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

November 13, 2017

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 ASME CODE (CAC NO. MF9597, EPID L-2017-LLR-0021)

Dear Mr. Hanson:

By letter dated March 31, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17095A268), as supplemented by letter dated July 14, 2017 (ADAMS Accession No. ML17200C952), 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, Unit 1.

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 I3R-22 for the remainder of the third inservice inspection interval at Braidwood Station, Unit 1, currently scheduled to end on July 28, 2018.

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 In-service Inspector.

Enclosure 2 transmitted herewith contains sensitive unclassified 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. STN 50-456

Enclosures:

1. Safety Evaluation (Public)
2. Safety Evaluation (Official Use Only – Proprietary)

cc w/encl 1: Distribution via Listserv

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

SAFETY EVALUATION BY THE OFFICE NUCLEAR REGULATION

RELIEF REQUEST I3R-22 REGARDING

EXAMINATION OF REACTOR PRESSURE VESSEL HEAD PENETRATION NOZZLES

EXELON GENERATION COMPANY, LLC

BRAIDWOOD STATION, UNIT 1

DOCKET NO. 50-456

Proprietary information pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 2.390 has been redacted from this document. Redacted information is identified by blank space enclosed within double brackets as shown here [[ ]].

Enclosure 1

1.0 INTRODUCTION

By letter dated March 31, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17095A268), as supplemented by letter dated July 14, 2017 (ADAMS Accession No. ML17200C952), 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 American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, requirements at Braidwood Station, Unit 1.

Pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(z)(1), Exelon submitted relief request I3R-22 to perform alternate examinations of peened reactor pressure vessel head penetration nozzles (RPVHPNs) and associated J-groove 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.

10 CFR 50.55a(g)(6)(ii)(D), *Reactor vessel head inspections,* requires licensees of pressurized water reactors to augment their inservice inspection interval (ISI) of the reactor vessel closure head (RVCH) with ASME Code Case N-729-4, "Alternative Examination Requirements for PWR [Pressurized Water Reactor] Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds, Section XI, Division 1," with conditions. As a result of recent rulemaking, *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.

Exelon stated in its submittal and supplement (in the remainder of this safety evaluation (SE), "Exelon stated" or "Exelon noted," refers to its submittal dated March 31, 2017 (ADAMS) Accession No. ML17095A268), as supplemented by letter dated July 14, 2017 (ADAMS Accession No. ML17200C952)), that nozzle Nos. 67, 71, and 73, and the vent line nozzle will not be credited with the reduced inspection frequency because these four nozzles did not receive adequate peening. Exelon plans to re-peen these four nozzles during subsequent refueling outage(s) and will reevaluate these four nozzles for compliance with the peening qualification process. Exelon stated that once these four nozzles have been mitigated in accordance with Section 4.3.8 of MRP-335, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," Revision 3-A (ADAMS Accession No. ML16319A282), and documented to meet the requirements as part of the design control process, these four nozzles will be credited with the requested reduced inspection frequency inspection schedule.

The numbered RPVHPNs (1 through 78) are categorized into four groups. There are 53 control rod drive mechanism nozzles with thermal sleeves, 2 reactor vessel level indication system nozzles with modified thermal sleeves, 5 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 (RVCH) 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 third ISI interval is the ASME Code, Section XI, 2001 Edition including Addenda through 2003. The Code of Construction is the ASME Code, Section III, 1971 Edition through Summer 1973 Addenda.

3.3 Applicable Code Requirement

At the time of the licensee's submittals dated March 31 and July 14, 2017, 10 CFR 50.55a(g)(6)(ii)(D) required the inspection of RPVHPNs using ASME Code Case N-729-1 with certain conditions. The licensee requested, in part, relief from 10 CFR 50.55a(g)(6)(ii)(D)(*5*), which requires the volumetric inspection every refueling outage for RPVHPN with existing cracks.

On July 18, 2017, the *Federal Register* (82 FR 32934) published an 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.

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 [primary water stress corrosion cracking], 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

Exelon stated that because flaws attributed to PWSCC have been identified in RPVHPNs at Braidwood Station, Unit 1, the RPVHPNs are examined volumetrically and/or using surface techniques every scheduled refueling outage in accordance with the above requirements.

Because the inspection requirements remain the same between ASME Code Cases N-729-1 and N-729-4, and in an effort to reduce unnecessary regulatory burden, the NRC did not request the licensee to revise their relief request to reference ASME Code Case N-729-4 with conditions as specified in 10 CFR 50.55a(g)(6)(ii)(D). As a result, this SE will frequently refer to Code Case N-729-1 despite the fact that ASME Code Case N-729-4 as conditioned in 10 CFR 50.55a(g)(6)(ii)(D) is applicable to the licensee's relief request by the first refueling outage starting after August 17, 2017, as specified in the rule.

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

Exelon stated that the examination schedule of ASME Code Case N-729-1 does not address the effects of peening or the associated inspection frequency for RPVHPNs. Electric Power Research Institute (EPRI) developed, by analysis, a volumetric or surface reexamination interval for RPVHPNs and J-groove welds that have received peening application as documented in the topical report, MRP-335, Revision 3-A. The technical basis in MRP-335, Revision 3-A, demonstrates that for any peening process meeting the performance criteria, the re-examination interval can be extended.

Exelon peened RPVHPNs and associated J-groove welds using the ultra high pressure cavitation peening process in the 2016 refueling outage at Braidwood Station, Unit 1.

3.5 <u>Proposed Alternative</u>

In lieu of volumetric and/or surface examining the RPVHPNs and J-groove welds every refueling outage per 10 CFR 50.55a(g)(6)(ii)(D)(5), Exelon proposed the following:

(a) Exelon proposed to perform the required ISI examinations after completion of the follow-up inspection per Item No. B4.60, Table 4-3 of MRP-335, Revision 3-A (i.e., once every 10-year inspection interval). The ISI Examinations include volumetric or surface examinations of peened RPVHPNs and a demonstrated volumetric or surface leak path assessment through all J-groove welds each time the periodic volumetric or surface examination is performed at an interval not to exceed one inspection interval.

(b) Exelon proposed not to perform the follow-up inspection in the first (N+1) refueling outage after peening implementation, but will perform the examination in the second (N+2) refueling outage.

Exelon stated that it will continue to perform bare-metal visual examination of all RPVHPNs per the requirements of Code Case N-729-1 (or an NRC approved later version) during each refueling outage.

Exelon noted that prior to peening application, it performed a base line RPVHPN inspection in accordance with ASME Code Case N-729-1 as conditioned by 10 CFR 50.55a and found no conditions requiring repair in the areas of RPVHPNs to be peened.

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

Exelon stated that when the applicable MRP-335, Revision 3-A, performance criteria are met, peening mitigation prevents initiation of PWSCC. Exelon further stated that the flaws that are not detected in the pre-peening nondestructive examination are addressed through the required follow-up inspection. Exelon proposed to perform the follow-up examination during the second refueling outage (N+2) after application of peening. Exelon noted that peening also has the benefit of arresting PWSCC growth of shallow surface flaws that are located in regions at the surface where the residual plus normal operating stress is compressive.

To prevent the initiation of new PWSCC, peening has to reduce the peak tensile stresses at the wetted surface of material to be less than the "threshold" stress for initiation of PWSCC. Exelon stated that based on laboratory testing, a tensile stress of +20 kilopound per square inch (ksi) is a conservative 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. Transient stresses that occur only for relatively short periods of time are not applicable. Exelon stated that the MRP-335 performance criterion provides additional conservatism by limiting the surface stress to +10 ksi (tensile) for the case of RPVHPNs when normal operating stresses are considered.

Exelon stated that the follow-up examination and bare metal visual examination monitor the potential for growth of small flaws in the RPVHPNs and J-groove weld that are too shallow to be reliably detected in the pre-peening ultrasonic (UT) examination. Exelon further stated that for the cold head operating conditions of the RPVHPNs and 18 month refueling cycle at Braidwood Station, conducting the first inspection at the N+2 outage (36 months post-peening) was sufficient to identify any cracking that may have been missed in the pre-peening inspection. Exelon based this assertion on MRP-335, Revision 3-A, Section 5.2.3.2 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) (PVP paper).

Exelon noted 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 explained that the unpeened residual stress of the material does not have a significant effect on the final peened surface compressive stress and depth of compression. Exelon stated that testing shows that regardless of the initial stress state (i.e., high tension or high compression), the final stresses will be compressive.

3.6.2 Peening Performance Criteria

MRP-335, Revision 3-A, specifies the following key performance criteria:

(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., Alloy600/82/182) 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: 0.04 inches 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 (i.e., 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 consists of qualification testing on mockups, analysis of residual and operating stresses, PWSCC evaluation, and disposition of deviations during mockup testing.

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 March 31, 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 inside diameter 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.

Residual Stress Measurements

As part of peening qualification, Exelon measured residual stresses in the peened mockups 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-355 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 Braidwood Station's 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 that 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.

Residual Stress Measurement, Accuracy, and Effect

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

]]

[[

]]

[[

]]

Exelon stated that the XRD measurement errors are assessed for the minimum nominal depth of compression, 0.04 inch for outside diameter surfaces and 0.01 inch for inside diameter 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% 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 outside diameter surface (at the depth of 0.04 inch) and inside diameter 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.

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. However, Exelon noted that the site implementation did result in a number of deviations as documented in various condition reports (CRs) which are discussed further in this SE.

[[

]]

[[

]]

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, 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, 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. Exelon compared surface roughness measurements before and after peening on representative mock-up test coupons. Exelon confirmed 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 confirmed 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 un-peened conditions are not high enough to raise the risk of inducing PWSCC initiation.

Based on 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

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 pressure and temperature, Exelon performed a residual and operating stress analysis.

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

Exelon noted that the 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 evaluated, the steady-state residual plus operating stress is 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 stated that the post-peening residual plus operating surface stress levels 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 performed PWSCC evaluation to determine the susceptibility of the peened RPVHPN locations to PWSCC and to estimate the life of the peened locations. The PWSCC evaluation addresses the susceptibility of the peened 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 pressurized water reactors to determine the extent of stress corrosion cracking of peened vs non-peened samples. The peened samples were mitigated to a compressive depth of 0.01 inch, which meets the minimum nozzle inside diameter 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 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.

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 concluded that in a laboratory study, cracks within the compressive stress layer are expected to arrest.

Exelon asserted that its proposed inspection schedule (N+2 followed by inspections at 10 year intervals) is appropriate for identifying all preexisting cracks, irrespective of whether they are fast or slow growing. As a basis for this position, Exelon referenced topical report, MRP-395 Revision 3, "Materials Reliability Program: Reevaluation of Technical Basis for Inspection of Alloy 600 PWR Reactor Vessel Top Head Nozzles (MRP-395), EPRI, Palo Alto, CA, 2014 (PVP paper) 3002003099," which discusses the inspection frequency for RPVHPNs. and the technical paper PVP 2016-64032. These documents consider the growth of PWSCC flaws under conditions consistent with the operating environment of these heads.

As a supplement to MRP-395, the technical paper PVP2016-64032 demonstrated the acceptability of a 36-month UT interval for reactor vessel heads with previously detected PWSCC that operate at T_{cold} temperature.

Technical paper PVP2016-64032 contains crack growth analyses based on the crack growth rate corresponding to the 95th percentile of the crack growth rate distribution used for the development of MRP-395 rather than the crack growth rate associated with the 75th percentile of the distribution. The 75th percentile is generally used for regulatory purposes and was used in MRP-395. The PVP paper stated that the use of the crack growth rate associated with the 95th percentile of the crack growth rate distribution represents the upper end of material susceptibility for RPVHPNs in U.S. pressurized water reactor plants.

The PVP paper calculated that a 10 percent through wall crack in an unpeened RPVHPN which is not detected by the volumetric examination and is allowed to grow at a rate consistent with the 95th percentile of the MRP-395 crack growth distribution will not begin to leak for at least two refueling outages (36 months). Based on the PVP paper, Exelon reasoned that, even without crediting changes in crack growth rate that may occur as a result of peening, the PVP paper supports its proposal to inspect in the N+2 refueling outage rather than inspecting in both the N+1 and N+2 refueling outages.

3.6.4 <u>Peening Implementation</u>

Description of Peened Area

As discussed in Attachment 2 to the March 31, 2017, letter, Exelon peened RPVHPNs and J-groove welds at Braidwood Station, Unit 1, in the 2016 refueling outage. Exelon peened the outer surface of the RPVHPNs and J-groove welds using an outside diameter 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 peening process to meet and exceed the 0.04 inch minimum depth of compression for OD of RPVHPNs.

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 testing demonstrated that the depth of compression required by MRP-335 for this location, 0.01 inch, could be reliably achieved.

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

Exelon noted that exceptions to the above peened RPVHPNs are nozzles that have been previously repaired, e.g., nozzles that were repaired by weld overlays. Exelon noted that J-groove weld and top portion of the outside surface of nozzle No. 69 has been mitigated with a weld overlay. For nozzle No. 69, peening of the weld repair area is not required because the weld overlay material, Alloy 52, is less susceptible to PWSCC than Alloy 82/182 weld material. However, Exelon did peen the required inside surface of the nozzle and the outside surface of the nozzle below the weld overlay to the top of the threads as required by MRP-335.

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 SPQR is the qualification report that demonstrates desired results are achieved per MRP-335 with a set of bounding parameters. The peening procedure used in the field implements the process per the requirements defined in the SPQR.

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 CR 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 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. Exelon stated that based on these results a follow-up inspection in the N+1 refueling outage is not necessary.

Peening Implementation Results

Exelon stated that it successfully completed peening of ID and OD surfaces of nozzle penetrations 1 - 78 in compliance with the SPQR except nozzles 67, 71, and 73, as discussed further below. Exelon stated that all performance requirements defined in MRP-335 have been met and in some cases substantially exceeded.

For nozzle penetrations 1 - 66, 68, 70, and 72, the entire required inspection area, as specified in ASME Code Case N-729-1, of the nozzle OD was fully peened. This substantially exceeds the peening coverage requirement defined in MRP-335.

For CETC nozzle penetrations with guide funnels, Nos. 74 to 78, part of the guide funnel was removed to provide access to enable achieving 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, Revision 3-A.

Nozzle penetration No. 69 has an embedded flaw repair which required a modified nozzle segment motion profile to be run. This motion profile applied cavitation peening to the exposed OD portion of the nozzle between the embedded flaw repair and the threaded region of the nozzle as shown in the SPQR.

Peening Implementation Deviations

Exelon identified peening process anomalies in nozzle Nos. 1, 42, 67, 71, 73, and 75, and the vent line as discussed below. Exelon stated that the anomalies for nozzle Nos. 1, 42, and 75 are not significant with respect to the requirements of MRP-335, Revision 3-A. However, Exelon found that the deviation associated with nozzle Nos. 67, 71, 73, and the vent line requires further verification by testing and may require re-peening in a future refueling outage.

Exelon stated that all essential variables/critical parameters remained within qualified ranges as defined in SPQR for the surfaces peened except as summarized below. There were several instances where essential variables or secondary variables were outside of the pre-defined ranges as specified in the SPQR during peening application in the field. Exelon evaluated the deviations in accordance with its vendor's 10 CFR Part 50, Appendix B condition reporting process.

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

Exelon stated that essential variables/critical parameters are monitored on a continuous basis during the peening application. Therefore, any deviation similar to that experienced in the CRs discussed above would be detected in an ongoing basis and further addressed. In addition, Exelon performed extent-of-condition reviews in relation to above CRs 2017-1767 (Tier 14B nozzles) and 2017-1944 (vent line nozzle). Exelon determined that these issues were isolated to the nozzles in Tier 14B and vent line and corrected for future applications.

3.7 Duration of Proposed Alternative

The proposed alternative is requested for the remainder of the third Inservice Inspection Interval for Braidwood Station, Unit 1, currently scheduled to end on July 28, 2018.

4.0 NRC STAFF EVALUATION

4.1 Background

In its SE for MRP-335, 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, 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).

For Braidwood Station, Unit 1, 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. 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 results of the qualification meets the performance criteria defined in MRP- 335, Revision 3-A. The NRC staff finds 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 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, above, 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

MRP-335 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.

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 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 provide a base 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 result 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 ¼ 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 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. If a PWSCC flaw is located within the compressive stress layer of the peened nozzle, the estimated life could be between these two cases, but the flaw is expected to arrest. Exelon concluded that its proposed inspection schedule (N+2 followed by inspections at 10 year intervals) is appropriate for identifying all preexisting cracks, irrespective of whether they are fast or slow growing. Based on MRP-395, Revision 3, and paper PVP 2016-64032, the NRC staff finds that regardless whether there is a crack in the peened RPVHPNs, the proposed inservice examinations (N+2 followed by inspections at 10 year intervals) 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 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 N-729-1. The staff notes that the area contained in Figure 2 of ASME Code Case N-729-1 exceeds both the area required by MRP-335 and the area where stresses more tensile than +20 ksi are expected. Based on 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.

The NRC staff determined that Exelon peening of the RPVHPNS and J-groove welds was acceptable for most of the nozzles with the following deviations.

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

[[

]]

The NRC staff finds that nozzle Nos. 67, 71, 73, and vent line are required to be re-tested to verify if MRP-335 requirements are met. If not, these nozzles will be re-peened to meet MRP-335 requirements. The NRC notes that this SE applies to these four nozzles after the four nozzles have been either repeened or retested showing that they satisfy the performance criteria of MRP-335, Revision 3-A.

The NRC staff finds that Exelon adequately explained the cause of the peening deviations and provided corrective actions to resolve the deviations. The staff finds it acceptable for the licensee to apply the approved relief to the affected nozzles only when the nozzles have been verified to meet the MRP-335 requirements.

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 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.

Exelon asked not to volumetrically inspect the peened RPVHPNs at the N+1 refueling outage and provided a deterministic assessment based on the 95 percentile of the crack growth rate distribution which bounds all actual data pertinent to this issue. The NRC assessed this request by evaluating the proposed crack growth methodology and assessing issues relating to defense-in-depth.

The NRC staff finds that the methodology used by the licensee to reach a conclusion that leakage will not occur in less than two refueling outages is consistent with generally accepted engineering practice. The staff determines that even under the scenario that a 10 percent through wall crack exists (and is not detected at the time of peening) the plant can operate for two fuel cycles before the peened nozzles leak. The staff further determines that the plant can operate for a significantly longer time before experiencing significant reactor vessel closure head corrosion or nozzle ejection. The NRC 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. Additionally, Exelon has reactor coolant system leakage detection capability to monitor low levels of leakage in containment.

Therefore, the NRC staff finds that the alternative to eliminate the first (N+1) refueling outage examination provides an acceptable level of quality and safety.

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 I3R-22 for the remainder of the third inservice inspection interval at Braidwood Station, Unit 1, currently scheduled to end on July 28, 2018.

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 In-service Inspector.

Principal Contributor: J. Tsao, NRR/DE/EPNB

Date of issuance: November 13, 2017

SUBJECT: BRAIDWOOD STATION, UNIT 1, RELIEF FROM THE REQUIREMENTS OF THE ASME CODE (CAC NO. MF9597) DATED NOVEMBER 13, 2017

DISTRIBUTION:
PUBLIC w/encl 1
RidsNrrDorlLpl3-2 Resource
RidsNrrPMByron Resource
RidsNrrPMBraidwoodResource
RidsNrrLASRohrer Resource
RidsRgn3MailCenter Resource
RidsNrrDorlDpr Resource
RidsAcrs_MailCTR Resource

ADAMS Accession No.: ML17249A298 ***via e-mail**

OFFICE	DORL/LPL3-2/PM	DORL/LPL3-2/LA	EPNB/BC	DORL/LPL3/BC
NAME	JWiebe	SRohrer	DAlley*	DWrona
DATE	9/25/17	9/19/17	9/18/17	11/13/17

OFFICIAL RECORD COPY