIS nozzle welds. The licensee stated that approximately 70 percent of the CRDM and RVLIS nozzle weld surface is expected to be scanned by UT. Approximately 83 percent of the RVH ferritic steel heat affected zone is expected to be covered by UT. The actual CRDM and RVLIS nozzle volume examined will be calculated after the as-built dimensions of the weld are known and the examination is performed. The licensee anticipated that greater than 80 percent of the examination volume will obtain two-directional coverage for the CRDM and RVLIS nozzle modified configuration. The licensee indicated that there is no portion of the CRDM or RVLIS nozzle weld volume that does not receive at least single direction UT coverage. The licensee stated that UT coverage of the modified CETC nozzle configuration will receive essentially 100 percent coverage.

The licensee stated that it will perform a final surface PT examination on the entire weld for the CRDM, RVLIS, and the CETC nozzle welds. PT examination will also be repeated on the remediated surfaces. Further, the licensee will examine the volume in question to the extent practical using the 70-degree L-wave and 45-degree L-wave axial UT examination scans. All portions of the repair will receive surface PT examination and at least single-direction UT coverage of the volume. The licensee indicated that the final examination of the new weld and immediate surrounding region will be sufficient to verify that defects have not been induced in the ferritic low alloy steel RVH base material, due to the welding, to the extent practical.

The licensee indicated that the combination of performing PT and UT examinations during the IDTB repair provides assurance of structural integrity. Thus, the licensee requests relief from the progressive surface examination requirements specified in NB-5245.

Preservice and Inservice Examinations

Below is the proposed PSI and ISI examination regiment for RPVHPNs repaired as shown in Figures A-9 and A-18 of the licensee's October 4, 2018, letter.

Parts Examined	Examination Requirement/figure	PSI/ISI Examination Method	Acceptance Standards	Extent/frequency
CRDM/ RVLIS	Figure A-9	Surface	N-729-4, -3130	All nozzles, each refueling outage
CETC	Figure A-18	Volumetric	N- 729-4, -3130	All nozzles, each refueling outage

ASME Code Case N-729-4 provides requirements for the inspection of RPVHPNs with nozzles having partial penetration welds. ASME Code Case N-729-4, Table 1, Item B4.20, permits either volumetric or surface examination. Because either volumetric or surface examination is acceptable, surface examination will be used for PSI and ISI for repaired CRDM and RVLIS nozzles as shown in Figure A-9 of the licensee's October 4, 2018, letter because tooling access is limited. The volumetric examination will be used for PSI and ISI for repaired CETC nozzles as shown in Figure A-18 of the licensee's October 4, 2018, letter.

The licensee stated that Figure A-9 of it's October 4, 2018, letter is used to establish the examination area of a repaired CRDM or RVLIS nozzle for the PSI following repair and for future ISI. Similarly, Figure A-18 of the licensee's October 4, 2018, letter is used to establish the examination area of a repaired CETC nozzle for the PSI following repair and for future ISI. The licensee explained that the established examination areas are equivalent to that required by Figure 2 in Code Case N-729-4 because the relief request requires the examination of the nozzle weld and the same area above the CRDM nozzle weld, RVLIS nozzle weld, CETC nozzle weld and the CETC nozzle base material below the weld as would be required by Figure 2 in the Code Case. Therefore, PSI following repair and future ISI will comply with Code Case N-729-4 as modified by 10 CFR 50.55a(g)(6)(ii)(D).

3.1.7 <u>Duration of Proposed Alternatives</u>

The licensee stated that the provisions of this relief request are applicable for the fourth ISI interval for Braidwood Station, Units 1 and 2, currently scheduled to end on July 28, 2028, and

October 16, 2028, respectively. The modification installed in accordance with the provisions of this relief shall remain in place for the design life of the modification, until another alternative is approved by the NRC or until the RVH is replaced.

3.2 NRC Staff Evaluation

Pursuant to 10 CFR 50.55a(z)(1), the NRC staff reviewed the proposed alternative to determine whether it provides an acceptable level of quality and safety in accordance with ASME Code, Sections III and XI, Code Cases N-638-6 and N-729-4. Specifically, the NRC staff considered the following aspects of the licensee's technical basis: (1) evaluation of the IDTB weld repair technique; (2) flaw and corrosion evaluations; and (3) evaluation of alternative examinations and coverage.

3.2.1 IDTB Weld Repair Technique

The NRC staff notes that the significant changes between the original nozzle and the repaired nozzle are the removal of a portion of the original nozzle and the installation of a new attachment weld. Based on Figures A-2 on the licensee's October 4, 2018, letter, which shows the configuration of the modified nozzle, the NRC staff finds that the repaired nozzle without a portion of the original nozzle does not affect its structural support to the functionality of the CRDM. As for the new attachment weld, the licensee followed the ASME Code, Section III, design requirements from which it did not ask relief. Nevertheless, the NRC staff performed an independent calculation and determined that the size of the new attachment weld will support all the loads of the repaired nozzle. Therefore, the NRC staff finds that the new weld is designed to support the necessary loadings and, therefore provides an acceptable level of quality and safety.

The licensee stated that its vendor has qualified the IDTB welding technique in repairing RPVHPNs using mockups since 2001. During these repair evolutions, the site crew performs training on mockups for each of their respective specialties (i.e., machining, welding, and NDE). The NRC staff finds that the use of the machining, welding and NDE mockups ensure quality fabrication and examinations of the repair and therefore provides an acceptable level of quality and safety.

The licensee stated that in lieu of using direct measurement, it will use heat flow calculations to determine the maximum anticipated interpass temperature to ensure interpass temperature limits are not exceeded. The NRC staff finds that the proposed heat flow calculations are the same as prescribed in Code Case N-638-6 that the NRC approved in RG 1.14 7, Revision 18. The NRC staff finds that the proposed heat flow calculations will provide reasonable assurance that the required interpass temperature limits will not be exceeded and therefore provides an acceptable level of quality and safety.

ASME Code Case N-638-6, paragraph 4.0(b), requires the new attachment weld be examined by surface and ultrasonic methods when the temperature of the completed weld has been at ambient temperature for at least 48 hours. In lieu of this requirement, the licensee proposed to start the 48-hour waiting period when the third layer is deposited to perform the examination. The NRC staff notes that the 48-hour waiting period is to permit any potential fabrication defects or cracking in the weld to emerge so that the weld could be repaired prior to placing the weld in service. The licensee stated that EPRI Report 1013558, "Temper bead Welding Applications, 48-Hour Hold Requirements for Ambient Temperature Temper Bead Welding," December 2006 (ADAMS Accession No. ML070670060), provides justification for starting the 48-hour hold after completing the third temper bead weld layer rather than waiting for the weld to cool to-ambient temperature. The NRC staff finds that starting the UT examination after the 48-hour hold time from the completion of the third temper bead weld layer provides an acceptable level of quality and safety because the EPRI research provides reasonable assurance that the completed weld will not be affected by the proposed earlier examination time.

ASME Code Case N-638-6, paragraph 4.0(b), requires that after welding, surface, and volumetric examinations be performed on the final weld and the band around the area defined in paragraph 1.0(d) of the code case. As an alternative, the licensee proposed to perform surface examination using liquid penetrant testing on the band around the area to be welded, which includes the exposed surface area of RVH base metal as shown in Figure A-3 of the licensee's October 4, 2018, letter. Based on the above, the NRC staff finds that the proposed PT and UT examinations will cover the affected area of the new weld satisfactorily. Therefore, the NRC staff finds that the proposed examination coverage provides an acceptable level of quality and safety.

3.2.2 Flaw and Corrosion Evaluations

The NRC staff evaluated the licensee's analyses of the triple point anomaly, postulated flaw growth from the existing J-groove weld into the RVH, corrosion evaluation, loose parts evaluation and updated analyses.

Triple Point Anomaly Evaluation

The licensee requested relief from the ASME Code, Section III, NB-5000, so that potential anomalies at the triple point location may remain in service. The NRC staff noted that the ASME Code, Section III, NB-5330(b), prohibits the existence of indications that are characterized as cracks, lack of fusion, or incomplete penetration regardless of length. As an alternative to NB-5330(b), the licensee analyzed a postulated crack-like anomaly at the triple point in accordance with the ASME Code, Section XI, IWB-3600, to justify operating with the anomaly left in service. The results of the licensee's analyses demonstrate that a postulated 0.10-inch weld anomaly is acceptable for 40 years. Based on the above, the NRC staff finds that the licensee has adequately demonstrated by analysis and mockup testing that the triple point weld anomaly provides an acceptable level of quality and safety to remain in service without affecting structural integrity of the repaired nozzle for 40 years.

Flaw Evaluation for the J-groove Weld

The ASME Code, Section XI, IWB-3132.3, requires that successive examinations be performed on a weld that contains an unacceptable flaw. The licensee proposed not to re-examine the remnant J-groove weld in the future because it is difficult to examine the remnant J-groove weld with reasonable confidence. As an alternative, the licensee analyzed a postulated flaw in the remnant J-groove weld in accordance with the ASME Code, Section XI, IWB-3132.3, and IWB-3610(d)(2), to demonstrate that the flaw is acceptable. The licensee used LEFM and EPFM to analyze the flaw growth and stability. The licensee postulated the worst-case flaw in the J-groove weld in which the flaw extends the entire length of the weld and the flaw tip has reached the interface between the butter and the RVH base metal. The flaw is postulated to propagate into the RVH base metal by fatigue. The licensee's analysis showed that the modified RPVHPN is acceptable for the remaining life of the unit plus a 20-year life extension following an IDTB weld repair. Because the licensee's analysis is in accordance with the ASME Code, Section XI, IWB-3132.3, and IWB-3610(d)(2), the NRC staff finds that it is acceptable that the licensee derived the crack stress intensity factors for initial "as-left" flaws using the finite element model. The NRC staff recognizes that the postulated flaw was not able to satisfy the margins in the ASME Code, Section XI, IWB-3600, which describes the LEFM approach. However, because licensee's analysis is in accordance with the ASME Code, Section XI, IWB-3132.3, and IWB-3610(d)(2), the NRC staff finds that the licensee use of EPFM to accept the postulate flaw provides an acceptable level of quality and safety.

Based on the above, the NRC staff finds that based on a combination of LEFM and EPFM analyses of a postulated remaining flaw in the original Alloy 82/182 J- groove weld, the modified RPVHPN provides an acceptable level of quality and safety for the remaining life of the unit plus a 20-year life extension following an IDTB weld repair. The licensee demonstrated that the postulated flaw in the remaining portion of the J-groove weld provides an acceptable level of quality and safety for 33 years of remaining operation (based on a 60- year plant licensed life).

Corrosion Evaluation

The NRC staff noted that as a result of the nozzle repair, an area in the RPV penetration bore is exposed to primary coolant. The licensee considered various corrosion mechanisms and that general corrosion of the exposed RVH base metal will most likely occur in the affected bore area. Based on the licensee's calculation, the NRC staff finds that the bore of the RVH penetrations provides an acceptable level of quality and safety in terms of general corrosion for 40 years following the nozzle repair.

Loose Parts Evaluation

The NRC staff reviewed the potential for fragments of the degraded J-groove weld falling into the reactor. To address this concern, the licensee postulated the radial cracks to occur in the J-groove weld due to the dominance of hoop stresses. The licensee determined that the possibility of occurrence of transverse cracks that could intersect the radial cracks is unlikely because there are no forces that would drive a transverse crack, and the radial cracks would relieve the potential transverse crack driving forces. The licensee stated that 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. Based on the above, the NRC staff finds that the licensee has adequately demonstrated that the fragments from the remnant J-groove weld are not likely to fall into the reactor vessel to become loose parts and therefore provides an acceptable level of quality and safety.

Updated Analyses

The NRC staff determined that the EFT does not affect the PWSCC evaluation because the flaw growth analysis estimates the minimum time for a PWSCC flaw to reach 75 percent through-wall of the original wall thickness and does not related to the stresses. The NRC staff further determined that the EFT does not affect the general corrosion evaluation of the RVH bore because the evaluation is not related to stresses. The NRC staff finds that the EFT issue does not affect the heat flow calculations to limit the ambient interpass temperature because the heat flow calculations are not related to stresses. Based on the above, the NRC staff finds that the EFT effect on the cumulative usage factor of the operating stress analysis is insignificant for the nozzle opening and the flaw analysis of the triple point weld anomaly.

3.2.4 Examinations

The NRC staff reviewed the adequacy of the examinations, and whether they will provide reasonable assurance that structural integrity of the repaired nozzle will be maintained. As such, the NRC evaluated the requirements of the pre-welding examination, acceptance examinations, and preservice and inservice examinations as discussed below.

Pre-Welding Examination

In its letter dated October 4, 2018, the licensee states that prior to making the new attachment weld, it will perform PT of the RVH penetration bore and the inside diameter of the nozzle as shown in Figures A-3 and A-4. The examination coverage will be from the top of the J-groove weld to 1/2 inch above the bottom of the remnant nozzle. Based on the above, the NRC staff finds that the examination coverage provides an acceptable level of quality and safety to ensure that the relevant surfaces are free of defects prior to installing the new attachment weld.

Acceptance Examination

In its letter dated October 4, 2018, the licensee states that after the repair the proposed acceptance examination consists of UT and PT as shown in Figure A-3 and A-12. The proposed UT examination will extend at least 1-inch above the new attachment weld and at least 1/4-inch depth into the RVH base metal wall thickness underneath the new attachment weld. In addition, the proposed PT examination area includes the new weld surface and extends upward on the nozzle inside surface to include the area required by ASME Code Case N-729-4, Figure 2, and at least 1/2 inch of the RPVHPN bore area below the new weld. The NRC staff recognizes that the weld taper transition region will be excluded from UT examination because the UT transducer cannot be positioned to examine the taper transition region of the new weld. However, based on its letter dated October 4, 2018, the licensee will examine the surface of the taper transition region by PT. The NRC staff finds that the proposed acceptance examinations provides an acceptable level of quality and safety because PT and UT will cover sufficient area and volume of new weld and the surrounding region of the RVH bore to provide reasonable assurance of structural integrity of the new weld and associated RPVHPN region.

The licensee requested to deviate from the requirement of the ASME Code, Section III, NB-5245, related to incremental surface examinations of the new attachment weld. The NRC staff notes that the licensee cannot meet this requirement because of the welding layer deposition sequence (i.e., each layer is deposited parallel to the penetration centerline). As an alternative, the licensee proposed to perform PT and UT examinations of the final weld to the extent possible. Based on the above, the NRC staff finds that the proposed UT examination and the final PT examination will be able to detect fabrication defects and the incremental surface examinations are not needed and therefore provides an acceptable level of quality and safety.

Preservice and Inservice Inspections

The licensee stated that following the repair, the PSI and ISIs of repaired nozzles will comply with ASME Code Case N-729-4 as conditioned by 10 CFR 50.55a(g)(6)(ii)(D) and as depicted in Figures A-9 and A-18 of its October 4, 2018, letter. The licensee stated that it will perform the surface or volumetric examination of the new attachment weld in accordance with ASME Code Case N-729-4, Table 1, Item B4.20. This includes the examination of the weld taper transition extending up to at least the "a" distance above the top edge of the weld taper on the nozzle inside surface, where "a" includes the surface area and volume required by ASME Code Case N-729-4, Figure 2. Figure 2 defines the distance "a" as equal to 1.5 inches for the nozzle incidence angle less than or equal to 30 degrees to the horizontal plane, or 1 inch for the incidence angle greater than 30 degrees to the horizontal plane. The NRC staff finds that the licensee's proposed PSI and ISI examinations provide an acceptable level of quality and safety because the extent of examination area and volume specified in Figure A-9 its October 4, 2018, letter satisfies the examinations required by Figure 2 of ASME Code Case N-729-4.

Paragraph 10 CFR 50.55a(g)(6)(ii)(D)(5) specifies that if a flaw attributed to PWSCC has been identified in a RPVHPNs, even if it is accepted for continued service under paragraph 3130 or 3140 of ASME Code Case N-729-4, all RPVHPNs, including the repaired RPVHPNs, must be inspected during each refueling outage instead of the re-inspection intervals required by Table 1, Note (8) of ASME Code Case N-729-4. The licensee has not asked relief from inspecting all RPVHPNs during every refueling outage.

In summary, the NRC staff determines that the proposed alternative provides reasonable assurance of structural integrity of the repaired RPVHPNs because: (a) the weld design and the proposed repair are performed in accordance with the ASME Code, Sections III and XI, Construction Code, and Code Case N-638-6 with alternatives that the licensee has satisfactorily addressed with respect to quality and safety, (b) the licensee has performed necessary analyses to demonstrate the acceptability of the RVH and repaired RPVHPNs containing postulated flaws to remain in service for 33 years, and (c) the licensee will examine the repaired RPVHPNs every refueling outage in the future in accordance with ASME Code Case N-729-4 as conditioned by 10 CFR 50.55a(g)(6)(ii)(D).

4.0 CONCLUSION

As set forth above, the NRC staff concludes that RR I4R-09 will provide an acceptable level of quality and safety for the repaired RPVHPNs. 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 authorizes the use of RR I4R-09 at Braidwood Station, Units 1 and 2, for the fourth ISI interval currently scheduled to end on July 28, 2028, and October 16, 2028, respectively.

All other requirements of ASME Code, Section XI, and 10 CFR 50.55a(g)(6)(ii)(D) for which relief was not specifically requested and authorized by the NRC staff remain applicable, including the third-party review by the Authorized Nuclear Inservice Inspector.

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