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

June 4, 2018

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 2 – RELIEF FROM THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS CODE (EPID L-2017-LLR-0155)

Dear Mr. Hanson:

By letter dated December 20, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17360A173), as supplemented by letter dated April 12, 2018, (ADAMS Accession No. ML18102B213), Exelon Generation Company, LLC (Exelon, the licensee), submitted a request to the U.S. Nuclear Regulatory Commission (NRC) for the use of alternatives to certain American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, requirements at Braidwood Station (Braidwood), Unit 2.

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.

The NRC 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 set forth in 10 CFR 50.55a(z)(1). Therefore, the NRC staff authorizes the use of relief request I4R-07 for the fourth inservice inspection interval at Braidwood, Unit 2, currently scheduled to start on October 16, 2018, and end on October 16, 2028.

The NRC staff has determined that the safety evaluation provided in Enclosure 2 contains proprietary information pursuant to 10 CFR Section 2.390, "Public inspections, exemptions, requests for withholding." Accordingly, the staff has prepared a non-proprietary version, which is provided in Enclosure 1.

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.

Enclosure 2 transmitted herewith contains sensitive unclassified non-safeguards information. When separated from Enclosure 2, this document is DECONTROLLED.

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,

David J. Wrona, Chief
Plant Licensing Branch III
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 50-457

Enclosures:
1. Safety Evaluation (Non-proprietary)
2. Safety Evaluation (Proprietary)

cc without Enclosure 2
Listserv

ENCLOSURE 1
(NON-PROPRIETARY)

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELIEF REQUEST I4R-07 REGARDING EXAMINATION OF

REACTOR PRESSURE VESSEL HEAD PENETRATION NOZZLES

EXELON GENERATION COMPANY, LLC

BRAIDWOOD STATION, UNIT 2

DOCKET NO. 50-457

Proprietary information pursuant to Title 10 of the *Code of Federal Regulations* Section 2.390 has been redacted from this document.

Redacted information is identified by blank space enclosed within double brackets as shown here [[ ]].

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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELIEF REQUEST I4R-07 REGARDING EXAMINATION OF

REACTOR PRESSURE VESSEL HEAD PENETRATION NOZZLES

EXELON GENERATION COMPANY, LLC

BRAIDWOOD STATION, UNIT 2

DOCKET NO. 50-457

1.0 INTRODUCTION

By letter dated December 20, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17360A173), and supplement dated April 12, 2018 (ADAMS Accession No. ML18102B213), Exelon Generation Company, LLC (Exelon, the licensee), submitted a request to the U.S. Nuclear Regulatory Commission (NRC or Commission) for the use of alternatives to certain requirements of American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, at Braidwood Station (Braidwood), Unit 2.

Specifically, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(z)(1), Exelon submitted relief request I4R-07 to perform alternate examinations of peened reactor pressure vessel head penetration nozzles (RPVHPNs) and associated partial penetration J-groove attachment welds on the basis that the proposed 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 Commission may require the licensee to follow an augmented inservice inspection (ISI) program for systems and components for which the Commission deems that added assurance of structural reliability is necessary.

The regulation under 10 CFR 50.55a(g)(6)(ii)(D), "Augmented ISI requirements: Reactor vessel head inspections," requires licensees of pressurized-water reactors (PWRs) to augment their ISI interval of the reactor vessel closure 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. As a result of recent rulemaking, the *Federal Register* (82 FR 32934) published on July 18, 2017, states that all licensees of PWRs need to use Code Case N-729-4 to examine their RPVHPNs after August 17, 2017.

Paragraph 10 CFR 50.55a(z) states that alternatives to the requirements of paragraphs (b) through (h) of 10 CFR 50.55a or portions thereof may be used when authorized by the Director, Office of Nuclear Reactor Regulation, or Director, Office of New Reactors, as appropriate. A proposed alternative must be submitted and authorized prior to implementation. The applicant or licensee must demonstrate that: (1) *Acceptable level of quality and safety*. The proposed alternative would provide an acceptable level of quality and safety; or (2) *Hardship without a compensating increase in quality and safety*. 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 NRC staff finds that regulatory authority exists for the licensee to request the use of an alternative and the NRC to authorize the proposed alternative.

3.0 TECHNICAL EVALUATION

3.1 Affected Components

The affected components are 79 peened RPVHPNs which include nozzles numbered 1 through 78 and the nozzle for the vent line, and associated peened J-groove attachment welds.

The numbered RPVHPNs (1 through 78) are categorized into four groups. There are 53 control rod drive mechanism nozzles with thermal sleeves; two reactor vessel level indication system nozzles with modified thermal sleeves; five core exit thermocouple column (CETC) nozzles with guide funnels; and 18 spare nozzles. The "peened RPVHPNs" includes 78 numbered nozzles and one vent line nozzle.

All nozzles are part of the reactor vessel closure head pressure boundary. The inside diameters (IDs) and the outside diameters (ODs) of the RPVHPNs are 2.75 and 4 inches, respectively. The vent line nozzle is nominal pipe size 1. The RPVHPNs are made of SB-167, UNS N06600 (Alloy 600). The J-groove welds are made of ENiCrFe-3 (Alloy 182) and ERNiCr-3 (Alloy 82) filler material.

3.2 Applicable Code Edition and Addenda

The applicable Code of Record for the fourth ISI interval is ASME Code, Section XI, 2013 Edition. The Code of Construction is ASME Code, Section III, 1971 Edition through Summer 1973 Addenda.

3.3 Applicable Code Requirement

The regulation under 10 CFR 50.55a(g)(6)(ii)(D) require the inspection of RPVHPNs using ASME Code Case N-729-4 with certain conditions.

The regulation 10 CFR 50.55a(g)(6)(ii)(D)(1) requires, in part, "Holders of operating licenses or combined licenses for PWRs as of or after August 17, 2017, shall implement the requirements of ASME boiler and pressure vessel (BVP) Code Case N-729-4 instead of ASME BPV Code

Case N-729-1, subject to the conditions specified in paragraphs (g)(6)(ii)(D)(2) through (4) of this section, by the first refueling outage starting after August 17, 2017.

The requirements of ASME Code Case N-729-4, Figure 2, "Examination Volume for Nozzle Base Metal and Examination Area for Weld and Nozzle Base Metal," is applicable to the RPVHPNs.

The regulation of ASME Code Case N-729-4, Paragraph -2410, specifies that the reactor vessel upper head penetrations shall be examined on a frequency in accordance with Table 1 of the ASME Code Case. Exelon stated that because no flaws attributed to primary water stress-corrosion cracking (PWSCC) have been identified at Braidwood, Unit 2, the RPVHPNs are examined every four fuel cycles in accordance with Examination Category B4.20.

As an alternative to the requirements above, required inspections will be conducted in accordance with the inspection requirements for Alloy 600 RPVHPNs mitigated by peening, based on Table 4-3 in the materials reliability program (MRP)-335, Revision 3-A, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," November 2016; including relief from Final Safety Evaluation (ADAMS Accession No. ML16208A485), Condition 5.4(a) requirement for inspection in the second refueling outage post peening application (i.e., N+2 outage) which is reflected in MRP-335, Table 4-3, Note (11)(c).

As stated above, on July 18, 2017, the Federal Register (82 FR 32934) published a NRC final rule to update 10 CFR 50.55a. As part of this rulemaking activity, 10 CFR 50.55a(g)(6)(ii)(D) was updated to require all licensees of PWRs to use ASME Code Case N-729-4 in lieu of N-729-1.

Exelon's main relief request referenced N-729-4; however, some parts of Exelon's attachments referenced N-729-1 instead of N-729-4. The NRC staff finds this discrepancy immaterial. The volumetric inspection requirements from which the licensee is requesting relief have not changed due to this update. However, the location of the requirements, whether in NRC conditions or the applicable ASME Code Case version of N-729, have changed. The following paragraphs identify the location of the current regulatory requirements.

1. 10 CFR 50.55a(g)(6)(ii)(D) requires the inspection of RPVHPNs using ASME Code Case N-729-4 with certain conditions.

2. ASME Code Case N-729-4, Note 8 of Table 1, states, in part, "If flaws are attributed to PWSCC, whether or not acceptable for continued service in accordance with -3130 or -3140, the re-inspection interval shall be each refueling outage."

3. ASME Code Case N-729-4, Figure 2, is applicable to the examination of RPVHPNs.

3.4. <u>Reason for Request</u>

Exelon stated that Code Case N-729-4 requires volumetric and/or surface examination of the Braidwood, Unit 2, RPVHPNs and associated J-groove welds of all nozzles every 8 calendar years or before reinspection year (RIY) equals 2.25. Braidwood Station Unit 2 examines the RPVHPNs every four fuel cycles, nominally every 72 months. The examination schedule of N-729-4 does not address the effects of surface stress improvement by peening or the associated inspection frequency for RPVHPNs in this mitigated state.

The Electric Power Research Institute (EPRI) developed, using appropriate analytical tools, a volumetric or surface re-examination interval for Alloy 600 RPVHPNs and associated Alloy 82/182 J-groove attachment welds that have received peening application. This technical basis demonstrates that for any peening process meeting the performance criteria of Section 4.3.8 of MRP-335, the reexamination interval can be changed to the Table 4-3 inspection schedule.

Exelon stated that it implemented the ultra-high pressure cavitation peening process at Braidwood, Unit 2, in the 2017 refueling outage (A2R19). Exelon stated that the peening process implemented meets or exceeds the residual plus operating stress, the coverage area and the depth of compression requirements specified in MRP-335. Exelon requested a change to the reexamination interval of the peened RPVHPNs.

3.5 Proposed Alternative

In lieu of inspection requirements in 10 CFR 50.55a(g)(6)(ii)(D)(1), Exelon requested: (1) to implement an alternative inspection frequency consistent with requirements of MRP-335, Revision 3-A, Table 4-3, and (2) not performing the follow-up inspection in the second refueling outage after peening per the requirement in Table 4-3 Note (11)(c).

The alternative inspection frequency requirements for peened RPVHPNs per MRP-335, Table 4-3, require a pre-peening baseline inspection, follow-up inspection, and subsequent ISI, as summarized below.

Pre-Peening Baseline Inspection

Prior to performance of peening but during the same outage, examinations are to be performed in accordance with the requirements in MRP-335 Table 4-3, Note (13). Examinations include volumetric or surface examinations of essentially 100 percent of the required volume or equivalent surfaces of the nozzle tube as identified in Figure 2 of N-729-4, and a demonstrated volumetric or surface leak path assessment through all J-groove welds. The leak path examination detects through-wall cracking by checking for areas at the interface (annulus) between the nozzle tube and low-alloy steel head where leakage has caused a loss of interference fit. Exelon has performed the pre-peening baseline inspection.

Follow-Up Inspection

During the follow-up inspection, a volumetric examination of 100 percent of the required volume or equivalent surfaces of the RPVHPN is to be performed and a leak path examination is also to be performed. Exelon proposed to perform the follow-up volumetric inspection in N+4 (N is defined as the refueling outage when peening is performed) refueling outage in lieu of in the second refueling outage after peening per Table 4-3 Note (11)(c). The follow-up inspection schedule is based on the value of the RIY parameter regarding volumetric inspection and effective degradation year (EDY) parameter regarding visual inspection. Exelon stated that its proposed alternative is consistent with the N-729-4 Table 1, Item B4.20, requirement, which specifies a maximum volumetric re-examination frequency of every 8 calendar years or before RIY equals 2.25. In its letter dated April 12, 2018, Exelon stated that the projected RIY is 1.84 at the time of the N+4 follow-up inspection peening or end of Cycle 23 for Braidwood, Unit 2; therefore, inspection at N+4 refueling outage satisfies N-729-4.

Furthermore, Exelon contended that it has not identified any PWSCC in RPVHPNs which supports performing volumetric inspection in the N+4 refueling outage and is in compliance with N-729-4.

Subsequent ISI Program

Exelon noted that the ISI examinations of peened RPVHPNs will be performed after completion of the follow-up inspection per Item B4.60, Table 4-3 of MRP-335. Examinations include volumetric or surface examinations of peened penetrations at an interval not to exceed one inspection interval (nominally 10 calendar years), and a demonstrated volumetric or surface leak path assessment through all J-groove welds each time the periodic volumetric or surface examination is performed.

3.6 Basis for Use

The basis for the proposed alternative is discussed in the following subsections as peening effect, peening performance criteria, peening qualification, and peening implementation.

3.6.1 Peening Effect

When the applicable MRP-335 performance criteria are met, peening mitigation prevents initiation of PWSCC. Exelon stated that the possibility of pre-existing flaws that are not detected in the pre-peening nondestructive examination is addressed through the required follow-up inspection that is performed during the fourth refueling outage (N+4) after application of peening in compliance with N-729-4. Peening also can arrest PWSCC growth of shallow surface flaws that are located in regions at the surface where the residual plus normal operating stress is compressive. Exelon stated that this secondary benefit is not credited in the main analyses of MRP-335 because these analyses assume that the bounding stress effect meeting the performance criteria is achieved.

In order to prevent the initiation of new PWSCC, peening has to reduce the peak tensile stresses at the wetted surface of material to less than the "threshold" stress for initiation of PWSCC. Based on laboratory testing, a tensile stress of +20 kilopound per square inch (ksi) is a lower bound of the stress level below which PWSCC initiation will not occur over plant life. This applies to steady-state stresses during normal operation because stress corrosion cracking initiation is a long-term process, and does not apply to transient stresses that occur only for relatively short periods of time. The MRP-335 performance criterion limits the surface stress to +10 ksi (tensile) for the case of RPVHPNs when normal operating stresses are considered.

Exelon stated that the potential for growth of small flaws too shallow to be reliably detected in the pre-peening ultrasonic (UT) examination, or for flaws located in the J-groove weld metal, is addressed by the follow-up UT examination, and by the ongoing visual examinations for evidence of leakage performed at the same schedule as prior to peening. Exelon further stated that the N+4 and subsequent 10-year interval program of inspections addresses PWSCC.

Stress Effect to Prevent Future PWSCC Initiations

The compressive residual stress depth required by the performance criteria ensures that the stress improvement effect extends a significant distance into the material. Exelon stated that the Braidwood, Unit 2, peening met or exceeded the MRP-335 depth of compression requirements. The deterministic and probabilistic analyses in MRP-335 that form the basis for the requested inspection relief show that it is not necessary for growth of shallow pre-existing flaws to be arrested by the post-peening stress field. Pre-existing flaws are effectively addressed by the combination of pre-peening and follow-up inspections. Exelon noted that in cases when a shallow pre-existing flaw is located within a region of compressive residual plus operating stress, PWSCC growth of the pre-existing flaw would be arrested. Exelon further noted that the likelihood that a pre-existing flaw exists below the depth of peening application is low since there have been no discoveries of PWSCC at Braidwood, Unit 2. The lack of discovery of PWSCC supports performing inspection in N+4 in compliance with N-729-4.

Effect of Pre-Existing Residual Stresses

Exelon stated that high residual tensile stresses do not interfere with the ability of peening to develop the stress effect needed to be effective. The peening effect is self-normalizing with regard to the level of pre-peening residual stresses. Exelon reported that AREVA verified that the unpeened residual stress state of the material does not have a significant effect on the final peened surface compressive stress and depth of compression. Testing supports that regardless of the initial stress state (i.e., high tension or high compression), the final compressive stresses would be within a -63 ksi to -81 ksi range. Exelon concluded that theory and test data show that peening results in high compressive residual stresses regardless of the starting state of the residual stresses.

3.6.2 Peening Performance Criteria

Exelon stated that its peening of RPVHPNs at Braidwood, Unit 2, satisfies the following key performance criteria in Revision 3-A of MRP-335:

(1) The stress in RPVHPNs and J-groove welds, prior to consideration of operating stresses, must be compressive on all peened surfaces. After peening, the residual stress plus operating stress on peened surfaces must not exceed +10 ksi (tensile).

(2) Peening must be applied to the full wetted area of the susceptible material (i.e., Alloy 600/82/182) that has a pre-peened residual plus operating stresses at component surface of at least +20 ksi (tensile). The susceptible material locations to be considered are (a) the wetted surface of the J-groove weld and butter material, and (b) the inside and outside surfaces of the RPVHPN material as defined in Figures 4-1, 4-2, and 4-3 of MRP-335, Revision 3-A.

(3) The compressive residual stress field must extend to a nominal minimum depth of: (a) 0.04-inch on the susceptible area of the outside surface of the RPVHPN and wetted surface of the J-groove attachment weld and butter, and (b) 0.01-inch on the susceptible area of the inside surface of the RPVHPN.

(4) The peening process is effective for at least the remaining service life of RPVHPNs and J-groove welds (i.e., the residual plus operating surface stresses after considering the effects of thermal relaxation and load cycling (or shakedown) must remain no greater than +10 ksi (tensile)).

3.6.3 Peening Qualification

Exelon stated that peening affects the performance of nuclear safety-related systems and components, thus, it shall be performed in accordance with a quality assurance program meeting the requirements of 10 CFR 50, Appendix B. Further, as a special process, peening is required to be controlled consistent with Appendix B, Criterion IX, "Control of Special Processes." As such, the personnel and procedures involved are required to be appropriately qualified. Exelon noted that because industry standards that apply to peening are not available, these qualifications shall be done to peening vendor requirements developed and documented per the vendor's 10 CFR 50, Appendix B, quality assurance program.

Exelon's qualification program is discussed in terms of qualification testing on mockups, residual stress measurement, accuracy of residual stress measurement, qualification testing results, additional testing for peening qualification, residual and operating stress analysis, and PWSCC evaluation as follows.

Qualification Testing on Mockups

Exelon demonstrated the effectiveness of peening based on surface stress achieved, depth of compression reached, and sustainability of the stress effect as discussed in the Special Process Qualification Record (SPQR) in Attachment 3 to the letter dated December 20, 2017. The SPQR includes a description of the demonstration testing of peening of mockups representative of the geometry, material, accessibility, and surface condition of the RPVHPNs in the field.

Exelon peened a total of 18 site-specific, full-scale mockup coupons as part of the qualification testing that included various nozzle configurations and site-specific materials. The test coupons were peened within control parameters. This testing was used to determine and define the ranges of acceptable values for the critical process parameters (i.e., essential variables) in accordance with MRP-335, Revision 3-A, Performance Criterion 4.3.8.1, for application in the plant. The essential variables are the important variables that could change during process implementation and need to be monitored. Process controls are in place that stop the peening if the essential variables fall outside of qualified boundaries. **[[**

]]

Exelon stated that it achieved the performance requirements in the qualification testing despite the geometric limitations associated with the application of peening to RPVHPNs, such as limited access associated with ID annulus peening or CETC downhill nozzle to reactor vessel head clearance.

Through testing and calculations, Exelon demonstrated that compressive stresses of sufficient magnitude were present over an area and to a depth sufficient to meet the requirements of MRP-335, Revision 3-A.

Residual Stress Measurements

Exelon performed demonstration testing in accordance with MRP-335 Performance Criterion 4.3.8.1 to determine the residual stress state at peened surfaces. Exelon measured residual stress on full scale peened test coupons representative of the geometry, material, accessibility, and surface condition of the components to be peened. This is to ensure that the required stress effect was achieved in each portion of the component area required to be peened.

Exelon examined the surface of peened test coupons using X ray Diffraction (XRD) measurement. Based on XRD measurements, Exelon confirmed that the stresses at the required wall depth of RPVHPN and J groove weld coupon met the requirement of the MRP-335 performance criteria. For each of the peened areas, Exelon identified the magnitude and depth of the compressive residual stresses that would be developed by lower bound allowable values of the critical peening parameters.

[[

]]

A few of the Braidwood, Unit 2, RPVHPNs have thermal sleeves. Thermal sleeve centering tabs rub on the nozzles and create wear areas on the nozzles. Exelon reasoned that these wear areas could constitute areas where the precise geometry of the wear area could affect the effectiveness of the peening process. As part of the qualification process, Exelon investigated the effects of this wear on the effectiveness of peening. Exelon determined that the wear process created a cold worked surface which is more compressive than the surrounding area. Exelon also determined that the compressive stresses achieved by peening these areas, exceeded the requirements for compressive stresses. Exelon proposed that as a result of the high compressive stresses at these wear areas, all other, non-worn areas would be bounding to the worn areas with respect to peening effectiveness.

Accuracy of Residual Stress Measurement

In accordance with MRP-335, Revision 3-A, Performance Criterion 2.3.6, Exelon has considered the residual stress measurement uncertainty when assessing the surface stress after peening of mockups. **[[**

---

1 **[[**

]]

]]

[[

]]

[[

]]

Exelon stated that the XRD measurement errors are assessed for the minimum nominal depth of compression, 0.04-inch for OD surfaces and 0.01-inch for ID surfaces, where the nominal depth refers to the depth of the compressive residual stress that is reliably obtained in demonstration testing (i.e., for at least 90 percent of the locations measured). **[[**

]]

Exelon reported that the uncertainty (error) of the XRD measurements has been validated and included in the assessment for the peening performance criteria for surface stress magnitudes, depth of compression and operating stress analysis. This assessment shows that the minimum depth of compression for all OD surface (at the depth of 0.04-inch) and ID surface (at the depth of 0.01-inch) has been achieved for more than 90 percent of the XRD measurements, even when the worst-case uncertainty (error) is applied to the stress measurement value. Exelon stated that uncertainty in XRD residual stress measurements from the samples meet the uncertainty requirements of MRP-335, Revision 3-A, Section 2.3.6.

---

2 [[

]]

Qualification Testing Results

[[

]] Exelon stated that although peening process deviations occurred during qualification testing, deviations did not affect surface compression magnitude or depth of compression or were outside of the high stress areas of interest. Exelon corrected the problems that occurred during qualification testing prior to site implementation.

[[

]]

[[

]]

Exelon concluded that qualification testing achieved the desired results. The testing established essential variables for the peening equipment. The residual stress satisfied the nominal depth requirement for the compressive residual stress of MRP-335, Revision 3-A, Performance Criterion 4.3.8.1.2 (i.e., residual stress in the nominal depth of compression). The magnitude of the residual stress at the surface was combined with the operating stress at the surface to demonstrate compliance with MRP-335, Revision 3-A, Performance Criterion 4.3.8.1.1 (i.e., magnitude of surface stress).

Additional Testing for Peening Qualification

Exelon evaluated the effect of peening on surface roughness and inspectability by comparing surface roughness measurements before and after peening on representative mock up test coupons. Exelon found that the surface roughness was not significantly increased using the bounding peening parameters, and the maximum surface roughness does not affect the capability to perform UT, penetrant testing, and eddy current testing. Exelon further evaluated the effect of peening to induce surface cracking and found that there were no peening induced cracks on the peened surface.

Based on its evaluation of the transition region, Exelon verified that the tensile stresses on the surfaces in transition regions from peened to unpeened conditions are not high enough to raise the risk of inducing PWSCC initiation.

Based on its evaluation of vibration, Exelon noted that peening will not affect the integrity of the thermal sleeve, its connection to the nozzle, and nearby components as a result of flow induced vibration.

Exelon conducted testing to determine if over peening would adversely impact the peened surface. This testing demonstrated that erosion, roughening, or the development of surface cracks could occur, but only if the surface is peened for times much longer than the maximum permitted by the peening procedures.

Residual and Operating Stress Analysis

Topical Report MRP-335, Revision 3-A, requires that following adjustment of stresses to account for reductions in compressive stresses due to thermal cycling and other issues associated with aging, the surface residual stress plus normal operating stress in the peened area shall not exceed +10 ksi. During the qualification testing, Exelon measured the stresses on the peened area at ambient pressure and temperature. To demonstrate the peened RPVHPNs satisfy the required stresses of +10 ksi at the operating conditions, Exelon performed a residual and operating stress analysis at operating pressure and temperature.

Exelon used finite element modeling to apply operating pressure and temperature to derive the residual and operating stresses at operating conditions. Exelon evaluated the effects of both thermally induced stress relaxation and load cycling (shakedown) induced stress relaxation in the stress analysis.

Exelon's residual plus operating stress analysis includes the effect of cyclic loading which causes the compressive residual stresses to relax due to shakedown. At all representative points in the finite element model evaluated, the steady state residual plus operating stress at operation conditions is demonstrated to be more compressive than the +10 ksi required by MRP-335, Revision 3-A.

Exelon reported that when matching the worst-case scenarios for surface compression magnitudes, nozzle geometries, materials, XRD error, and operating stress, the maximum post-peening residual plus operating stress levels are still more compressive than the required +10 ksi stress level. **[[**

]]

Exelon determined that: (1) all performance criteria for the residual plus operating stress analysis in peened RPVHPNs and J-groove weld mockups have been met in accordance with MRP-335, Revision 3-A; (2) **[[**

]]

Exelon concluded that the post peening residual plus operating surface stress levels at operating conditions are more compressive than the MRP-335 requirement of +10 ksi tensile. Exelon explained that the increased margin to the residual plus operating stress to the +10 ksi requirement places the nozzles in an increased compressive state that reduces the susceptibility to initiation and increases the duration before a small pre-existing flaw may be detectable.

PWSCC Evaluation

Exelon evaluated the susceptibility of the peened RPVHPN to PWSCC and to estimate the life of the peened locations. The PWSCC evaluation addresses the susceptibility of the peened nozzle locations to: (1) PWSCC crack initiation; (2) growth of cracks within the depth of the compressive stress layer; and (3) growth of cracks deeper than the compressive stress layer.

Exelon exposed Alloy 600 specimens to simulated nominal primary environment in PWRs to determine the extent of stress corrosion cracking of peened versus non-peened samples. The peened samples were mitigated to a compressive depth of 0.01 inch, which meets the minimum nozzle ID depth requirements of MRP-335. The test result show that all of the non-peened specimens were heavily cracked. None of the peened specimens revealed any evidence of PWSCC indications or significant grain boundary attack. Based on this testing, the peened samples did not exhibit any PWSCC even though the peened depth was only 1/4 of that required by MRP-335, Revision 3-A, for outside surfaces (i.e., 0.04 inches).

Exelon concluded that PWSCC initiation is not expected in locations that have been peened based on: (1) excellent operating experience with surface stress improvement techniques; (2) laboratory experience with surface stress improvement; and (3) stress analysis results considering residual stresses, operating conditions, and stress sustainability that meet the stated requirements of MRP-335, Revision 3-A.

Exelon estimated the life of peened components assuming three scenarios: (1) locations where no PWSCC cracking is present; (2) locations where undetected PWSCC cracking is shallower than the depth of compression; and (3) locations where undetected PWSCC cracking is deeper than the depth of compression. Exelon concluded that the life of peened locations where no undetected PWSCC flaws are present (first scenario) is estimated to be beyond the period of a 60 year plant license. The life of peened locations where an undetected flaw is beyond the depth of the compressive stress layer (third scenario) could be very short. On the other hand, the reduced tensile stresses near the surface may reduce crack growth rates and result in a longer life. For peened locations where an undetected PWSCC flaw is within the compressive stress layer (second scenario), the estimated life could be between the first and third scenarios. Exelon noted that in a laboratory study, cracks within the compressive stress layer are expected to arrest. Exelon concluded that the peened RPVHPNs at Braidwood, Unit 2, with periodic inspections are acceptable for the remaining life of the plant.

3.6.4 Peening Implementation

Description of Peened Area

Exelon peened RPVHPNs and J-groove welds at Braidwood, Unit 2, in the 2017 refueling outage. Exelon peened the outer surface of the RPVHPNs and J-groove welds using an OD tool that rotates the water jet around the outer circumference of the nozzle and J-groove weld. Accessibility of the nozzle outside surface and J-groove weld surface is sufficient to permit the Exelon peened the inside surface of the nozzle using an ID tool that rotates the water jet around the inner circumference of the nozzle. For peening the inside surface of RPVHPNs that have thermal sleeves, the ID annulus tool moves the thermal sleeve to one side to allow the water jet access to fit into the annulus region between the outside surface of the thermal sleeve and inside surface of the RPVHPN. Lack of clearance between the nozzle and the thermal sleeve adversely affects the depth of penetration to which compressive stresses may be achieved; however, Exelon's mock-up testing demonstrated that the depth of compression required by MRP-335, Revision 3-A, for this location, 0.01 inch could be reliably achieved.

Exelon confirmed that the actual area peened included the entire area required by Figure 2 of Code Case N 729-4 and as shown in Figures 4 1, 4 2, and 4 3, of MRP-335, Revision 3-A. Exelon noted that the area required to be peened by MRP-335 is a subset of the area actually peened in the field.

Process Description

Performance demonstration is the method used to ensure that peening fully covers all of the areas that require peening, and achieves the desired magnitude and depth of residual compressive stresses. The critical parameters to be controlled ensure that peening develops the intended levels of compressive residual stresses in each peened area. The peening qualification is documented in Exelon's SPQR that demonstrates desired results are achieved per MRP-335, Revision 3-A, with a set of bounding parameters. The peening procedure used in the field implements the process per the requirements defined in the SPQR. Essential variables are recorded for each nozzle during peening application.

Exelon stated that if critical parameters exceed the specified range during the peening process, the deviation is displayed on the peening controls system and is evaluated or the process is shut down automatically. If peening is stopped for any reason the process is restarted in accordance with the approved peening process procedures to ensure adequate peening coverage. Exelon will issue a Condition Report if corrective action is required for conditions that are outside of the approved peening process procedures.

Through its qualification program, Exelon demonstrated that, based on the use of the proposed peening process, the depth of compression required by MRP-335, Revision 3-A, was met or exceeded. Exelon further stated that the actual peened area exceeds the required areas as specified in MRP-335. Exelon proposed that the existence of compressive stresses over a larger area and to a greater depth than required by MRP-335 reduces the likelihood that a small pre-existing flaw would grow to a detectable size in one fuel cycle.

Peening Implementation Results

In Attachment 2 to the December 20, 2017, letter, Exelon stated that it successfully completed peening of inside and outside surfaces of nozzle penetration numbers 1 to 78 in compliance with the SPQR. The results of the peening process is described below:

For nozzle penetration numbers 1 to 73, and 77, the entire required inspection area of the nozzle OD was fully peened which substantially exceed the peening coverage requirement defined in MRP-335.

For CETC nozzle penetrations with guide funnels, numbers 74 to 76, and 78, part of the guide funnel was removed to provide access to the required peening coverage area as shown in the SPQR, Appendix F. For these nozzle penetrations, the area of the nozzle OD with 20 ksi and greater stress has been fully peened by a conservative margin which meets the peening coverage requirement defined in MRP-335. In addition, the majority of the inspection area was peened with the exception of the small inspection area covered by the funnel lip.

Exelon successfully peened the ID surface of nozzle penetration numbers 1 to 78. Exelon successfully peened the OD and ID of the vent line nozzle and the associated J-groove weld.

3.7 Duration of Proposed Alternative

Exelon requested relief for the 4th ISI interval for Braidwood, Unit 2, currently scheduled to start on October 16, 2018, and end on October 16, 2028.

4.0 NRC STAFF EVALUATION

4.1 Background

In its safety evaluation (SE) for MRP-335, Revision 3-A, the NRC staff did not address the qualification of a specific peening process or whether a specific peening application has achieved the required performance criteria such as stresses on the peened surface of a component. Specifically, the NRC's SE did not address the uncertainty associated with the measurement of residual stresses on the surface and effective depth of peened components. The surface stress and effective peening depth are key parameters in crack growth calculations. Growth of cracks which exist, but are not detected, at the time of peening affect the timing of post-peening inspections. At the time of its review of MRP-335, Revision 3-A, the NRC noted that issues associated with qualification of peening processes, including measurement uncertainties, should be addressed on a plant-specific basis and that plants desiring inspection relief in accordance with MRP-335, Revision 3-A, should propose alternatives to the requirements of 10 CFR 50.55a(g)(6)(ii)(D) in accordance with 10 CFR 50.55a(z).

The NRC staff evaluated the technical basis in the proposed relief request to determine whether the inspection relaxation requested for peened RPVHPNs is acceptable based on the peening qualification, plant specific implementation, and proposed inspection intervals.

4.2 Peening Qualification

Exelon stated that the purpose of its qualification testing program is to demonstrate that the proposed peening process will achieve the area of coverage, depth of compression and surface stresses as required by MRP-335, Revision 3-A. Exelon accomplished its qualification program by peening 18 full-scale mockups using a variety of essential variables; measuring the results of the surface and at-depth residual stresses over the area required to be peened; adjusting the as-measured stresses to account for operating stresses and shakedown through finite element analyses; and assessing the susceptibility of the peened surfaces to PWSCC through testing.

[[

]]

The NRC staff finds that even when the minimal essential variable values were used in the field, Exelon added additional coverage area and more process on time to achieve the baseline results. Therefore, the NRC staff finds that the proposed peening process meets the performance criteria of MRP-335, Revision 3-A.

Essential Variables

[[

.]]

[[

]]

The NRC staff finds that Exelon satisfactorily clarified how the acceptable range of [[ ]] was determined. The staff further finds that the [[ ]] were determined based on a combination of the field implementation requirements, equipment capabilities, and performance criteria as specified in MRP-335, Revision 3-A. The staff finds that the licensee's approach to these issues to be in accordance with engineering principles on the subject matter and, therefore, acceptable.

The NRC staff finds that the essential variables considered in the qualification testing are reasonable because these variables will affect the residual stress and depth of compression achieved in the nozzles and J-groove welds at the plant.

Stress Measurements and Measurement Uncertainty

Exelon used XRD to measure the stresses on the mockups. The NRC staff notes that there have been questions concerning the accuracy of the XRD technique because of its measurement uncertainty and error based on various laboratory testing. [[ ]] The NRC staff finds that the results of the qualification meets the performance criteria defined in MRP-335, Revision 3-A, and that Exelon has satisfactorily clarified the measurement error values in the SPQR.

The NRC staff finds that Exelon has evaluated the XRD measurement errors using a reasonable error band. The NRC staff finds that Exelon used industry standards and guidelines to determine the accuracy of their measurements. Further, Exelon used a third-party review to assist in validation of its stress measurements. The NRC staff found Exelon's determination of error of each measurement was reasonable and in accordance with acceptable engineering practices. In no case did the use of these uncertainties cause a performance criteria to not be met. **[[**

]]

Deviation of Peening Qualification

As noted in Section 3.6.2 of this SE, under "Qualification Testing Results," Exelon identified instances of deviations during peening qualification. The NRC staff finds that Exelon has satisfactorily addressed the deviations during peening qualification because Exelon determined that the deviations did not affect surface compression magnitude or depth of compression or were outside the high-stress area of interest. Based on its review of the deviations and subsequent Exelon action, the NRC staff finds that Exelon resolved the peening qualification issue and that all baseline parameters obtained in the qualification tests achieved acceptable peening results.

Residual and Operating Stress Analysis

Topical report MRP-335, Revision 3-A, requires that operating stresses be more compressive that +10 ksi (tensile). Exelon proposed that the peening parameters used will produce a peened surface that meets this criterion. Exelon demonstrated compliance through measurement of post-peening stresses at ambient conditions and adjustment of the measured stresses via finite element analysis to reflect operating conditions (pressure and temperature) and shakedown (loss of peening stresses via thermal cycles). **[[**

]]

[[

]] Exelon also stated that even when the worst-case uncertainties are applied to the above values, the residual stresses meet the requirements of MRP-335, Revision 3-A.

The NRC staff finds that Exelon's residual and operating stress analysis used appropriate input from the stress obtained in the qualification testing; used appropriate finite element model; and considered loads from operating conditions, transients, and shakedowns. Therefore, the NRC staff finds that the stress analysis is acceptable. The NRC staff finds that Exelon has demonstrated that at all representative points in the finite element model evaluated, the steady-state residual plus operating stress is less than the +10 ksi required by MRP-335, Revision 3-A. The NRC staff finds that the stress analysis result provides a basis that peening is viable.

PWSCC Evaluation

The NRC staff noted that Exelon performed testing for crack initiation and growth as part of the peening qualification. Exelon exposed peened and unpeened Alloy 600 specimens in simulated nominal PWR primary environment. The test results show that all of the non-peened specimens were heavily cracked whereas the peened specimens were not cracked. The peened samples had only 0.01-inch of depth of compression which is only 1/4 of the peening depth required for outer surfaces.

The NRC staff recognizes the results of Exelon's laboratory studies and analyses demonstrating favorable outcome in terms of PWSCC initiation and crack growth in the depth of compression of a peened component. The NRC staff finds that Exelon's testing is reasonable because it used simulated PWR primary coolant environment, standard bend specimens, and appropriate duration. The staff finds that Exelon's PWSCC testing provides additional evidence that peening will minimize crack initiation. The staff finds that Exelon has demonstrated that PWSCC initiation is not expected in the peened locations based on: (1) operating experience; (2) laboratory experience with surface stress improvement; and (3) stress analysis results considering residual stresses, operating conditions, and stress sustainability that meet the requirements of MRP-335, Revision 3-A.

As for the life of peened RPVHPNs, Exelon concluded that if no PWSCC flaws are present, a peened nozzle is estimated to have a life of more than 60 years. If a PWSCC flaw is deeper than the depth of compression, the life of the peened nozzle could be very short. However, the reduced tensile stresses near the peened nozzle surface may reduce crack growth rates and result in a longer life for the peened nozzle. Exelon stated that if a PWSCC flaw is located within the compressive stress layer of the peened nozzle, the estimated life could be between these two cases. Exelon concluded that its proposed inspection schedule is appropriate for identifying all preexisting cracks, irrespective of whether they are fast or slow growing. Based on MRP-395, Revision 3, and the technical paper, "Deterministic Technical Basis for Re-Examination Interval of Every Second Refueling Outage tor PWR Reactor Vessel Heads Operating at T_{cold} with Previously Detected PWSCC," No. PVP 2016-64032, Copyright 2016 by ASME (http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=2590183), the NRC staff finds that regardless whether there is a crack in the peened RPVHPNs, the proposed inservice examinations provide reasonable assurance that the peened RPVHPNs will maintain structural integrity to the end of plant life.

4.3 Plant-Specific Peening Implementation

The NRC staff finds that Exelon has satisfied MRP-335, Revision 3-A, Performance Criterion 4.3.8.1 (i.e., stress effect and magnitude of surface stresses), because Exelon peened additional paths (overlapping) on the nozzle and J-groove to reduce the likelihood of areas that are not peened. The peening process includes the steps for peening overlap. The NRC staff further finds that Exelon has peened the nozzle and J-groove weld areas that are consistent with Figure 2 of ASME Code Case N-729-4. The staff notes that the area contained in Figure 2 of ASME Code Case N-729-4 exceeds both the area required by MRP-335, Revision 3-A, and the area where tensile stresses higher than +20 ksi are expected. Based on the above, the NRC staff finds that the peening coverage is acceptable.

The NRC staff finds that Exelon has considered the necessary essential variables in the field application based on qualification testing on mockups. Therefore, the staff finds that essential variables considered are acceptable.

4.4 Inspection Requirements

Based on Exelon's qualification tests, stress analysis, PWSCC evaluation, and site-specific implementation, the NRC staff determines that peening will provide the necessary compressive stresses with a depth of compression on the RPVHPNs and J-groove welds to minimize PWSCC initiation. Therefore, the NRC staff finds that the alternative to perform the inservice examination once every 10 calendar years after peening provides an acceptable level of quality and safety.

As stated above, Exelon proposed to perform the follow-up inspection of peened RPVHPNs during the N+4 refueling outage instead of during the N+2 refueling outage as specified in MRP-335, Revision 3-A.

The NRC assessed this request by evaluating the proposed crack growth methodology and assessing issues relating to defense in depth measures. The NRC staff notes that Braidwood Unit 2 has the 'cold' reactor vessel head (i.e., EDY less than 8) whose RPVHPNs have not experienced any degradation. If crack does occur in the cold head, crack growth in the cold head would be slower than in the 'hot' head.

Exelon stated that it calculated the RIY = 1.62 at the time of peening or end of Cycle 19 for Braidwood, Unit 2, using the equation in Code Case N-729-1 with actual, plant-specific data. Using this same equation beginning at the time of the most recent volumetric examination (i.e., prior to the start of Cycle 20), the projected RIY for Cycle 20 through the end of Cycle 23 (i.e., 4 cycles later) was calculated to be 1.84. This value satisfies the most recent revision (Code Case N-729-4), Table 1, Item B4.20 requirement which specifies a maximum volumetric re-examination frequency of every 8 calendar years or before RIY = 2.25. Exelon stated that because the reactor pressure vessel RIY is less than 2.25 through the end of Cycle 23, a follow-up volumetric inspection in the N+4 refueling outage is supported.

The NRC staff determines that the plant can operate for a significantly longer time before experiencing significant reactor vessel closure head corrosion or nozzle ejection. The staff notes that significant defense-in-depth exists with respect to inspections of the RPVHPNs in that bare metal visual examinations will be performed every refueling outage as required by the NRC SE for MRP-335, Revision 3-A. Additionally, Exelon has reactor coolant system leakage detection capability to monitor low levels of leakage in the containment. The NRC staff notes that the proposed follow-up inspection at the N+4 refueling outage is acceptable because: (1) the reactor vessel head at Braidwood, Unit 2, is 'cold' (i.e., EDY is less than 8), (2) periodic volumetric examinations in the past and a baseline pre-peening examination were performed, (3) RPVHPNs have not experienced any degradation, (4) no deviation from the peening process during peening application in the field, (5) any potential surface connected cracking would be detected by the bare metal visual examination which will be performed every refueling outage, and (6) the predicted RIY is less than the required value of 2.25.

Based on the above evaluation, the NRC staff finds that the proposed alternate schedule for the follow-up inspection and inservice examination provides reasonable assurance of the structural integrity and leakage tightness of peened RPVHPNs.

5.0 CONCLUSION

As set forth above, the NRC staff determines 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 relief request I4R-07 for the fourth ISI interval at Braidwood, Unit 2, currently scheduled to start on October 16, 2018, and end on October 16, 2028.

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.

Principal Contributor: J. Tsao, NRR/DMLR/MPHB

Date of issuance: June 4, 2018

SUBJECT: BRAIDWOOD STATION, UNIT 2 – RELIEF FROM THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS CODE (EPID L-2017-LLR-0155) DATED JUNE 4, 2018

DISTRIBUTION:
NON-PUBLIC
RidsACRS_MailCTR Resource
RidsNrrDmlrMphb Resource
RidsNrrDorlLpl3 Resource
RidsNrrLAIBetts Resource
RidsNrrLAJBurkhardt Resource
RidsNrrLASRohrer Resource
RidsNrrPMBraidwood Resource
RidsRgn3MailCenter Resource
JTsao, NRR/DMLR/MPHB

ADAMS Accession Nos.:
Proprietary: ML18121A288
Non-Proprietary: ML18162A184 *via email

OFFICE	NRR/DORL/LPL3-2/PM	NRR/DORL/LSPB/LA	NRR/DMLR/MPHB/BC*
NAME	JWiebe	SRohrer	DAlley
DATE	05/03/18	05/03/18	04/18/18
OFFICE	NRR/DORL/LPL3/BC		
NAME	DWrona		
DATE	06/04/18		

OFFICIAL RECORD COPY