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

January 10, 2018

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

SUBJECT: BYRON STATION, UNIT 1 – RELIEF FROM THE REQUIREMENTS OF THE ASME CODE (CAC NO. MF9854; EPID L-2017-LLR-0042)

Dear Mr. Hanson:

By letter dated June 15, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17170A146), 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 (ASME) *Boiler and Pressure Vessel Code* (ASME Code), Section XI, requirements at Byron Station (Byron), 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 I4R-15 for the remainder of the fourth inservice inspection interval at Byron, Unit 1, currently scheduled to end on July 15, 2025.

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. STN 50-454

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-15 REGARDING EXAMINATION OF

REACTOR PRESSURE VESSEL HEAD PENETRATION NOZZLES

EXELON GENERATION COMPANY, LLC

BYRON STATION, UNIT 1

DOCKET NO. 50-454

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 [[ ]].

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1.0 INTRODUCTION

By letter dated June 15, 2017 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17170A146), 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 (ASME) Boiler and Pressure Vessel Code (ASME Code), Section XI, requirements at Byron Station (Byron), Unit 1.

Specifically, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(z)(1), Exelon submitted relief request I4R-15 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.

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, *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 the ASME Code, Section XI, 2007 Edition including Addenda through 2008. 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 June 15 and July 14, 2017, the regulations under 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 RPVHPNs 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 identifies the location of the current regulatory requirements.

1. Paragraph 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 [primary water stress-corrosion cracking (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.

Exelon stated that because flaws attributed to PWSCC have been identified in RPVHPNs at Byron, 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 its 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 safety evaluation (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 surface stress improvement by peening or the associated inspection frequency for RPVHPNs that have been peened. The 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, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 3-A)," November 2016 (ADAMS Accession No. ML16319A282). 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 2017 refueling outage at Byron, Unit 1.

3.5 Proposed Alternative

The licensee proposed the following alternative 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):

(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 baseline 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 Byron, Unit 1, 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," Paper No. PVP2016-64032, Copyright 2016 by ASME (PVP Paper; publicly available at http://proceedings.asmedigitalcollection.asme.org/data/conferences/asmep/90477/v01bt01a046-pvp2016-64032.pdf).

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

Revision 3-A of MRP-335 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., 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 consists of qualification testing on mockups, analysis of residual and operating stresses, PWSCC evaluation, and disposition of deviations during mockup testing as discussed below.

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 June 15, 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. **[[**

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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

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.

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A few of the Byron, Unit 1, 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.

Residual Stress Measurement, Accuracy, and Effect

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. [[

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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). **[[**

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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.

<u>Qualification Testing Results</u>

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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. 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 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 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 in the finite element model 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. **[[**

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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) **[[**

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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.

<u>PWSCC Evaluation</u>

Exelon evaluated 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 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 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)," September 2014 (ADAMS Accession No. ML14307B007), which discusses the inspection frequency for RPVHPNs. and the technical paper PVP 2016-64032 (PVP Paper). These documents consider the growth of PWSCC flaws under conditions consistent with the operating environment of these heads.

As a supplement to MRP-395, Revision 3, the PVP Paper demonstrated the acceptability of a 36-month UT interval for reactor vessel heads with previously detected PWSCC that operate at T_{cold} temperature.

The PVP Paper 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, Revision 3, 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, Revision 3. 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. PWR 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>

<u>Description of Peened Area</u>

As discussed in Attachment 2 to the June 15, 2017, letter, Exelon peened RPVHPNs and J-groove welds at Byron, Unit 1, 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 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, Revision 3-A, 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, Revision 3-A. 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 by weld overlays. Exelon noted that J-groove weld and top portion of the outside surface of nozzle number 31, 43, 64, and 76 have been mitigated with weld overlays. For these nozzles, 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 these four nozzles and the outside surface of these nozzles below the weld overlay to the top of the threads as required by MRP-335.

<u>Process Description</u>

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, 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.

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

Peening Implementation Results

In Attachment 2 to the June 15, 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. Exelon stated that all performance requirements defined in MRP-335, Revision 3-A, have been met and in some cases substantially exceeded.

Exelon stated that it peened the entire required outside surface inspection area of nozzle penetration numbers 1-30, 32-42, 44-63, 65-74, and 77, as specified in ASME Code Case N-729-1.

Nozzle penetration numbers 31, 43, and 64 have an embedded flaw repair which required a modified nozzle segment motion profile to be applied. This motion profile applied 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.

For CETC nozzle penetrations with guide funnels (numbers 75 and 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 outside surface area of the nozzle 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.

The CETC nozzle penetration number 76 has an embedded flaw repair that extends down approximately 1/2 inches above the CETC guide funnel. For this nozzle, the guide funnel was removed and the full nozzle and remainder segments of a standard motion profile were run, in addition to the modified nozzle segment motion profile. The result is the entire outside surface portion of the nozzle not covered by the threads has been fully peened.

Exelon stated that it successfully completed peening of inside surfaces of nozzle penetration numbers 1 to 78 in compliance with the SPQR. Exelon stated that all performance requirements defined in MRP-335, Revision 3-A, have been met and, in some cases, substantially exceeded.

Exelon stated that the inside and outside surfaces of the vent line nozzle and associated J-groove weld have been peened successfully.

Peening Implementation Deviations

Exelon identified the following in-process deviations discussed in its CRs as shown in its July 14, 2017, letter. In all cases, Exelon corrected the deviations and successfully re-peened the affected nozzles during the 2017 refueling outage.

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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.

3.7 Duration of Proposed Alternative

Exelon requested the proposed alternative for the remainder of the fourth ISI interval for Byron, Unit 1, currently scheduled to end on July 15, 2025.

4.0 NRC STAFF EVALUATION

4.1 Background

In its 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).

For Byron, 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, 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.

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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

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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. **[[**

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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). **[[**

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]] 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 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 the PVP Paper, 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, 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-729-1. 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, 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.

The NRC staff notes that there were deviations related to peening as shown in Section 3.6.4 of this SE, under the heading "Peening Implementation Results." However, for each of the

deviations, Exelon was able to re-peen the affected nozzles successfully. The NRC staff determined that Exelon's peening of the RPVHPNS and J-groove welds was acceptable for all nozzles.

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^{th} 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 NRC 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 I4R-15 for the remainder of the fourth ISI interval at Byron, Unit 1, currently scheduled to end on July 15, 2025.

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.

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Date of issuance: January 10, 2018

SUBJECT: BYRON STATION, UNIT 1 - RELIEF FROM THE REQUIREMENTS OF THE ASME CODE (CAC NO. MF9854; EPID L-2017-LLR-0042) DATED JANUARY 10, 2018

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