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10 CFR 50.55a

RS-18-108

August 30, 2018

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

Byron Station, Unit 2
Renewed Facility Operating License No. NPF-66
NRC Docket No. STN 50-455

Subject: Request for Alternative Follow-up Inspection for Reactor Pressure Vessel Head Penetration Nozzles with Mitigated Alloy 600/82/182 Peened Surfaces in Accordance with 10 CFR 50.55a(z)(2)

References:

1) Letter from David J. Wrona (U.S. Nuclear Regulatory Commission) to Bryan C. Hanson (Exelon Generation Company, LLC), "Byron Station, Unit No 2 - Relief from the Requirements of the ASME Code (CAC No. MF9018)," dated September 19, 2017 (ML17249A241)

2) Letter from Kevin Hsueh, (U.S. Nuclear Regulatory Commission) to Matthew Sunseri, (EPRI), "Final Safety Evaluation of the Electric Power Research Institute MRP-335, Revision 3, 'Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement [Peening],' (TAC No. MF2429)," dated August 24, 2016 (ML16208A485)

3) Letter from Electric Power Research Institute (EPRI) to U.S. Nuclear Regulatory Commission, "Transmittal of Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 3-A), EPRI, Palo Alto, CA: 2016. EPRI Report 3002009241," dated November 8, 2016 (ML16319A282)

In accordance with 10 CFR 50.55a, "Codes and standards," paragraph (z)(2), Exelon Generation Company, LLC (EGC), is requesting relief from the current examination requirements of Reactor Pressure Vessel Head Penetration Nozzles (RPVHPN) performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Code Case N-729-4 on the basis that compliance with these requirements would result in hardship without a compensating increase in the level of quality and safety.

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EGC has implemented the Ultra High Pressure Cavitation Peening (UHPCP) process at Byron Station Unit 2. As documented in NRC Safety Evaluation (SE) dated September 19, 2017 (Reference 1), required inspections will be conducted in accordance with the inspection requirements for Alloy 600 RPVHPNs mitigated by peening, based on Reference 2 and Table 4-3 in MRP-335, Revision 3-A. MRP-335 R3-A Table 4-3 Note (11)(b) states that inspections shall be performed in the first (N+1) and second (N+2) refueling outages after peening mitigation, which are applicable to Byron Station Unit 2 since the UHPCP process was implemented. Relief was granted from the requirements of 10 CFR 50.55a(g)(6)(ii)(D) to permit the alternative in which inspection in the first refueling outage post peening application (N+1) is not performed. Therefore , the current authorized follow-up inspection is in the second refueling outage post peening application (N+2).

During the initial peening application in the spring 2016 refueling outage (B2R19), 9 RPVHPNs at Byron Station Unit 2 did not receive complete peening coverage meeting the performance criteria of MRP-335, Revision 3-A (Reference 3). Subsequently, EGC successfully peened the ID, OD, or both surfaces of these 9 penetrations (as needed) during the fall 2017 refueling outage (B2R20) to satisfy MRP-335, Revision 3-A requirements.

As discussed in the Attachment 1 Relief Request I4R-16, EGC proposes as an alternative to the requirements of 10 CFR 50.55a(g)(6)(ii)(D) and is requesting relief to perform a single follow-up inspection in the third (N+3) refueling outage for specific nozzles after peening considering hardship and considering assessments and supplemental evaluations that provide reasonable assurance of the low likelihood of leakage affecting the RPVHPNs at Byron Station Unit 2 under the proposed alternative. EGC requests for the 70 RPVHPNs that were peened during B2R19 that a single follow-up volumetric examination be performed during the third (N+3) refueling outage to align with the follow-up volumetric examination for the 9 RPVHPNs that were peened during B2R20. Approval of this request would allow EGC to align the timing of the follow-up volumetric examination of all 79 RPVHPNs to a single refueling outage, thereby reducing: personnel containment entries, risk of working in a locked high radiation area (LHRA) and total personnel collective radiation dose.

Supporting supplemental evaluations include the following:

1) Electric Power Research Institute (EPRI), Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 3-A), EPRI Publication No. 3002009241, Final Report, dated November 2016 (Reference 3)

2) Technical Note TN-4069-00-01, Revision 0, "MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing," Dominion Engineering, Inc., dated August 2018 (Attachment 2)

3) Technical Note TN-4069-00-02, Revision 0, "Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service," Dominion Engineering, Inc., dated August 2018 (Attachment 3)

In accordance with 10 CFR 50.55a(z)(2), the proposed alternatives may be authorized by the NRC provided a hardship without a compensating increase in quality and safety. EGC concludes the proposed alternatives meet this requirement.

EGC concludes that the follow-up inspections for the 70 identified RPVHPNs during the N+2 Unit 2 spring 2019 refueling outage (B2R21) and for the 9 RPVHPNs during the N+2 Unit 2 fall 2020 refueling outage (B2R22) per MRP-335 R3-A Table 4-3 Note (11)(b) constitutes a hardship without a compensating increase in level of quality or safety. Based on the assessment and supplemental evaluations, EGC concludes that the proposed alternative to extend the inspection of the 70 identified nozzles to N+3 to align with the 9 nozzles would provide an acceptable level of quality and safety.

EGC requests approval of the proposed alternative by March 4, 2019, in support of the Byron Unit 2 spring 2019 refueling outage (B2R21).

There are no regulatory commitments contained within this letter.

Should you have any questions concerning this letter, please contact Ms. Lisa A. Simpson at (630) 657-2815.

Respectfully,

David M. Gullott
Manager – Licensing
Exelon Generation Company, LLC

Attachments:

1) 10 CFR 50.55a Relief Request I4R-16, Alternative Follow-Up Inspection for Reactor Pressure Vessel Head Penetration Nozzles with Mitigated Alloy 600/82/182 Peened Surfaces in Accordance with 10 CFR 50.55a(z)(2)

2) Dominion Engineering, Inc. Technical Note TN-4069-00-01, Revision 0, "MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing," dated August 2018

3) Dominion Engineering, Inc. Technical Note TN-4069-00-02, Revision 0, "Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service," dated August 2018

Cc: Regional Administrator – NRC Region III
NRC Senior Resident Inspector – Byron Station
Illinois Emergency Management Agency

ATTACHMENT 1

10 CFR 50.55a Relief Request I4R-16

Alternative Follow-Up Inspection for Reactor Pressure Vessel Head Penetration Nozzles with Mitigated Alloy 600/82/182 Peened Surfaces in Accordance with 10 CFR 50.55a(z)(2)

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Request for Relief
Alternative Follow-Up Inspection for Reactor Pressure Vessel Head Penetration Nozzles with Mitigated Alloy 600/82/182 Peened Surfaces in Accordance with 10 CFR 50.55a(z)(2)

1.0 ASME CODE COMPONENTS AFFECTED:

Component Numbers:	Unit 2, Reactor Vessel 2RC01R
Description:	Alternative Post Peening Follow-Up Inspection for Reactor Pressure Vessel Head Penetration Nozzles (RPVHPNs) Having Pressure-Retaining Partial-Penetration J-groove Welds with Mitigated Alloy 600/82/182 Peened Surfaces
Code Class:	Class 1
Examination Category:	ASME Code Case N-729-4
Code Item:	B4.20
Identification:	RPVHPN Numbers 1 through 66, 70, 72, 76 and 78 (P-1 through P-66, P-70, P-72, P-76 and P-78)
Reference Drawing:	Closure Head Assembly: 185282E
Size:	4 Inch Nominal Outside Diameter, 2.75 Inch Nominal Inside Diameter (Vent Nozzle NPS 1)
Material:	SB-167 UNS N06600 (Alloy 600), ENiCrFe-3 (Alloy 182), and ERNiCr-3 (Alloy 82)

2.0 APPLICABLE CODE EDITION AND ADDENDA:

Inservice Inspection (ISI) and Repair/Replacement Programs: American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, 2007 Edition including 2008 Addenda [1]. Examinations of the RPVHPNs are performed in accordance with 10 CFR 50.55a(g)(6)(ii)(D), which specifies the use of ASME Code Case N-729-4 with conditions.

Code of Construction [Reactor Pressure Vessel (RPV)]: ASME Section III, 1971 Edition through Summer 1973 Addenda.

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3.0 APPLICABLE CODE REQUIREMENT:

ASME Code Case N-729-4 contains requirements for the inspection of RPVHPNs, with or without flaws, as conditioned by 10 CFR 50.55a(g)(6)(ii)(D). The specific Code requirements for which use of the proposed alternative is being requested are as follows:

Code of Federal Regulations (CFR) 10 CFR 50.55a(g)(6)(ii)(D)(1) requires (in part):

"Holders of operating licenses or combined licenses for pressurized-water reactors as of or after August 17, 2017 shall implement the requirements of ASME BPV Code Case N-729-4 instead of ASME BPV Code Case N-729-1, subject to the conditions specified in paragraphs (g)(6)(ii)(D)(2) through (4) of this section, by the first refueling outage starting after August 17, 2017."

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" [2], Figure 2, "Examination Volume for Nozzle Base Metal and Examination Area for Weld and Nozzle Base Metal," is applicable to the RPVHPNs.

ASME Code Case N-729-4, Paragraph -2410 specifies that the reactor vessel upper head penetrations shall be examined on a frequency in accordance with Table 1 of the Code Case (Refer to [2], hereafter known as N-729-4). Since flaws attributed to Primary Water Stress Corrosion Cracking (PWSCC) have been identified at Byron Station Unit 2, the RPVHPNs are examined every fuel cycle per Table 1, Note (8), of ASME Code Case N-729-4 in accordance with Code Item B4.20.

As granted by the NRC under Safety Evaluation dated September 19, 2017 [3] and as an alternative to the requirements above, the required inspection will be conducted in accordance with the inspection requirements for Alloy 600 RPVHPNs mitigated by peening, based on Table 4-3 in MRP-335, R3-A (Refer to [4], hereafter known as MRP-335 R3-A). Relief was also granted from Final Safety Evaluation [5] Condition 5.4 requirement for inspection in the first refueling outage post peening application (N+1), which is reflected in MRP-335 R3-A Table 4-3 Note (11)(b). The current authorized follow-up inspection is in the second refueling outage post peening application (N+2), which is also reflected in MRP-335 R3-A Table 4-3 Note (11)(b).

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4.0 REASON FOR REQUEST:

Exelon Generation Company, LLC (EGC) has implemented the Ultra High Pressure Cavitation Peening (UHPCP) process at Byron Station Unit 2. In addition to the relief granted by the NRC under Safety Evaluation dated September 19, 2017 [3], EGC is requesting relief from the requirements of 10 CFR 50.55a(g)(6)(ii)(D) to permit performance of a single follow-up inspection subsequent to peening in the third (N+3) refueling outage for the nozzles identified in Section 1.0. MRP-335 R3-A Table 4-3 Note (11)(b) requires inspections to be performed in the first (N+1) and second (N+2) refueling outages after peening mitigation, which are applicable to Byron Station Unit 2 since the UHPCP process was implemented. Therefore, the current authorized follow-up inspection is in the second refueling outage post peening application (N+2).

During the initial peening application in spring 2016 (B2R19), 9 RPVHPNs at Byron Station Unit 2 did not receive complete peening coverage meeting the performance criteria of MRP-335 R3-A [4]. The specific affected nozzles are identified in a response to NRC Request for Additional Information submitted by EGC on July 14, 2017 [6]. Eight CRDM penetrations and the vent line penetration were affected (9 total penetrations). EGC successfully peened the ID, OD or both surfaces of these 9 penetrations (as needed) during the fall 2017 refueling outage (B2R20) to satisfy MRP-335 R3-A requirements. Therefore, all 79 RPVHPNs at Byron Station Unit 2 are now successfully peened in accordance with MRP-335 R3-A.

In 2017, the NRC approved mitigation credit in accordance with the requirements of MRP-335 R3-A [4] for the RPVHPNs at Byron Station Unit 2. As part of the Safety Evaluation [3], the NRC approved EGC's request to take exception to the follow-up volumetric examination specified by MRP-335 R3-A for the first (N+1) refueling outage after the baseline inspection. EGC requests for the 70 RPVHPNs that were peened in spring 2016 (B2R19), that the follow-up volumetric examination specified by MRP-335 R3-A for the second (N+2) refueling outage be extended by one cycle to the third (N+3) refueling outage to align with the follow-up volumetric examination for the 9 RPVHPNs that were peened during the fall 2017 refueling outage (B2R20). Approval of this request would allow EGC to align the timing of the follow-up volumetric examination of all 79 RPVHPNs to a single refueling outage, thereby reducing personnel containment entries, risk of working in a Locked High Radiation Area (LHRA) and total personnel collective radiation dose. Performance of the required follow-up inspection for the 70 identified nozzles (Section 1.0) during the N+2 Unit 2 spring 2019 refueling outage (B2R21) and for the 9 nozzles during the N+2 Unit 2 fall 2020 refueling outage (B2R22) is considered a hardship without a compensating increase in the level of quality and safety in accordance with 10 CFR 50.55a(z)(2) based on the assessments and supplemental evaluations described below.

As described in detail in section 5.0 below, considering radiological dose and industrial safety concerns and considering assessments based in part on the application of results in MRP-335 R3-A [4] for N+3 follow-up timing (deterministic analysis) and extension of experience for unmitigated CRDM nozzles in Technical Notes ([7], [8]), EGC is requesting that a single follow-up inspection be conducted in the N+3 refueling outage for the 70 identified RPVHPNs (i.e., to align with the N+2 inspection for the 9 RPVHPNs during the Unit 2 fall 2020 refueling outage (B2R22)).

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5.0 PROPOSED ALTERNATIVE AND BASIS FOR USE:

5.1. Proposed Alternative

MRP-335 R3-A [4] and the corresponding NRC Safety Evaluation [5] specify that for heads operating at reactor cold leg temperature (T_{cold}) (EDY < 8) with previously detected PWSCC, follow-up volumetric examinations be performed in the first (N+1) and second (N+2) refueling outages after the baseline inspection and peening are performed. EGC has already obtained approval for an alternative to the requirements of 10 CFR 50.55a(g)(6)(ii)(D) in which the follow-up volumetric examination specified by MRP-335 R3-A for the first (N+1) refueling outage after peening is not performed. As an alternative to the requirements of 10 CFR 50.55a(g)(6)(ii)(D), a single follow-up inspection is proposed to be conducted in the third (N+3) refueling outage for the 70 identified nozzles (Section 1.0) after peening considering hardship and considering assessments and supplemental evaluations that provide reasonable assurance of the low likelihood of leakage affecting the RPVHPNs at Byron Station Unit 2 under the proposed alternative. Synchronization of the follow-up inspection timing for all 79 nozzles at Byron Station Unit 2 would have the benefits of reducing the number of personnel containment entries, risk of working in a LHRA, and total personnel collective radiation dose. Supporting supplemental evaluations include: MRP-335, R3-A, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," November 2016 [4], Technical Note TN-4069-00-01, Revision 0, "MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing," August 2018 [7] and Technical Note TN-4069-00-02, Revision 0, "Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service," August 2018 [8].

The inspection frequency requirements for Item B4.60 RPVHPNs mitigated by peening surface stress improvement (SSI) per MRP-335 R3-A Table 4-3 [4] require a pre-peening baseline inspection, follow-up inspection, and subsequent in-service inspection. EGC's proposed alternative under this relief only applies to the follow-up inspection for the 70 identified RPVHPNs (Section 1.0), where a volumetric examination of 100% of the required volume or equivalent surfaces of the nozzle tube is to be performed and a leak path examination is also to be performed.

5.2. Basis for Hardship

The components listed in this request are located inside containment and in areas involving occupational radiation exposure. Volumetric testing of RPVHPNs requires personnel exposure during test equipment set-up, during testing and during demobilization of the test equipment. Volumetric testing of the 70 nozzles peened during B2R19 under the approved N+2 follow-up inspection would require an unnecessary increase in worker radiation exposure since similar equipment set-up, demobilization, and tool change-out activities are required at the following outage to inspect the other 9 nozzles peened during B2R20. The increase in exposure represents an activity adverse to As-Low-As Reasonably Achievable (ALARA) program practices.

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Based on exposure historical data at Byron Station, the additional occupational dose if volumetric testing of the RPVHPNs were performed in two separate outages is estimated to be approximately 240 to 272 mRem. This estimate includes approximately 80 mRem to set-up and demobilize equipment and approximately 160 to 192 mRem due to testing activities such as tool change-out and expected probe failure changes. A higher dose would be expected if difficulties during testing are experienced or if execution abnormalities occur due to a potential tool breakdown requiring LHRA entry and subsequent additional dose accrual.

In summary, performance of the examinations in two separate outages results in hardships that are not compensated for by a corresponding increase in safety or quality. Furthermore, performing inspections in two separate outages could introduce potential hazards to personnel safety for the following reasons:

1. Requires additional occupational radiation exposure due to entry inside containment. The increase in dose is estimated to be approximately 240 to 272 mRem based on historical data but can be higher if tool breakdowns or issues occur requiring additional personnel entry, which is inconsistent with industry ALARA practices.
2. Combining two inspections to one inspection reduces risk of industrial accidents. Fewer number of containment entries and potential entries to LHRA decreases the potential for industrial safety risks.
3. Potential for increases in contamination exposure due to entries inside containment and entry to LHRA.

As a result, EGC has concluded that performance of a follow-up inspection in the second refueling outage after peening for the 70 identified RPVHPNs (Section 1.0) during the N+2 Unit 2 spring 2019 refueling outage (B2R21) and for the 9 RPVHPNs during the N+2 Unit 2 fall 2020 refueling outage (B2R22) constitutes a hardship without a compensating increase in the level of quality and safety. The proposed alternative to perform the follow-up inspection for the 70 nozzles in the N+3 outage to align inspection for all 79 nozzles is supported by the assessments and supplemental evaluations under Section 5.3, which provides reasonable assurance of the low likelihood of leakage in RPVHPNs at Byron Station Unit 2.

5.3. Basis for Assessments and Supplemental Evaluations

The additional 18 months for an N+3 follow-up inspection at Byron Station Unit 2 has the advantage of allowing more time for potential shallow pre-existing flaws to grow and become more readily detectable at the time of the follow-up inspection. A shallow, slow-growing flaw would be expected to grow in depth by more than an additional 50% for an N+3 inspection compared to an N+2 inspection, considering the additional 1.5 years (50%) of time for growth and the acceleration in growth rate with increasing crack size and crack-tip stress intensity factor. Considering that ultrasonic testing (UT) is not qualified to detect shallow flaws extending less than 10% through the nozzle wall, the N+3 follow-up inspection would be more effective in addressing slow-growing flaws prior to implementing the long-term 10-year inspection interval.

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In accordance with MRP-335 R3-A [4] and the corresponding NRC Safety Evaluation [5], EGC shall perform a bare metal visual examination of each RPVHPN for evidence of pressure boundary leakage every refueling outage. This requirement ensures, in the unlikely event of through-wall cracking prior to the time of an alternative N+3 follow-up volumetric examination, that the through-wall cracking is identified in a timely fashion, with minimal time for circumferential cracking in the nozzle tube at the top of the weld to develop and minimal time for conditions to develop producing low-alloy steel corrosion due to the concentration of boric acid. As for unmitigated heads, the demonstrated leak path assessment examinations required whenever a volumetric examination is performed (including immediately prior to peening as part of the pre-peening baseline inspection), provide defense-in-depth to identify leakage through both the J-groove weld and nozzle base metal. Recent industry experience [9] with a leaking CRDM penetration affected by cracking of the J-groove weld illustrated the sensitivity of the demonstrated leak path assessment examination as an early indication of leakage.

Through consideration of a matrix of deterministic PWSCC crack growth calculations, MRP-335 R3-A [4] shows how the timing of volumetric examinations subsequent to peening are effective to prevent pressure boundary leakage. The matrix of cases considers the growth of hypothetical, shallow PWSCC flaws located in the nozzle Alloy 600 base metal that exist at the time of peening. The hypothetical flaws are too shallow to be reliably detected in the pre-peening baseline inspection. The evaluation per TN-4069-00-01 [7], which is based on the crack growth results previously available in Section 5.2.3.2 of MRP-335 R3-A investigates how effective the N+1 or N+3 follow-up inspection timing would be compared to the N+2 follow-up inspection timing in the case of heads operating at reactor cold-leg temperature (T_{cold}) with a nominal 18 month fuel cycle to prevent through-wall cracking and pressure boundary leakage. The identical low fraction of deterministic cases in the matrix for RPVHPNs operating at T_{cold} shows through-wall cracking assuming the N+3 timing as often as assuming the N+2 timing, demonstrating how the N+3 timing would ensure a similarly low likelihood of leakage. The crack growth results also show that the N+1 follow-up examination timing is not as effective as N+2 or N+3 timing as growth of shallow PWSCC flaws over a period of 18 months for T_{cold} heads may not be sufficient for the flaw to become deep enough to be reliably detectable using UT.

The experience for unmitigated heads in the U.S. operating at T_{cold}, including that for Byron Station Unit 2 prior to peening, shows that in practice and without taking credit for the peening surface stress improvement, through-wall cracking and leakage are unlikely to occur during an alternative N+3 follow-up inspection. A 2016 PVP conference paper [10] evaluated in detail the PWSCC indications detected in 25 RPVHPNs in T_{cold} heads by that time, all in the area of the toe of the J-groove weld on the nozzle OD. All of these PWSCC indications, including those affecting Byron Station Unit 2, were detected in T_{cold} heads having nozzle material supplied by B&W Tubular Products. Through an extension of the assessment of plant experience in the PVP paper, the evaluation per TN-4069-00-02 [8] demonstrates how substantial margin against growth upward to the nozzle annulus and against consequential leakage would still be expected with a 4.5-year inspection (i.e., N+3 for units with nominal 18-month fuel cycles).

The above assessments and supplemental evaluations demonstrate that an N+3 follow-up inspection maintains the same level of safety as an N+2 follow-up inspection.

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On this basis, a 54-month (N+3) follow-up inspection for the 70 identified RPVHPNs (Section 1.0) provides reasonable assurance of the low likelihood of leakage in RPVHPNs to support use of the requested alternative timing of the follow-up inspection.

5.4. Conclusions

Approval of the requested alternative to perform the follow-up inspection of the 70 identified RPVHPNs (Section 1.0) during the N+3 outage would permit alignment of the timing of the follow-up inspection for all 79 RPVHPNs at Byron Station Unit 2, eliminating hardship concerns including occupational hazards, personnel contamination, and additional radiation exposure from performing two separate inspections. The savings in dose is estimated to be approximately 240 to 272 mRem considering historical data but can be higher depending on difficulties experienced that may require additional personnel containment entry.

EGC has determined that the following assessments and supplemental evaluations further provide reasonable assurance of the low likelihood of leakage affecting the RPVHPNs at Byron Station Unit 2 under the proposed alternative:

1. The additional cycle for an N+3 inspection has the advantage of allowing more time for potential slow-growing flaws to become more readily detectable during the follow-up inspection for this unique situation where follow-up inspections are performed in two separate outages.
2. Bare metal visual examinations for evidence of leakage are required and will be performed every refueling outage. The demonstrated leak path assessment examinations required whenever a volumetric examination is performed provide defense-in-depth to identify leakage through both the J-groove weld and nozzle base metal.
3. The deterministic crack growth results presented within Section 5.2.3.2 of MRP-335 R3-A demonstrate how the N+3 follow-up inspection timing is as effective as the N+2 timing in the case of heads operating at T_{cold} with a nominal 18-month fuel cycle to prevent through-wall cracking and pressure boundary leakage. The crack growth results also show that the N+1 follow-up examination timing is not as effective as N+2 or N+3 timing as growth of shallow PWSCC flaws over a period of 18 months for T_{cold} heads may not be sufficient for the flaw to become deep enough to be reliably detectable using UT.
4. Without taking credit for the application of peening SSI, the experience for unmitigated heads in the U.S. operating at T_{cold} demonstrates how through-wall cracking and leakage are unlikely to occur during an alternative N+3 inspection.

EGC concludes that the follow-up inspections for the 70 identified RPVHPNs (Section 1.0) during the N+2 Unit 2 spring 2019 refueling outage (B2R21) and for the 9 RPVHPNs during the N+2 Unit 2 fall 2020 refueling outage (B2R22) per MRP-335 R3-A Table 4-3 Note (11)(b) [4] constitutes a hardship without a compensating increase in level of quality or safety in accordance with 10 CFR 50.55a(z)(2). Based on the assessment and supplemental evaluations, EGC concludes that the proposed alternative (extend the inspection of the 70 identified nozzles to N+3 to align with the

9 nozzles) would provide an acceptable level of quality and safety. Thus, EGC requests the NRC approve the proposed alternative.

6.0 DURATION OF PROPOSED ALTERNATIVE:

The proposed alternative is requested for the remainder of the 4th Inservice Inspection Interval for Byron Station Unit 2, currently scheduled to end on July 15, 2025.

7.0 PRECEDENT:

In NRC letter dated September 19, 2017 [3], the NRC provided their authorization to implement Byron Station Unit 2 Relief Request I4R-14, Revision 1, regarding the examination schedule of reactor pressure vessel head penetration nozzles.

8.0 ACRONYMS:

ALARA	As-Low-As Reasonably Achievable
ASME	American Society of Mechanical Engineers
CFR	Code of Federal Regulations
CRDM	Control Rod Drive Mechanism
EDY	Effective Degradation Year
EPRI	Electric Power Research Institute
ID	Inner Diameter
ISI	Inservice Inspection
LHRA	Locked High Radiation Area
mRem	Milli Roentgen Equivalent Man
MRP	[EPRI] Materials Reliability Program
OD	Outer Diameter
PWR	Pressurized Water Reactor
PWSCC	Primary Water Stress Corrosion Cracking
RPV	Reactor Pressure Vessel
RPVHPN	Reactor pressure vessel [upper] head penetration nozzle
SSI	Surface Stress Improvement
T_{cold}	Reactor Cold-leg Temperature
UHPCP	Ultra High Pressure Cavitation Peening
UT	Ultrasonic Testing

9.0 REFERENCES:

1. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 2007 Edition including 2008 Addenda
2. 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," Approved June 22, 2012

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3. Letter from D. Wrona (U.S. Nuclear Regulatory Commission) to B. Hanson (Exelon Generation Company, LLC), "Byron Station, Unit No 2 - Relief from the Requirements of the ASME Code (CAC No. MF9018)," dated September 19, 2017 - Relief Request I4R-14 Regarding Examination of Reactor Pressure Vessel Head Penetration Nozzles [NRC ADAMS Accession No. ML17249A241]

4. Letter from Electric Power Research Institute (EPRI) to U.S. Nuclear Regulatory Commission, "Transmittal of Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335 Revision 3-A), EPRI, Palo Alto, CA: 2016. EPRI Report 3002009241," dated November 8, 2016 (available at www.epri.com) [NRC ADAMS Accession No. ML16319A282]

5. Letter from K. Hsueh (U.S. Nuclear Regulatory Commission) to M. Sunseri (EPRI), "Final Safety Evaluation of the Electric Power Research Institute MRP-335, Revision 3, 'Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement [Peening]' (TAC No. MF2429)," dated August 24, 2016 [NRC ADAMS Accession No. ML16208A485]

6. Letter from D. M. Gullott (Exelon Generation Company, LLC) to U.S. Nuclear Regulatory Commission, "Response to Request for Additional Information for Byron Station and Braidwood Station Post Peening Relief Requests," dated July 14, 2017, including AREVA Licensing Report ANP 3601NP Revision 0, "Response to Request for Additional Information for Byron Station Unit 2 and Braidwood Station Unit 1," dated July 2017 (Non-Proprietary) [NRC ADAMS Accession No. ML17200C952]

7. Technical Note TN-4069-00-01, Revision 0, "MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing," Dominion Engineering, Inc., Reston VA, August 2018

8. Technical Note TN-4069-00-02, Revision 0, "Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service," Dominion Engineering, Inc., Reston VA, August 2018

9. Letter from A. J. Vitale (Entergy) to U.S. Nuclear Regulatory Commission, "Licensee Event Report # 2018-001-00, 'Penetration Indications Discovered During Reactor Pressure Vessel Head Inspection,' Indian Point Unit No. 2," dated May 21, 2018 [NRC ADAMS Accession No. ML18149A126]

10. G. White, K. Fuhr, M. Burkardt, and C. Harrington, "Deterministic Technical Basis for Re-Examination Interval of Every Second Refueling Outage for PWR Reactor Vessel Heads Operating at T_{cold} with Previously Detected PWSCC," Proceedings of the ASME 2016 Pressure Vessels & Piping Conference, ASME, PVP2016-64032

ATTACHMENT 2

Dominion Engineering, Inc. Technical Note TN-4069-00-01, Revision 0

MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing

August 2018

Dominion Engineering, Inc.

TECHNICAL NOTE

MRP-335 R3-A Matrix of Deterministic Crack Growth Calculations for T_{cold} Reactor Vessel Top Head Nozzles Evaluated for Alternative Peening Follow-up Volumetric Examination Timing

TN-4069-00-01
Revision 0

August 2018

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RECORD OF REVISIONS

Rev.	Description	Prepared by Date	Checked by Date	Reviewed by Date	Approved by Date
0	Original Issue	M. Burkardt 8/24/2018 M. Burkardt Senior Engineer	A. J. Simon 08/24/2018 A. J. Simon Engineer	G. A. White 8/24/2018 G. A. White Principal Engineer	G. A. White 8/24/2018 G. A. White Principal Engineer

The last revision number to reflect any changes for each section of the technical note is shown in the Table of Contents. The last revision numbers to reflect any changes for tables and figures are shown in the List of Tables and the List of Figures. Changes made in the latest revision, except for Rev. 0 and revisions which change the technical note in its entirety, are indicated by a double line in the right hand margin as shown here.

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1 INTRODUCTION

Through consideration of a matrix of deterministic primary water stress corrosion cracking (PWSCC) crack growth calculations, MRP-335 R3-A [1] shows how the timing of volumetric examinations subsequent to peening are effective to prevent pressure boundary leakage. The matrix of cases considers the growth of hypothetical, shallow PWSCC flaws located in the nozzle Alloy 600 base metal that exist at the time of peening. The hypothetical flaws are too shallow to be reliably detected in the pre-peening ultrasonic testing (UT) examination. This technical note, which is based solely on the crack growth results already available in Section 5.2.3.2 of MRP-335 R3-A, investigates how effective an N+1 or N+3 follow-up examination timing would be compared to the N+2 timing in the case of heads operating at reactor cold-leg temperature (T_{cold}) with a nominal 18-month fuel cycle to prevent through-wall cracking and pressure boundary leakage. The identical low fraction of deterministic cases in the matrix for reactor pressure vessel head penetrations nozzles (RPVHPNs) operating at T_{cold} shows through-wall cracking assuming the N+3 timing as assuming the N+2 timing, demonstrating how the N+3 timing would ensure a similarly low likelihood of leakage. The crack growth results also show that the N+1 follow-up examination timing is not as effective as N+2 or N+3 timing as growth of shallow PWSCC flaws over a period of 18 months for T_{cold} heads may not be sufficient for the flaw to become deep enough to be reliably detectable using UT.

2 EXISTING RESULTS IN MRP-335 R3-A FOR N+2 FOLLOW-UP TIMING

The matrix of deterministic crack growth cases applied in MRP-335 R3-A was designed to cover a wide range of potential conditions, including axial cracks initiating on both the nozzle ID and OD surfaces, both uphill and downhill azimuthal locations, a wide range of potential weld residual stress profiles, a wide range of crack growth rates due to material heat-to-heat variability (5^{th} to 95^{th} percentiles), and the full range of operating temperatures. Initial flaw depths of 0.010 in. (0.25 mm), 0.020 in. (0.51 mm), and 0.062 in. (1.58 mm) were applied to represent the range of flaws too shallow to be reliably detectable in the pre-peening UT examination.

Table 5-3 of MRP-335 R3-A presented a summary of all of the results, including both Alloy 82/182 piping butt welds and RPVHPNs. Only a small fraction of cases showed that the hypothetical shallow pre-existing flaw would grow to cause leakage without first becoming reliably detectable in one of the examinations required by MRP-335 R3-A subsequent to peening. The conclusion was that performing peening and examinations per the MRP-335 R3-A requirements provides a lower likelihood of leakage than unmitigated components examined per

the 10 CFR 50.55a augmented examination requirements for such components. Table 1 shows the subset of results from Table 5-3 of MRP-335 R3-A for RPVHPNs in heads operating at T_{cold}. In only 2 of 36 cases for N+2 timing was leakage predicted to occur due to the postulated axial cracking in the peened nozzle tube, compared to 7 of the 36 corresponding unmitigated cases.

3 APPLICATION OF RESULTS IN MRP-335 R3-A FOR N+1 AND N+3 FOLLOW-UP TIMING

Table 1 extends the summary results to assume N+1 and N+3 timing in addition to N+2 timing for the follow-up UT examination. The assumed examination schedule is shown in Table 2 for both the N+2 cases presented in Section 5.2.3.2 of MRP-335 R3-A and the N+1 and N+3 cases presented here. In the N+1 cases, each UT examination is shifted 1.5 calendar years earlier than for the N+2 cases, reflecting the nominal 18-month fuel cycles at Byron and Braidwood Stations. Similarly, in the N+3 cases, each UT examination is shifted 1.5 calendar years into the future. In each case, in accordance with MRP-335 R3-A, long-term UT examinations once every 10 years are assumed subsequent to the follow-up UT examination. Table 1 shows the same low fraction of deterministic cases predicting through-wall cracking assuming the N+3 timing as assuming the N+2 timing, demonstrating how the N+3 timing would ensure a similarly low likelihood of leakage. On the other hand, Table 1 shows that the N+1 timing is not as effective as N+2 or N+3 timing as three rather than two cases result in leakage with N+1 timing. Figure 1 illustrates how N+1 timing may result in insufficient growth for a shallow flaw to become detectable using UT.

The summary within Table 1 for the N+1 and N+3 timing for T_{cold} heads on a nominal 18-month fuel cycle was generated in the same manner as the results in Section 5.2.3.2 of MRP-335 R3-A, which assumed the N+2 timing, and solely by applying crack growth results already documented in MRP-335 R3-A:

- The same range of operating temperatures was applied as already assumed in MRP-335 R3-A, i.e., 547°F, 554°F, and 561°F. These temperatures bound T_{cold} for Byron Station Unit 2 and Braidwood Station Unit 1.
- As in MRP-335 R3-A, an operating capacity factor of 0.97 is conservatively assumed in consideration of refueling outages.
- In the same manner as in MRP-335 R3-A, the unmitigated UT examination schedule is every 8 years or before RIY = 2.25, whichever is less, in accordance with ASME Code Case N-729-4 [2] and 10 CFR 50.55a. Thus, the unmitigated cases are unchanged from the detailed results presented in Tables 5-16 through 5-18 of MRP-335 R3-A.
- The corresponding crack growth cases for peening with N+1, N+2, and N+3 examination timing are shown in Table 3, Table 4, and Table 5. These tables were generated by applying the examination schedules in Table 2 to the crack growth times available in Tables 5-13

through 5-15 of MRP-335 R3-A. In the same manner as in MRP-335 R3-A, the times after peening when a flaw is calculated to be deep enough to be detectable (i.e., depth at least 10% through the nozzle wall thickness) are compared to the examination schedule times to determine when the flaw in each sensitivity case is projected to be detected. Similarly, the calculated leakage times are considered to evaluate any cases in which leakage is predicted prior to UT detection.

- The two cases with leakage with N+3 timing (both in Table 3) are the same two cases with predicted leakage in MRP-335 R3-A for N+2 timing (both in Table 5-13 of MRP-335 R3-A). As mentioned in MRP-335 R3-A, both of these leakage cases assume an unlikely combination of conditions (high tensile weld residual stress profile combined with 95th percentile crack growth rate behavior, with an initial flaw depth of only 0.010 in. (0.25 mm) at the time of peening), and both of these leakage cases assume initiation on the nozzle ID surface. As discussed near the end of Section 2.3.2 of MRP-335 R3-A, operating experience shows a very low probability of PWSCC initiation on the nozzle ID surface. The large majority of PWSCC indications in RPVHPNs have been located on the nozzle outer surfaces.
- For the other cases in which detection by UT is predicted prior to leakage, the relative timing of the examination in which flaw detection is expected is shifted in just one case assuming N+3 instead of N+2 timing. This difference is exhibited for Case Number 17 in Table 3, for which flaw detection without leakage is expected at the fourth long-term ISI examination rather than the fifth ISI examination shown in Table 5-13 of MRP-335 R3-A.
- For the N+1 timing, there are four cases which produce different results than for the N+2 timing. The flaw modeled in Case Number 15 is detected in the first long-term ISI examination assuming N+1 timing rather than producing a leak when assuming N+2 timing. For Case Number 38, the relative timing of the examination in which flaw detection is expected is shifted to the third long-term ISI examination for N+1 timing rather than the second ISI examination for N+2 timing. Case Numbers 39 and 42 result in leakage for N+1 timing rather than flaw detection in the follow-up examination for N+2 timing, showing how the N+1 timing may not allow sufficient time for growth of shallow flaws, even those that grow according to the 95th percentile of material variability in crack growth rate.

Using Case Number 42 as an example, Figure 1 demonstrates how, even assuming growth at the 95th percentile of material variability, N+1 timing may not allow sufficient time for growth to a reliably detectable flaw size. In contrast, Figure 1 shows how the N+2 and N+3 timings of the follow-up examination are effective under the circumstances for this case for a T_{cold} head. Considering that UT performed in accordance with ASME Code Case N-729-4 [2] is not intended to detect shallow flaws extending less than 10% through the nozzle wall, performing the follow-up examination in the N+2 or N+3 refueling outage would be more effective in identifying slow-growing flaws prior to implementing the long-term 10-year ISI interval. Case Number 42 assumes a relatively high tensile weld residual stress profile (shown in Figure 5-36 of MRP-335 R3-A), 95th percentile crack growth rate behavior, an operating temperature of 561°F, and an initial flaw depth of 0.020 in. (0.51 mm). As a key intermediate result, the stress intensity factor at the deepest point of the semi-elliptical flaw calculated per the approach discussed in

MRP-335 R3-A is shown as a function of flaw depth in Figure 2. The flaw aspect ratio (2*c*/*a*), which is assumed to start at 4.0, reaches a minimum of 1.26 when the flaw is about 38% through-wall, and is 1.6 by the time the flaw grows through-wall.

4 RESULTS AND CONCLUSION

As shown in Table 1, the summary results assuming N+3 follow-up examination timing are identical to those assuming N+2 timing within MRP-335 R3-A [1]. Thus, the conclusion on the basis of the crack growth results already documented in MRP-335 R3-A is that the N+3 timing for the follow-up UT examination is as effective as the N+2 timing to address the potential for pre-existing PWSCC not detected in the pre-peening examination. The crack growth results also show that the N+1 follow-up examination timing is not as effective as N+2 or N+3 timing as growth of shallow PWSCC flaws over a period of 18 months for T_{cold} heads may not be sufficient for the flaw to become deep enough to be reliably detectable using UT.

5 REFERENCES

1. *Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 3-A)*. EPRI, Palo Alto, CA: 2016. 3002009241. [Freely downloadable at www.epri.com]

2. 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," Approval date: June 22, 2012.

Table 1. Summary of Deterministic Matrix for Cold-Head RPVHPN Crack Growth Calculations

Disposition	RPVHPN – Peened (N+1) (Note 1)		RPVHPN – Peened (N+2) (Note 2)		RPVHPN – Peened (N+3) (Note 3)		RPVHPN – No Peening (Note 4)	
Never Leaks, Never Detected	16 of 36	44%	16 of 36	44%	16 of 36	44%	8 of 36	22%
Detected in Follow-Up Exam	12 of 36	33%	14 of 36	39%	14 of 36	39%	N/A	N/A
Detected in ISI Exam	5 of 36	14%	4 of 36	11%	4 of 36	11%	21 of 36	58%
Leaks Before Extension of Intervals	0 of 36	0%	0 of 36	0%	0 of 36	0%	7 of 36	19%
Leaks After Extension of Intervals	3 of 36	8%	2 of 36	6%	2 of 36	6%		

NOTES:

(1) RPVHPN – Peened (N+1) results summarize cold head cases tabulated in Table 3 through Table 5.

(2) RPVHPN – Peened (N+2) results summarize cold head cases tabulated in MRP-335 R3-A Tables 5-13 through 5-15.

(3) RPVHPN – Peened (N+3) results summarize cold head cases tabulated in Table 3 through Table 5.

(4) RPVHPN – No Peening results summarize cold head cases tabulated in MRP-335 R3-A Tables 5-16 through 5-18.

Table 2. Inspection Schedule for Deterministic Matrix of Crack Growth Cases for Peened Cold Head RPVHPNs

	Inspection Time (yr)		
Inspection	Cold Head (N+1)	Cold Head (N+2)	Cold Head (N+3)
1st Follow Up	1.5	3	4.5
2nd Follow Up	N/A	N/A	N/A
1st ISI	11.5	13	14.5
2nd ISI	21.5	23	24.5
3rd ISI	31.5	33	34.5
4th ISI	41.5	43	44.5
5th ISI	51.5	53	54.5
6th ISI	61.5	63	64.5
7th ISI	71.5	73	74.5
Never Leaks	80	80	80

Table 3. Matrix of Deterministic Crack Growth Calculations for Peened RPVHPNs with Initial Flaw Depth of 0.010 in. (0.25 mm) (cold head cases only)

Case Number	Nozzle Tube Location ID/OD	Nozzle Tube Location UH/DH	Stress Profile	MRP-55 A600 CGR %ile	Temp. (°F)	Initial Depth (in.)	Initial Depth (mm)	Initial Aspect Ratio (2c0/a0)	Growth Time to 10%TW (yr)	Growth Time from 10% to Leak (yr)	N+1 Detection Time	N+2 Detection Time	N+3 Detection Time	Aspect Ratio at 10%TW (2c/a)	Total Length at 10%TW (in.)	Total Length at 10%TW (mm)
13	ID	UH	Low	5%	547	0.010	0.25	2.0	437.9	446.9	Never Leaks	Never Leaks	Never Leaks	1.1	0.069	1.7
14	ID	UH	Median	50%	554	0.010	0.25	3.0	47.5	51.6	5th ISI	5th ISI	5th ISI	1.2	0.072	1.8
15	ID	UH	High	95%	561	0.010	0.25	4.0	5.5	6.3	1st ISI	Leaks	Leaks	1.2	0.078	2.0
16	ID	DH	Low	5%	547	0.010	0.25	2.0	415.0	404.4	Never Leaks	Never Leaks	Never Leaks	1.1	0.066	1.7
17	ID	DH	Median	50%	554	0.010	0.25	3.0	44.3	45.7	5th ISI	5th ISI	4th ISI	1.1	0.070	1.8
18	ID	DH	High	95%	561	0.010	0.25	4.0	5.1	5.5	Leaks	Leaks	Leaks	1.2	0.075	1.9
19	OD	UH	Low	5%	547	0.010	0.25	2.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-
20	OD	UH	Median	50%	554	0.010	0.25	3.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-
21	OD	UH	High	95%	561	0.010	0.25	4.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-
22	OD	DH	Low	5%	547	0.010	0.25	2.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-
23	OD	DH	Median	50%	554	0.010	0.25	3.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-
24	OD	DH	High	95%	561	0.010	0.25	4.0	>80	>80	Never Leaks	Never Leaks	Never Leaks	-	-	-

Table 4. Matrix of Deterministic Crack Growth Calculations for Peened RPVHPNs with Initial Flaw Depth of 0.020 in. (0.51 mm) (cold head cases only)

Case Number	Nozzle Tube Location ID/OD	Nozzle Tube Location UH/DH	Stress Profile	MRP-55 A600 CGR %ile	Temp. (°F)	Initial Depth (in.)	Initial Depth (mm)	Initial Aspect Ratio (2c0/a0)	Growth Time to 10%TW (yr)	Growth Time from 10% to Leak (yr)	N+1 Detection Time	N+2 Detection Time	N+3 Detection Time	Aspect Ratio at 10%TW (2c/a)	Total Length at 10%TW (in.)	Total Length at 10%TW (mm)
37	ID	UH	Low	5%	547	0.020	0.51	2.0	207.8	446.2	Never Leaks	Never Leaks	Never Leaks	1.2	0.077	2.0
38	ID	UH	Median	50%	554	0.020	0.51	3.0	22.7	51.6	3rd ISI	2nd ISI	2nd ISI	1.5	0.093	2.4
39	ID	UH	High	95%	561	0.020	0.51	4.0	2.5	6.3	Leaks	1st Follow Up	1st Follow Up	1.7	0.108	2.7
40	ID	DH	Low	5%	547	0.020	0.51	2.0	191.1	404.1	Never Leaks	Never Leaks	Never Leaks	1.2	0.075	1.9
41	ID	DH	Median	50%	554	0.020	0.51	3.0	20.4	45.6	2nd ISI	2nd ISI	2nd ISI	1.5	0.091	2.3
42	ID	DH	High	95%	561	0.020	0.51	4.0	2.3	5.5	Leaks	1st Follow Up	1st Follow Up	1.7	0.106	2.7
43	OD	UH	Low	5%	547	0.020	0.51	2.0	10125.1	484.3	Never Leaks	Never Leaks	Never Leaks	1.6	0.097	2.5
44	OD	UH	Median	50%	554	0.020	0.51	3.0	1293.9	70.0	Never Leaks	Never Leaks	Never Leaks	1.7	0.108	2.7
45	OD	UH	High	95%	561	0.020	0.51	4.0	174.9	8.5	Never Leaks	Never Leaks	Never Leaks	1.9	0.120	3.1
46	OD	DH	Low	5%	547	0.020	0.51	2.0	9949.7	526.3	Never Leaks	Never Leaks	Never Leaks	1.5	0.095	2.4
47	OD	DH	Median	50%	554	0.020	0.51	3.0	1274.5	63.1	Never Leaks	Never Leaks	Never Leaks	1.7	0.106	2.7
48	OD	DH	High	95%	561	0.020	0.51	4.0	172.7	7.9	Never Leaks	Never Leaks	Never Leaks	1.9	0.120	3.0

Table 5. Matrix of Deterministic Crack Growth Calculations for Peened RPVHPNs with Initial Flaw Depth of 0.062 in. (1.58 mm) (cold head cases only)

Case Number	Nozzle Tube Location ID/OD	Nozzle Tube Location UH/DH	Stress Profile	MRP-55 A600 CGR %ile	Temp. (°F)	Initial Depth (in.)	Initial Depth (mm)	Initial Aspect Ratio (2c0/a0)	Growth Time to 10%TW (yr)	Growth Time from 10% to Leak (yr)	N+1 Detection Time	N+2 Detection Time	N+3 Detection Time	Aspect Ratio at 10%TW (2c/a)	Total Length at 10%TW (in.)	Total Length at 10%TW (mm)
61	ID	UH	Low	5%	547	0.062	1.58	2.0	0.0	447.1	1st Follow Up	1st Follow Up	1st Follow Up	2.0	0.124	3.2
62	ID	UH	Median	50%	554	0.062	1.58	3.0	0.0	49.9	1st Follow Up	1st Follow Up	1st Follow Up	3.0	0.187	4.7
63	ID	UH	High	95%	561	0.062	1.58	4.0	0.0	5.8	1st Follow Up	1st Follow Up	1st Follow Up	4.0	0.249	6.3
64	ID	DH	Low	5%	547	0.062	1.58	2.0	0.0	404.4	1st Follow Up	1st Follow Up	1st Follow Up	2.0	0.124	3.2
65	ID	DH	Median	50%	554	0.062	1.58	3.0	0.0	44.1	1st Follow Up	1st Follow Up	1st Follow Up	3.0	0.187	4.7
66	ID	DH	High	95%	561	0.062	1.58	4.0	0.0	5.0	1st Follow Up	1st Follow Up	1st Follow Up	4.0	0.249	6.3
67	OD	UH	Low	5%	547	0.062	1.58	2.0	0.0	604.5	1st Follow Up	1st Follow Up	1st Follow Up	2.0	0.124	3.2
68	OD	UH	Median	50%	554	0.062	1.58	3.0	0.0	67.3	1st Follow Up	1st Follow Up	1st Follow Up	3.0	0.187	4.7
69	OD	UH	High	95%	561	0.062	1.58	4.0	0.0	7.8	1st Follow Up	1st Follow Up	1st Follow Up	4.0	0.249	6.3
70	OD	DH	Low	5%	547	0.062	1.58	2.0	0.0	521.8	1st Follow Up	1st Follow Up	1st Follow Up	2.0	0.124	3.2
71	OD	DH	Median	50%	554	0.062	1.58	3.0	0.0	60.6	1st Follow Up	1st Follow Up	1st Follow Up	3.0	0.187	4.7
72	OD	DH	High	95%	561	0.062	1.58	4.0	0.0	7.3	1st Follow Up	1st Follow Up	1st Follow Up	4.0	0.249	6.3

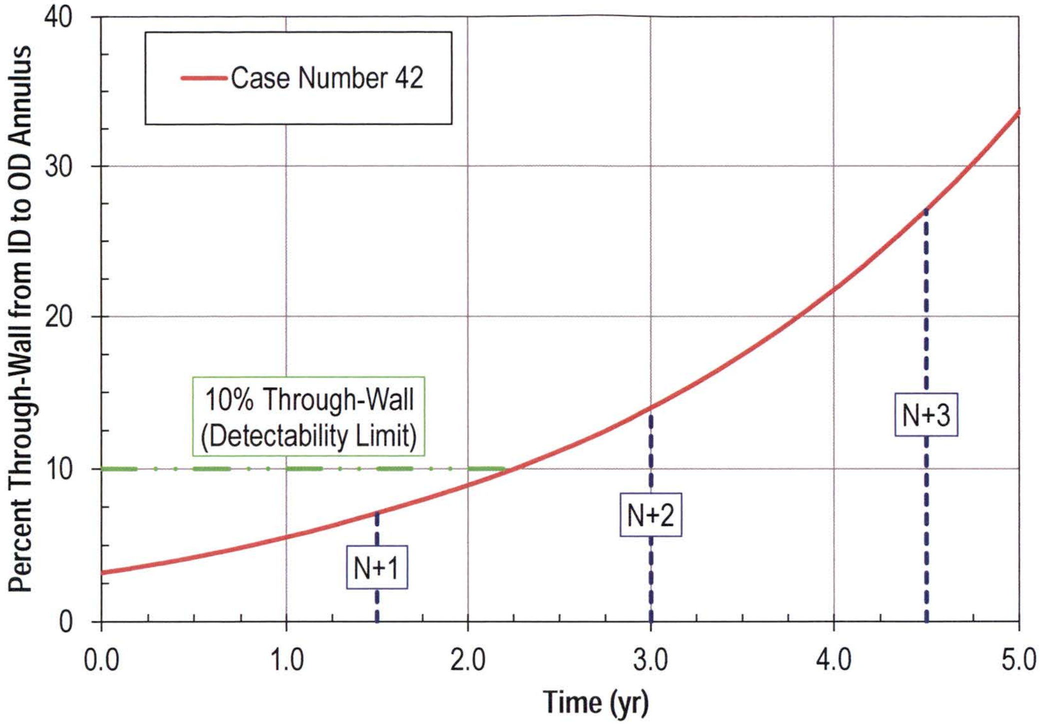

Figure 1. Example Flaw Depth vs. Time in Context of N+1, N+2, and N+3 Examination Timing and 10% UT Detectability Limit

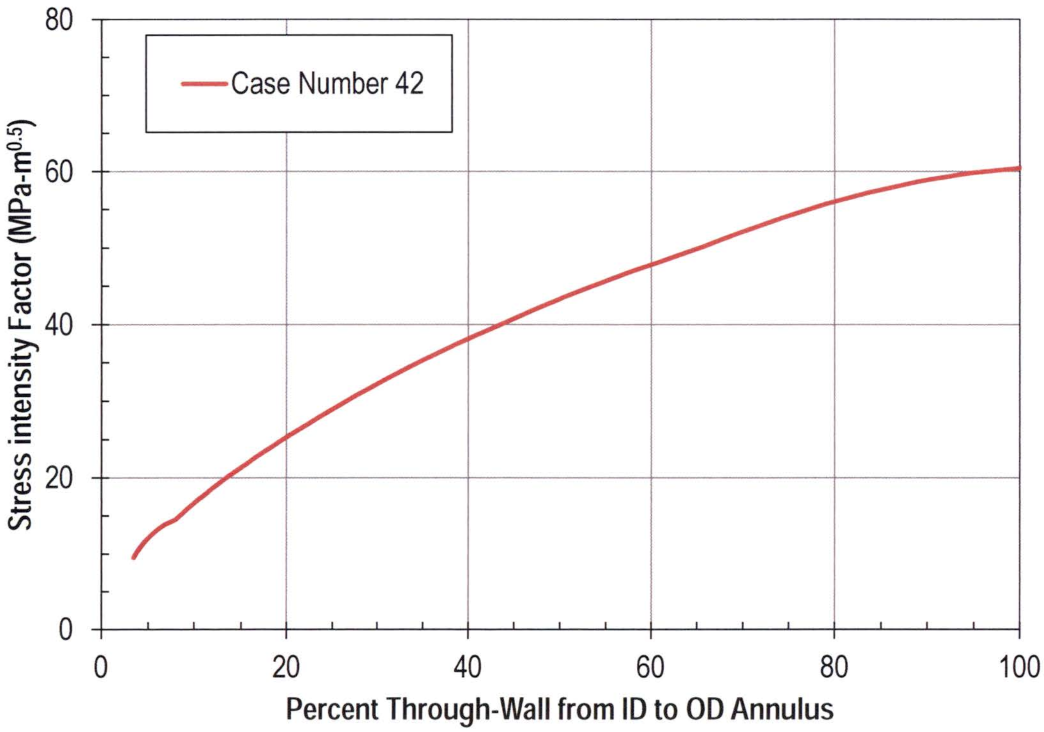

Figure 2. Stress Intensity Factor at Deepest Flaw Point vs. Flaw Depth for Figure 1

ATTACHMENT 3

Dominion Engineering, Inc. Technical Note TN-4069-00-02, Revision 0

Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service

August 2018

Dominion Engineering, Inc.

TECHNICAL NOTE

Experience for Unmitigated CRDM Nozzles in U.S. PWRs Evaluated for Margin Against Leakage Considering Additional PWSCC Growth if Indications Had Remained in Service

TN-4069-00-02
Revision 0

August 2018

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RECORD OF REVISIONS

Rev.	Description	Prepared by Date	Checked by Date	Reviewed by Date	Approved by Date
0	Original Issue	M. Burkardt 8/24/2018 M. Burkardt Senior Engineer	K. J. Fuhr 8/24/2018 K. J. Fuhr Senior Engineer	G. A. White 8/24/2018 G. A. White Principal Engineer	G. A. White 8/24/2018 G. A. White Principal Engineer

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LIST OF FIGURES

1 INTRODUCTION

A 2016 PVP conference paper [1] evaluated in detail the primary water stress corrosion cracking (PWSCC) indications detected in 25 reactor pressure vessel head penetration nozzles (RPVHPNs) in T_{cold} heads by that time, all in the area of the toe of the J-groove weld on the nozzle OD. All of these PWSCC indications, including those affecting the Byron Station Unit 2 and Braidwood Station Unit 1 heads, were detected in T_{cold} heads having nozzle material supplied by B&W Tubular Products. Figure 1, which is a modified version of Figure 7 from the PVP paper, illustrates how substantial margin against growth upward to the nozzle annulus and against consequential leakage would still be expected with a 4.5-year follow up examination interval, i.e., three cycles for units with nominal 18-month fuel cycles. Figure 2 illustrates how the remaining ligament above the axial flaw quantifies the remaining margin against leakage.

2 EXTENSION OF EXISTING PUBLISHED RESULTS

Using the same approach described in the PVP paper [1], Figure 1 was developed by plotting the nondestructive examination (NDE) dimensional data for PWSCC indications detected in heads operating at T_{cold} and adjusting the reported indications for a hypothetical examination interval of three 18-month cycles, or 4.5 years of calendar time. Figure 1 shows all 44 PWSCC nozzle tube indications in T_{cold} heads in the U.S. that have been sized using UT to date, including five indications in four CRDM nozzles at one PWR detected subsequent to the PVP paper.[1] The subset of flaws that were detected in less than 4.5 years since the prior examination are extrapolated to the size that would have been expected had each flaw not been detected until the third refueling outage (i.e., 4.5 years) after the prior examination. For two of the indications detected after one cycle, the available data for corresponding indications at the previous UT examination indicated a lack of growth over the previous cycle such that the projected crack size is the same as the detected size. For context, the vertical weld height at the nozzle OD (i.e., between the bottom/toe and the top/annulus in Figure 2), as determined through UT examination, ranges from 29 to 62 mm (1.16 to 2.44 in.) at the locations of the extrapolated indications. The initial vertical elevation of the top of the indication relative to the bottom/toe of the weld varies

[1] Rejectable planar indications were detected in the nozzle material of three penetrations at tack welds attaching the guide funnels to the end of the nozzle during the spring 2017 pre-peening examination at one unit [2]. These are not included because they are not associated with the region of elevated stress generated by the J-groove weld and were corrected through grinding.

from –10 to +15 mm (–0.41 to +0.60 in.), where a positive elevation applies when the top of the indication is above the bottom/toe of the weld.

The simulated growth for the extrapolated flaws is based on the assumption that the initial flaw depth was at the limit of detectability at the previous examination (for UT, assumed to be 10-15% through the nozzle wall thickness based on the range of flaw depths included in UT Performance Demonstration Initiative mockups). Alternatively, in some cases, the PWSCC indication was found to correspond to an indication reported during a previous outage but dispositioned as not service-related. In these cases, the depth of the earlier indication is applied to project the additional growth. An additional 18 or 36 months of service is projected for each extrapolated flaw, depending on whether the flaw was actually detected after two or after one 18-month cycle, respectively, since the previous UT examination. Similar to Figure 6 of the PVP paper [1], Figure 3 illustrates adjustment of the detected depth and length for each extrapolated PWSCC indication for the additional expected growth had detection been delayed.

The crack growth calculation considers stress intensity factors calculated both at the deepest and surface points on a semi-elliptical crack front. Crack growth is extrapolated forward in time by conservatively assuming a constant driving stress of 70 ksi (483 MPa) and using a crack growth rate percentile for the effect of material variability reflecting the elapsed time for growth from the assumed initial flaw depth to the detected depth, resulting in crack growth rate percentiles as high as the 92nd percentile.

The two flaws modeled to grow in depth through the nozzle wall thickness to penetrate the nozzle ID during the 4.5-year interval are conservatively modeled to transition instantaneously to an idealized through-wall flaw having the same total length as the semi-elliptical flaw at the point of penetration to the nozzle ID. Penetration to the nozzle ID does not affect leak tightness as growth to the nozzle annulus is necessary for pressure boundary leakage to occur. This fact is illustrated by Figure 2. The stress intensity factor for the idealized through-wall flaw is calculated per a standard published solution for an axial idealized through-wall flaw in a cylindrical pipe [3]. Figure 1 and Figure 3 each identify the point at which each of these two flaws is modeled to penetrate to the nozzle ID.

3 Results and Conclusion

Figure 1 shows the remaining vertical ligament to leakage (as defined in Figure 2), including the extrapolated results. Figure 1 shows that large amounts of margin against leakage (i.e., remaining vertical distance from the crack front to the nozzle annulus) would have been expected if the

volumetric examinations had been performed every 4.5 calendar years. The projected remaining ligament for every indication is greater than 20 millimeters, which exceeds the 16-mm nozzle tube thickness that bounds the margin available for growth of hypothetical nozzle ID flaws prior to leakage.

4 REFERENCES

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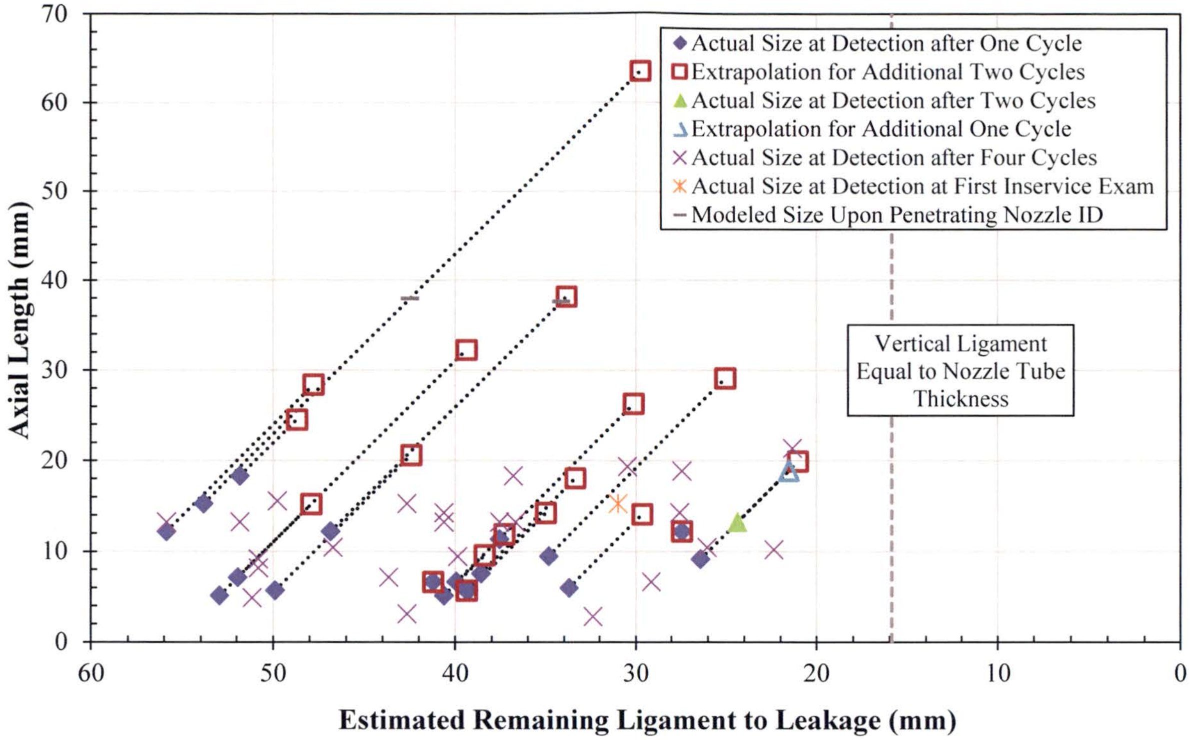

Figure 1. T_{cold} PWSCC Indication Remaining Ligament Adjusted to Hypothetical Three-Cycle Examination Frequency

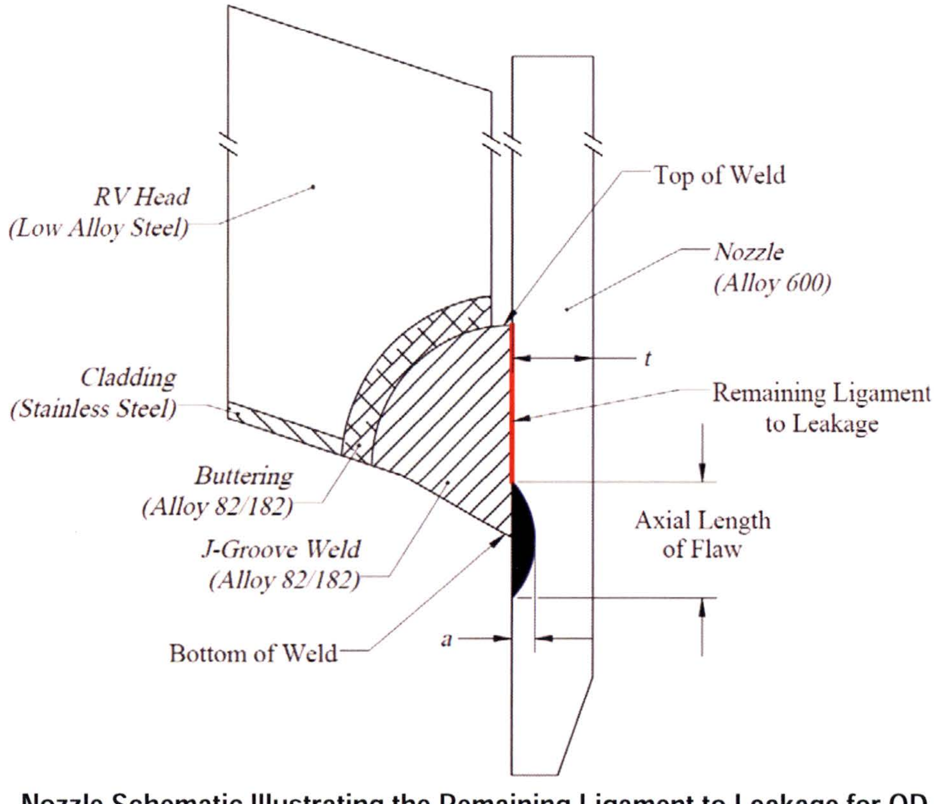

Figure 2. Nozzle Schematic Illustrating the Remaining Ligament to Leakage for OD PWSCC

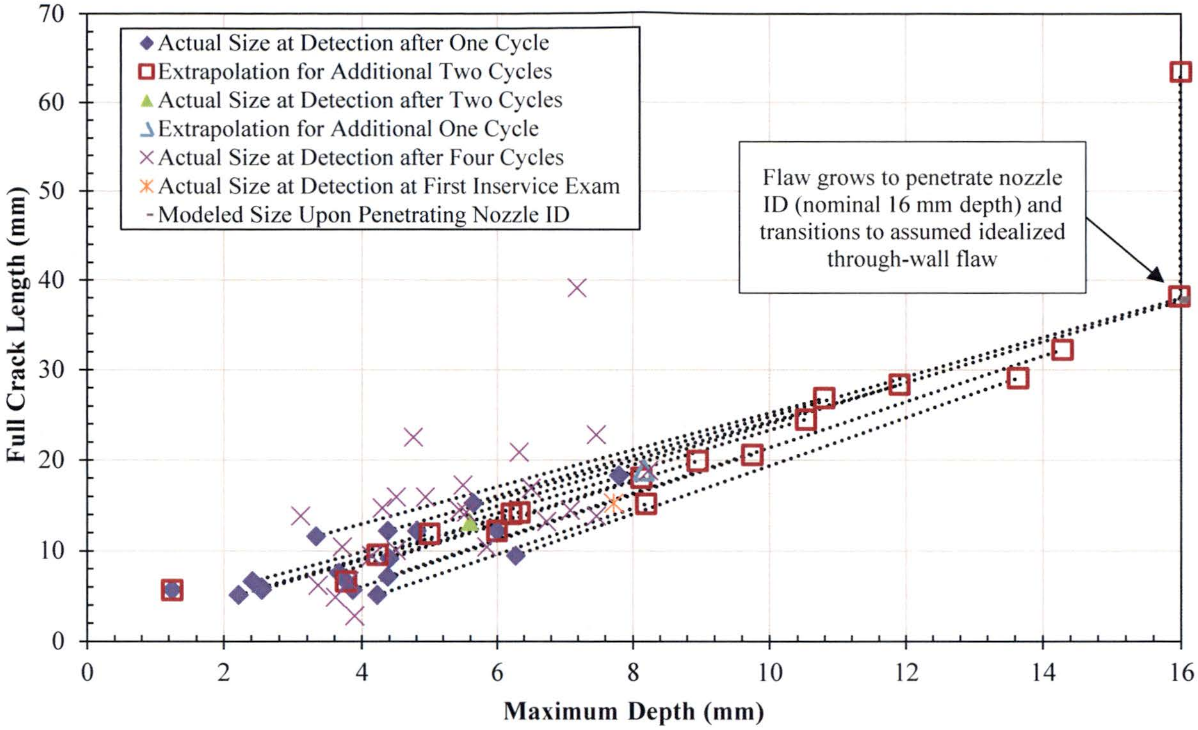

Figure 3. T_{cold} **PWSCC Indication Sizes Adjusted to Hypothetical Three-Cycle Examination Frequency**