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, UNIT 1 – RELIEF FROM THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS CODE (EPID L-2018-LLR-0126)

Dear Mr. Hanson:

By letter dated September 24, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18270A066), Exelon Generating Company, LLC (the licensee) submitted proposed alternative relief request (RR) I4R-08 requesting approval for alternative follow-up inspections of peening-applied reactor vessel head penetration nozzles for the fourth inservice inspection (ISI) interval of Braidwood Station (Braidwood), Unit 1.

Specifically, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.55a(z)(2), the licensee requested to use the proposed alternative on the basis that that compliance with the requirements would result in hardship or unusual difficulty without a compensating increase in the 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 the proposed alternative provides reasonable assurance of the integrity of the subject components and that complying with the requirement would result in hardship or unusual difficulty without a compensating increase in the 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)(2). Therefore, the NRC staff authorizes the use of the proposed alternative in RR I4R-08 at Braidwood, Unit 1, for the fourth 10-year ISI interval that is scheduled to end on July 28, 2028.

All other requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (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 Branch Chief
Plant Licensing Branch III
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. 50-456

Enclosure:
Safety Evaluation

cc: Listserv

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

RELIEF REQUEST I4R-08 REGARDING REPAIR AND EXAMINATION OF

REACTOR VESSEL HEAD PENETRATION NOZZLES

EXELON GENERATION COMPANY, LLC

BRAIDWOOD STATION, UNIT 1

DOCKET NOS. 50-456

1.0 INTRODUCTION

By letter dated Septémber 24, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18270A066), Exelon Generating Company, LLC (the licensee) submitted proposed alternative relief request (RR) I4R-08 requesting approval for alternative follow-up inspections of peening-applied reactor vessel head penetration nozzles (RPVHPNs or nozzles) for the fourth inservice inspection (ISI) interval of Braidwood Station (Braidwood), Unit 1.

The inspection requirements for the RPVHPNs are specified in paragraph (g)(6)(ii)(D) of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a, "Codes and Standards." As documented in the U.S. Nuclear Regulatory Commission (NRC) safety evaluation (SE) dated November 13, 2017 (ADAMS Accession No. ML17249A298), the application of water jet peening and associated inspection requirements were approved for these nozzles based on the guidance in Electric Power Research Institute (EPRI) Report, 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). With respect to the follow-up inspection, the mitigated nozzles are required to be inspected during the second (N+2) refueling outage (RFO) following the peening mitigation as discussed in MRP 335, Revision 3-A. The licensee proposed that the follow-up inspections of 75 RPVHPNs, mitigated during RFO A1R19 in the Fall of 2016, be inspected during RFO A1R22 (Spring of 2021) in alignment with the 4 nozzles mitigated during RFO A1R20.

Specifically, pursuant to 10 CFR 50.55a(z)(2), the licensee requested to use its proposed alternative on the basis that compliance with the specified requirements would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

2.0 REGULATORY EVALUATION

Components (including supports) that are classified as American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Class 1, Class 2, and Class 3 must meet the requirements in 10 CFR 50.55a(g)(4), "Inservice Inspection Standards Requirement for Operating Plants," throughout the service life of a boiling- or pressurized-water reactor (BWR or PWR). The exception is the design and access provisions and preservice examination requirements set forth in Section XI of editions and addenda of the ASME Code that become effective subsequent to editions specified in paragraphs (g)(2) and (3) of 10 CFR 50.55a, which are incorporated by reference in paragraph (a)(1)(ii) of 50.55a, to the extent practical within the limitations of design, geometry, and materials of construction of the components.

Pursuant to 10 CFR 50.55a(g)(6)(ii), the 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.

Pursuant to 10 CFR 50.55a(g)(6)(ii)(D), "Reactor Vessel Head Inspections," licensees of PWRs are required to augment their ISI of the reactor vessel head 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.

Paragraph (z)(2) of 10 CFR 50.55a states, in part, that alternatives to the requirements of 10 CFR 50.55a(g) may be used when authorized by the NRC if the licensee demonstrates 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 NRC to authorize the licensee's proposed alternative for Braidwood, Unit 1. Accordingly, the NRC staff reviewed and evaluated the licensee's request pursuant to 10 CFR 50.55a(z)(2).

3.0 TECHNICAL EVALUATION

3.1 Licensee's Proposed Alternative

ASME Code Components Affected

The subject components are ASME Code, Class 1, RPVHPNs that have pressure-retaining partial-penetration J-groove welds. These nozzles are ASME Code Case N-729-4, Item B4.20, components fabricated with Alloy 600/82/182 materials. Water jet peening (also called cavitation peening) was applied on the nozzles for mitigation of potential primary stress corrosion cracking (PWSCC) in accordance with the guidance in EPRI report MRP-335, Revision 3-A. The application of the peening process on the subject nozzles was approved in the NRC staff safety evaluation (SE) dated November 13, 2017 (ADAMS Accession No. ML17249A298).

Applicable ASME Code Edition and Addenda

The current code of record for the fourth ISI interval of Braidwood, Unit 1, is the 2013 Edition of ASME Code, Section XI. Examinations of the subject nozzles are performed in accordance with

10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of ASME Code Case N-729-4 with conditions.

Applicable Code Requirements

ASME Code Case N-729-4 addresses inspection requirements for RPVHPNs, as conditioned by 10 CFR 50.55a(g)(6)(ii)(D). The regulation in 10 CFR 50.55a(g)(6)(ii)(D)(1) requires in part that holders of operating licenses or combined licenses for PWRs as of or after August 17, 2017, shall implement the requirements of ASME Code Case N-729-4 instead of ASME Code Case N-729-1, subject to the conditions specified in paragraphs (g)(6)(ii)(D)(2) through (4) of 10 CFR 50.55a by the first RFO starting after August 17, 2017.

As previously discussed, the NRC SE dated November 13, 2017, approved the application of peening on the subject nozzles for mitigation of potential PWSCC, pursuant to 10 CFR 50.55a(z)(1). With respect to the follow-up inspections after the peening, the NRC staff's SE granted Braidwood, Unit 1, relief from conducting the first RFO inspection (N+1 inspection) after the peening application that is specified in EPRI report MRP-335 Revision 3-A, Table 4-3, Note (11)(b). As a result, the follow-up inspection required for the subject nozzles is the second RFO inspection (N+2 inspection) following the peening application. In addition, the licensee is required to perform ISI on the subject nozzles every 10 years, thereafter.

Proposed Alternative

The licensee requested that as an alternative to the requirements of 10 CFR 50.55a(g)(6)(ii)(D), a single follow-up examination is proposed to be conducted in the third (N+3) RFO for the 75 nozzles (peened in the Fall 2016 RFO). This alternative allows that the follow-up examinations of all 79 nozzles (including the associated welds) are conducted during a single RFO (in the Spring 2021 RFO (A1R22)).

Licensee's Basis

During the water jet peening application at Braidwood, Unit 1, in the Fall 2016 RFO (A1R19), 75 RPVHPNs were successfully peened, but 4 nozzles did not receive complete peening in accordance with the performance criteria of EPRI report MRP-335, Revision 3-A. The affected nozzles were 3 control rod drive mechanism nozzles (nozzle Nos. 67, 71, and 73) and the vent line nozzle. Subsequently, the licensee peened these 4 nozzles during the Spring 2018 RFO (A1R20), which completed the water jet peening on all 79 RVHPNs. The NRC's SE dated November 13, 2017, provides the licensee relief from conducting the first RFO follow-up inspection (N+1 inspection) for the 79 nozzles. Therefore, the licensee is currently only required to perform a follow-up inspection during the second RFO (N+2 follow-up inspection) on the subject nozzles.

In this RR, the licensee proposed that, for the 75 nozzles peened in the Fall of 2016, the second RFO volumetric examination (N+2 inspection) be postponed by one cycle to the third RFO to align with the follow-up volumetric examination for the 4 nozzles peened in spring 2018. The 4 nozzles are required to be inspection during RFO A1R22 in spring 2021. This would allow for aligning the timing of the follow-up volumetric examination of all 79 nozzles to a single RFO (in the spring of 2021(A1R22)).

In its determination of the hardship and level of quality and safety, the licensee considered the following factors: (1) radiological dose and industrial safety concerns; (2) deterministic analysis results for N+3 follow-up inspection timing; and (3) nondestructive examination capabilities for RPVHPNs. The licensee estimated that by combining the inspections a radiological dose savings of approximately 192 to 256 mRem (millirem) would be possible. The licensee estimated this radiological dose hardship based on historical data but indicated that it could be higher, if tool breakdowns or issues occur requiring additional personnel entry. The licensee stated that this alternative would reduce industrial safety concerns by minimizing required personnel containment entries, risk of working in a locked high radiation area and total personnel collective contamination risk.

The licensee provided summaries of deterministic crack growth calculations and evaluations from MRP-335, Revision 3-A, and a 2016 pressure vessel and piping (PVP) conference paper, "Deterministic Technical Basis for Re-Examination Interval of Every Second Refueling Outage for PWR Reactor Vessel Heads Operating at T_{cold} with Previously Detected PWSCC," Proceedings of the ASME 2016 PVP Conference, PVP2016-64032, Copyright 2016 by ASME (http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=2590183) in Attachments 2 and 3, respectively, of the licensee's proposed alternative. The licensee's analysis showed that an additional 18 months for an N+3 follow-up inspection at Braidwood, Unit 1, has the advantage of allowing more time for potential shallow pre-existing flaws to grow and become more readily detectable at the time of the N+3 follow-up inspection. The licensee reasoned that a shallow, slow-growing flaw would be expected to grow in depth by more than an additional 50 percent for an N+3 inspection compared to an N+2 inspection time period, considering the additional 1.5 years (50 percent) of time for growth and the acceleration in growth rate with increasing crack size and crack-tip stress intensity factor. The licensee also noted that ultrasonic testing (UT) is not qualified to detect shallow flaws extending less than 10 percent through the nozzle wall; therefore, the N+3 follow-up inspection should be more effective in addressing slow-growing flaws. Additionally, the licensee noted that bare metal visual examinations would be performed each refueling outage for evidence of pressure boundary leakage. Further, in accordance with 10 CFR 50.55a(g)(6)(ii)(D), a demonstrated leak path assessment examination is also required whenever a volumetric examination is performed. These examinations would provide a defense-in-depth (DID) measure to identify leakage prior to and during the N+3 follow-up inspection for the subject 75 nozzles and associated J-groove welds.

Based on these assessments, the licensee concluded that performance of the follow-up examinations in two separate outages would result in a hardship that is not compensated for by a corresponding increase in safety or quality.

Duration of the Proposed Alternative

The duration of the proposed alternative is for the fourth 10-year ISI interval which is scheduled to end on July 28, 2028.

3.2 NRC Staff Evaluation

The NRC staff has reviewed and evaluated the licensee's request on the basis that compliance with the specified requirements would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. The licensee provided the following basis for hardship associated with performing the follow-up inspections during the two RFOs in accordance with the current regulations.

- The licensee estimated that by combining the two follow-up inspections a radiological dose savings of approximately 192 to 256 mRem would be possible.

- The licensee stated that this alternative would reduce industrial safety concerns by minimizing required personnel containment entries, risk of working in a locked high radiation area and total personnel collective contamination risk.

The NRC staff finds that the licensee adequately identified the basis for hardship that involves the additional occupational radiation doses, potential for increases in industrial accident risks and potential for increases in contamination exposure. Therefore, the NRC staff finds the licensee meets the hardship requirement of 10 CFR 50.55a(z)(2).

The NRC staff reviewed the level of quality and safety of the licensee's proposed alternative that the N+2 inspection for the 75 nozzles (including the J-groove welds) is delayed to N+3 timing (RFO A1R22) to align with the N+2 follow-up inspection for the 4 nozzles to be performed during RFO A1R22 in the Spring of 2021.

The NRC staff notes that the degradation mechanism of concern is PWSCC resulting in leakage of primary coolant containing boric acid from the RPVHPNs and/or associated J-groove weld. This mechanism can cause two issues to challenge the structural integrity of the reactor coolant pressure boundary of the reactor pressure vessel (RPV) head or RPVHPNs. The first challenge is circumferential cracking, and resulting ejection, of a penetration nozzle from the RPV head. This could cause a small break loss-of-coolant accident (LOCA) or control rod misalignment. The second challenge is that the leakage could cause boric acid corrosion of the low alloy steel material that compromises the bulk thickness of the RPV head. Boric acid corrosion rates of low alloy steel could be up to 6 inches/year under very severe conditions as discussed in NRC report, NUREG/CR-6875, "Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials," J. H. Park, O. K. Chopra, K. Natesan, and W. J. Shack; July 2005 (ADAMS Accession No. ML052360563). After sufficient corrosion, a small or medium break LOCA could occur. To provide early detection of cracks and prevent such significant degradation in RPV heads and RPVHPNs, 10 CFR 50.55a(g)(6)(ii)(D) requires an inspection program for these components, including volumetric examinations and bare metal visual examinations. The NRC staff notes that the licensee applied peening on the subject nozzles and associated J-groove weld surfaces, in accordance with EPRI report MRP-335, Revision 3-A, to mitigate PWSCC initiation in these components.

The NRC staff recognizes that leakage is required to establish the necessary environmental conditions for circumferential cracking of the nozzle above the J-groove weld or boric acid corrosion of the low alloy steel RPV head. The licensee provided technical information regarding crack growth calculations and evaluations in Attachments 2 and 3 of their September 24, 2018, letter. The NRC staff reviewed the information and found the crack growth analyses were based on conservative assumptions and industry-wide crack size measurement data for T_{cold} RPV heads (operating at 547 – 561 degrees Fahrenheit (°F)). The NRC staff notes that the RPV head at Braidwood, Unit 1, is categorized as a "cold head" because the RPV head temperature ranges from 547 to 561 °F. The licensee's analysis includes a matrix of deterministic PWSCC crack growth calculations. The matrix considers various crack growth cases that involve different hypothetical initial crack sizes, crack aspect ratios, operating temperatures of T_{cold} heads and severity levels of stress profiles. The crack growth analysis discusses the effectiveness of follow-up volumetric examination timings after peening (i.e., N+1, N+2 and N+3 timings) to monitor pressure boundary leakage of the nozzles. The licensee's analysis for inspection timing effectiveness further estimates the growth of hypothetical, shallow PWSCC cracks that may exist in the base metal of the nozzle at the time of peening and would be too shallow to be reliably detected during pre-peening baseline inspection. Such a shallow crack depth is less than approximately 10 percent of the nozzle wall thickness. The licensee's evaluation indicated that both the N+2 and N+3 inspection schedules result in a similar low fraction of crack growth cases that would cause nozzle leakage.

The licensee's assessment is based on 36 calculations spanning a range of variables. In all cases of the licensee's assessment, the N+2 inspection case results mirrored the N+3 inspection case results in leakage potential and detection of flaws through inspection prior to leakage. The NRC staff performed a series of independent calculations to verify the licensee's assessment. The NRC staff analysis was based on the assumption of reasonable assurance of peening to prevent new crack initiation. The NRC staff's independent calculations found only a few specialized cases of crack growth and specific weld residual stress profiles where leakage could occur if the inspection frequency was increased from N+2 to N+3. The NRC staff found that these postulated leakage cases could be detected by ISIs, such as bare metal visual examinations performed every RFO, after the follow-up volumetric inspection. The NRC staff further found that these postulated leakage cases are limited to specific crack growth rates specific to hypothetical stress profiles. Based on the above, the NRC staff finds that the conclusions of the licensee's assessment are reasonable.

The NRC staff further assessed the possibility if a leak were to occur under the licensee's proposed alternative inspection and the adequacy of the DID inspection and monitoring requirements to address the structural integrity of the upper head or nozzles. The NRC staff notes that due to the T_{cold} head temperature of the RPV at Braidwood, Unit 1, the crack growth rates for circumferential flaw growth that would result in nozzle ejection would be sufficiently longer in time than the time resulting from the inspection frequency requested in the licensee's proposed alternative. This means that the N+3 follow-up inspection is likely to detect any potential crack(s) and the licensee could perform correction actions prior to the cracks causing nozzle ejection. Therefore, based on the above, the NRC staff finds the level of quality and safety of the licensee's proposed alternative to address circumferential cracking of the RPVHPNs is adequate. The NRC staff notes the licensee confirmed that a bare metal visual examination is performed on each nozzle for evidence of pressure boundary leakage every RFO in accordance with EPRI report MRP-335, Revision 3-A. The NRC staff finds that the visual examination is an effective DID inspection. While the bare metal visual examination cannot proactively prevent leakage through the reactor coolant pressure boundary, the frequency of examination, each RFO, reasonably addresses the consequences of such leakage.

The NRC staff also notes that technical specifications of Braidwood, Unit 1, requires operational leakage monitoring, which includes containment sump monitoring and atmosphere radioactivity monitoring. Given the licensee's peening mitigation and hardship, the NRC staff finds that a bare metal visual examination each outage, when coupled with operational leakage monitoring, provides reasonable assurance of structural integrity with the inspection period of the licensee's proposed alternative (N+3). In addition, if any leakage is identified, the nozzle would be required to be repaired.

Given the licensee's identified hardship, the NRC staff finds that the licensee has provided an adequate technical basis to extend the follow-up volumetric examination of the subject 75 RPVHPNs for one operating cycle (N+2 to N+3). The NRC staff also finds that the DID bare metal visual examination, along with operational leakage monitoring, provides reasonable assurance that the structural integrity of the RPVHPNs, associated J-groove welds, and RPV head is maintained.

4.0 CONCLUSION

The NRC staff finds that the proposed alternative provides reasonable assurance of the integrity of the subject components and that complying with the requirement would result in hardship or unusual difficulty without a compensating increase in the 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)(2). Therefore, the NRC staff authorizes the use of the proposed alternative in RR I4R-08 at Braidwood, Unit 1, for the fourth 10-year ISI interval that is scheduled to end on July 28, 2028.

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.

Principal Contributor: J. Collins, NRR

Date of issuance: June 5, 2019

SUBJECT: BRAIDWOOD STATION, UNIT 1 – RELIEF FROM THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS CODE (EPID L- 2018-LLR-0126) DATED JUNE 5, 2019

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