27780 Blue Star Highway, Covert, MI 49043

PNP 2025-053

10 CFR50.55a

July 31, 2025

ATTN: Document Control Desk
U.S. Nuclear Regulatory commission
Washington, DC 20555-0001

Palisades Nuclear Plant
NRC Docket 50-255
Renewed Facility Operating License No. DPR-20

Subject: Relief Request Number RR 5-9, *Proposed Alternative to ASME Section XI Code Requirements for Modification of Reactor Pressure Vessel Closure Head, Control Rod Drive Mechanisms and InCore Instrumentation Penetrations*

Pursuant to Title 10 of the Code of Federal Regulations (10 CFR) 50.55a, *Codes and standards*, paragraph (z)(1), Holtec[1] hereby requests Nuclear Regulatory Commission (NRC) approval of the attached relief request for the Palisades Nuclear Plant (PNP) Inservice Inspection (ISI) Program, fifth ten-year interval. The request is similar to relief requests previously approved by the NRC staff, see Attachment 1 for a list of previously approved Safety Evaluation Reports.

PNP ceased operation in the Spring of 2022. Holtec is performing modifications to the PNP to support restart of plant operations. The Palisades Reactor Vessel Closure Head (RVCH) Vessel Head Penetrations (VHPs) are constructed of materials that are susceptible to Primary Water Stress Corrosion Cracking (PWSCC). Modifications to the Palisades RVCH Control Rod Drive Mechanisms (CRDM) and InCore Instrument (ICI) VHPs are being preemptively implemented to mitigate the PWSCC susceptible materials. There are a total of 46 nozzles that will be modified under this request. Relief is requested in accordance with 10 CFR 50.55a(z)(1). The provisions of this relief are applicable to the fifth ten-year Inservice Inspection interval at PNP, which commenced on December 13, 2015, and is currently scheduled to end on December 12, 2025, as identified in the Fifth Interval Inservice Inspection Plan, submitted to the NRC on December 09, 2015,(Reference 2). While this relief request identifies the same code cases as the previous relief requests, updated versions of the applicable code cases, as approved by the NRC and identified in the Fifth Interval Inservice Inspection Plan are referenced in this submittal.

The documentation to support this request is provided in Attachment 1. In addition, as part of the alternative requested, Holtec is requesting use of ASME Code Case N-638-11 (Reference 3) with the elimination of the 48-hour hold time for ambient temperature temper bead welding.

This position is supported by Attachment 2, “White Paper: Ambient Temperature Temper Bead – Elimination of 48-Hour Hold Time from Code Case N-888 When Using Austenitic Filler Material.”

1 Holtec Palisades, LLC (“Holtec Palisades”) is the licensed owner of PNP. Pursuant to the license transfer amendment received in connection with the PNP restart (Reference 1), licensed operating authority has transferred from Holtec Decommissioning International, LLC ("HDI") to Palisades Energy, LLC (“Palisades Energy”).

Since Code Case N-888 is the culmination of temper bead code cases that have been produced over the years, combining requirements from Code Cases N-638 and N-839, and Appendix I in cases such as Code Cases N-740 and N-754, etc., the justification is also applicable to the planned use of Code Case N-638-11 at PNP.

This letter contains no new regulatory commitments.

Please refer any questions regarding this submittal to Frank Sienczak PNP Regulatory Assurance Manager, at (269) 764-2263.

Sincerely,

Jean A. Fleming

Digitally signed by Jean A. Fleming
DN: cn=Jean A. Fleming, o=Holtec Decommissioning International, LLC, ou=Regulatory and Environmental Affairs, email=J.Fleming@Holtec.com
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Jean A. Fleming
Vice President of Licensing and Regulatory Affairs
Holtec International

Attachments:

1. Relief Request RR-5-9 Proposed Alternative Requirements for the Modification of Reactor Vessel Closure Head Control Rod Drive Mechanism and InCore Instrumentation Penetrations in Accordance with 10 CFR 50.55a(z)(1) Inservice Inspection Program, Fifth Ten-Year Interval

2. White Paper: Ambient Temperature Temper Bead- Elimination of 48-Hour Hold Time from Code Case N-888 When using Austenitic Filler Material

References:

1. U.S. Nuclear Regulatory Commission (NRC) letter to Holtec, *Palisades Nuclear Plant – Order Approving Direct Transfer of Renewed Facility Operating License and Independent Spent Fuel Storage Installation General License and Issuance of Conforming Amendment 275 (EPID L-2023-LLM-0005),* dated July 24, 2025 (ADAMS Accession No. ML25167A243)

2. Entergy Nuclear Operations Inc. letter to NRC, "Inservice Inspection Master Program Fifth 10-year Interval", dated December 09, 2015 (ADAMS Accession No. ML15343A090)

3. ASME Code Case N-638-11 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique, Section XI, Division 1

cc: NRC Senior Resident Inspector, PNP
NRC Project Manager, PNP
NRC Regional Administrator, Region III

ATTACHMENT 1

Palisades Nuclear Power Plant
Docket No. 50-255/Renewed License No. DPR-20

Relief Request RR-5-9
Proposed Alternative Requirements for the
Modification of Reactor Vessel Closure Head
Control Rod Drive Mechanism and InCore
Instrumentation Penetrations

1.0 ASME CODE COMPONENT AFFECTED / APPLICABLE CODE EDITION

Component:	Reactor Vessel Closure Head (RVCH)
Description:	Reactor Vessel Head Penetrations (VHPs) with Nozzles Having Pressure-Retaining Partial-Penetration J-groove Welds
Code Class:	Class 1
Examination Category:	ASME Code Case N-729-6
Code Item:	B4.20
Identification:	VHP Numbers 1-16, 18-24, 26-28, 31, 32, 35, and 37-53
Reference Drawing:	232-122-11 Closure Head Assembly
Material:	Alloy 600 (SB-167) UNS N06600

ASME Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components”, 2007 Edition through 2008 Addenda

ASME Section XI, Code Case N-729-6, as amended in 10 CFR 50.55a(g)(6)(ii)(D)

ASME Section III, “Nuclear Vessels”, 1965 Edition through Winter 1965 Addenda (Original Construction Code)

ASME Section III, “Nuclear Power Plant Components”, Subsection NB, Division 1, Class 1 Components, 2019 Edition

2.0 APPLICABLE CODE REQUIREMENTS

The applicable requirements of the following American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code and Code Cases from which relief is requested are as follows:

ASME Code, Section XI, 2007 Edition through 2008 Addenda

- IWB-3132.3 states:

  A component whose volumetric or surface examination detects flaws that exceed the acceptance standards of Table IWB-3410-1 is acceptable for continued service without a repair/replacement activity if an analytical evaluation, as described in IWB-3600, meets the acceptance criteria of IWB-3600. The area containing the flaw shall be subsequently reexamined in accordance with IWB-2420(b) and (c).

- IWB-3420 states:

  Each detected flaw or group of flaws shall be characterized by the rules of IWA-3300 to establish the dimensions of the flaws. These dimensions shall be used in conjunction with the acceptance standards of IWB-3500.

ASME Code, Section III, 2019 Edition

- NB-5245 states in part:

  Fillet welded and partial penetration welded joints…shall be examined progressively using either magnetic particle or liquid penetrant methods.

- NB-5331(b) states:

  Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

Code Case N-638-11, *Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique*, provides requirements for automatic or machine gas tungsten arc welding (GTAW) of Class 1 components without the use of preheat or post weld heat treatment.

- Paragraph 1(a) states in part:

  This Case shall not be used to repair SA-302, Grade B material, unless the material has been modified to include 0.4% to 1.0% nickel, quenching and tempering, and application of a fine gain practice.

- Paragraph 2(b) permits use of existing welding procedures qualified in accordance with previous revisions of the Code Case. When the existing welding procedure was qualified in accordance with N-638-4, the test coupon base material was post-weld heat treated to comply with paragraph 2.1(a) of the Code Case (N-638-4) which states in part:

  The materials shall be post-weld heat treated to at least the time and temperature that was applied to the materials being welded.

- Paragraph 4(a)(2) states:

  When ferritic materials are used, the weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. When austenitic materials are used, the completed weld shall be nondestructively examined after the three tempering layers (i.e., layers 1, 2, and 3) have been in place for at least 48 hr. Examination of the welded region shall include both volumetric and surface examination methods.

3.0 REASON FOR REQUEST

The Palisades Nuclear Plant (PNP) ceased operation in the Spring of 2022. Holtec International, Inc. is performing modifications to the PNP to support the restart of plant operations. The Palisades RVCH VHPs are constructed of materials that are susceptible to Primary Water Stress Corrosion Cracking (PWSCC). Modifications to the Palisades RVCH Control Rod Drive Mechanisms (CRDM) and InCore Instrument (ICI) VHPs are being preemptively implemented to mitigate the PWSCC susceptible materials. There are a total of 46 nozzles that will be modified under this request.

Figure 11 shows the relative location of the nozzles in the RVCH.

The modification technique for nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53, sometimes referred to as the half-nozzle modification, is intended to be the same as was implemented previously for nozzles 29 and 30 in 2004, nozzles 25, 33, and 36 in 2018, and nozzles 17 and 34 in 2020. The half-nozzle modification involves machining away the lower section of the existing nozzle, then welding the remaining portion of the nozzle to the RVCH to form the new pressure boundary. The new weld also attaches a replacement lower nozzle that provides a means for reattaching the CRDM extension and grid structure. This technique requires relief from certain aspects of the ASME B&PV Code as described below.

Because of the risk of damage to the RVCH material properties or dimensions, it is not feasible to apply the post weld heat treatment (PWHT) requirements of the original Construction Code. As an alternative to the requirements of the RVCH Code of Construction, Holtec International, Inc. (Holtec) proposes to perform the modification of the VHPs utilizing the Inside Diameter Temper Bead (IDTB) welding method to restore the pressure boundary of the PWSCC susceptible nozzle penetrations. The IDTB welding method is performed with a remotely operated weld tool utilizing the machine GTAW process and the ambient temperature temper bead method with 50° F minimum preheat temperature and no PWHT. The modification described below will be performed in accordance with the 2007 Edition through 2008 Addenda of ASME Section XI, Code Case N-638-11, Code Case N-729-6, and the alternatives discussed in Section 4.0.

Basic steps for the IDTB modification are:

1. Cut the grid structure adjoining the nozzle and surrounding extensions.

2. Cut the nozzle close to the underside of the head and remove the nozzle extension.

3. Roll expansion of the nozzle above the area to be modified to stabilize the nozzle and prevent any movement when the nozzle is separated from the nozzle-to-RVCH J-groove weld.

4. Machining to remove the lower portion of the nozzle to above the J-groove weld. This machining operation also establishes the weld preparation area (Refer to Figure 1).

5. Liquid penetrant (PT) examination of the machined area (Refer to Figure 3).

6. Welding the remaining portion of the nozzle and the new lower replacement nozzle using Alloy 52M weld material (Refer to Figure 2).

7. Machining the weld and nozzle to provide a surface suitable for nondestructive examination (NDE).

8. PT and Ultrasonic Testing (UT) examination of the weld and adjacent region (Refer to Figure 3).

9. Preservice Inspection (PSI) (Baseline) ET and UT leak path (Refer to Figure 9).

10. Rotary peening of the modification region.

11. Visual examination of the rotary peened surface.

Note: The figures in this request are provided to assist in clarifying the above description. They are not intended to provide design information such as the location of the IDTB weld relative to the inner and outer spherical radii of the RVCH.

Two fabrication parameters are controlled to ensure the nozzle roll expansion is effective in performing its design function of mechanical support for the nozzle prior to the application of the IDTB weld. The parameters of interest are tool insertion depth and the torque setting on the assembly tool.

Tool insertion depth, based on tooling setup height, will be controlled so that the rolled region is contained within the RVCH penetration bore. The torque applied to the roll expander is controlled so that the desired amount of plastic deformation occurs. The torque limiter assembly will be set and independently verified with a calibrated torque wrench prior to use.

There were two roll expansions performed on CRDM Nozzle 5 during IDTB modification activities. The first roll expansion was performed inadvertently approximately 2.910-inches above the intended roll expansion within the RVCH penetration bore. Approximately 2-inches of the first roll expansion was positioned above the RVCH penetration bore. The same torque was applied to the inadvertent roll expansion as was planned for the intended roll expansion within the penetration bore. After the first inadvertent roll expansion was performed, a second roll expansion was performed at the appropriate elevation within the bore to provide mechanical support for the nozzle prior to application of the IDTB weld. The inadvertent roll expansion was evaluated and found to be acceptable within the existing bounding stress and fatigue analyses. Rotary peening will cover sufficient area above the upper most roll expansion to remediate residual tensile stresses.

The roll expansion process will be completed for nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53 and the two parameters of interest (tool insertion depth and applied torque) that could impact the susceptibility to PWSCC will be validated to be within process specifications. Additionally, rotary peening will be applied to remediate the tensile surface stresses in the roll expanded region.

In 2018, rotary peening remediation was performed to remediate tensile surface stresses for repaired nozzles 25, 33, and 36. In 2004, abrasive water jet machining was utilized to remove a small amount of material and create a residual compressive surface stress in the susceptible material in the roll expanded region for repaired nozzles 29 and 30. Since Revision 8 of Code Case N-638, the Case has permitted surface stress improvement peening on the final weld layer to create residual compressive surface stresses. In 2020, there was no action taken to remediate the tensile surface stresses in the roll expanded region for repaired nozzles 17 and 34 due to the short time period between the IDTB modification and the planned plant shutdown. Rotary peening, meeting the surface stress requirements of Reference 6, will be performed on previously repaired nozzles 17, 29, 30, and 34 to remediate residual tensile stresses.

As a result of roll expansion process control and rotary peening remediation, there is high confidence that adequate measures will be applied in the modification of nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53 and previously repaired nozzles 17, 29, 30, and 34 with respect to PWSCC for the life of the modification. This conclusion also includes the measures that were implemented during the 2018 repairs of nozzles 25, 33, and 36.

Holtec has determined that modification of the VHPs utilizing the alternatives specified in this request will provide an acceptable level of quality and safety. Relief is requested in accordance with 10 CFR 50.55a(z)(1).

4.0 PROPOSED ALTERNATIVE AND BASIS FOR USE

4.1 Welding Requirements

Code Case N-638-11 paragraph 1(a) states in part:

> This Case shall not be used to repair SA-302, Grade B material, unless the material has been modified to include 0.4% to 1.0% nickel, quenching and tempering, and application of a fine gain practice.

The RVCH material is SA-302 Grade B Modified, quenched and tempered plate. The Certified Material Test Reports (CMTRs) from Lukens Steel Company support the SA-302, Grade B material as having been modified to include 0.4% to 1.0% nickel and also that the material was quenched and tempered. Aluminum content is not reported on the CMTRs and the CMTRs do not identify that a fine grain practice was applied during the steelmaking process. Therefore, it is unknown if Aluminum-Nitride (AlN) pinning of the prior-austenite grain boundaries occurred that would have resulted in fine grains. It is also unknown if carbide formers such as Niobium (Nb) or Vanadium (V) were intentionally added to the "modified" formulation to promote fine grains, as these elements are not reported on the CMTR.

Electric Power Research Institute (EPRI) Report 1014351 (Reference 5) provides a comparison of the chemical and mechanical properties, heat treatment, and grain refinement practices of SA-302, Grade B Modified to SA-533, Grade B Class 1 materials. The chemical composition and the mechanical properties of SA-302, Grade B Modified materials are essentially identical to SA-533, Grade B Class 1, especially in the case when both materials have been Quenched and Tempered (which is the case at Palisades). Prior to 1987, the prescriptive Quench and Temper was the primary difference between SA-302, Grade B plate and SA-533, Grade B Class 1 plate specifications. The SA-533 specification in ASME Section II did not include a fine grain practice requirement until 1987. Code Case N-638-11 does not prohibit its use on SA-533, Grade B Class 1 plate manufactured prior to 1987.

The GTAW ambient temperature temper bead welding process is designed to develop a tough, ductile microstructure in the weld heat affected zone (HAZ) that is equivalent or superior to the surrounding base material. When performing GTAW ambient temperature temper bead welding in accordance with Code Case N-638-11, cooling rates are sufficiently high to obtain a very high percentage martensitic microstructure in the HAZ. Tempering of the HAZ is accomplished by the heat introduced from adjacent weld beads and successive weld layers. The degree of tempering is ideal for developing excellent notch toughness. Thus, two beneficial steps necessary to achieve an optimum HAZ microstructure occur during temper bead welding – a very high cooling rate step and tempering step(s). Finally, assurance of adequate notch toughness in the HAZ is obtained by the performance of impact testing (Charpy V notch testing) of the HAZ in accordance with Section 2.1 of the Code Case. The Framatome welding procedure, which will be used for performing the IDTB welding on the PNP RVCH, meets these requirements as the average lateral expansion value of the HAZ Charpy V notch specimens from the procedure qualification was greater than that of the unaffected base material.

The acceptable UT examination results reported at each refueling outage (RO) since installation in 2004 provide evidence for the previous IDTB repairs at Palisades in 2004, 2018, and 2020 that the plate material was not adversely affected by the temper bead weld process. Therefore, based on the discussion provided Holtec requests relief from the fine grain practice requirement specified in Code Case N-638-11 paragraph 1(a).

Code Case N-638-11 Paragraph 2(b) states:

> Existing welding procedure and welding operator qualifications performed in accordance with previous revisions of this Case may be used with this revision without requalification.

The welding procedure to be used on nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53 was qualified in accordance with N-638-4 (an earlier revision). Code Case N-638-4, Paragraph 2.1(a) states in part:

> The materials shall be post-weld heat treated to at least the time and temperature that was applied to the materials being welded.

Post-weld heat treatment (PWHT) can slightly degrade the fracture (notch) toughness of low alloy steels. Therefore, it is both reasonable and conservative to perform a simulated PWHT of test samples that will be used to evaluate base materials that have received PWHT during fabrication and placed into reactor service. However, it is not conservative to perform a simulated PWHT of welding qualification test plate material that will be compared to the temper bead heat affected zone (HAZ) for acceptance.

The temper bead weld procedure qualification is required to demonstrate that the Charpy V-notch test results from the weld HAZ are no less than the Charpy V-notch test results for the unaffected base material. EPRI Report 1025169, Section 3.0 (Reference 7) documents that simulated PWHT on procedure qualification test plates degrades the notch toughness of the test plate increasing the contrast between the impact properties of the base material test plate and the temper bead weld HAZ. In other words, the simulated PWHT makes passing the impact testing requirements of the temper bead procedure qualification less difficult. Therefore, simulated PWHT on the temper bead test coupon does not provide conservative results when the simulated PWHT time exceeds the actual PWHT time applied to the component during construction.

The RVCH material at Palisades has 40-hours of PWHT and the weld procedure qualification test plate has 30-hours of simulated PWHT. This condition does not comply with Code Case N-638-4, paragraph 2.1(a) which requires simulated PWHT on the temper bead qualification test plate to be equivalent to or exceed the total aggregate time applied to the component to be welded. There is no maximum limit on the simulated PWHT time.

The simulated PWHT requirement of Code Case N-638 has been recognized by the ASME Code Committee as non-conservative and was changed in Revision 7. Code Case N-638-11, paragraph 2.1(a) now states that simulated PWHT of the “test assembly is neither required nor prohibited. However, if used, the simulated PWHT shall not exceed the time or temperature already applied to the base material to be welded." The welding procedure to be used to implement the half nozzle modifications on nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53 complies with this requirement.

In conclusion, ambient temperature temper bead welding will be performed on nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53 in accordance with Code Case N-638-11 while the welding procedure was qualified in accordance with Code Case N-638-4. The qualified welding procedure does not comply with the simulated PWHT requirements of Revision 4 of the Code Case but does comply with the enhanced and more conservative simulated PWHT requirements in Revision 11 (i.e., N-638-11).

Therefore, Holtec requests approval to apply the simulated PWHT requirements of Code Case N-638-11, paragraph 2.1(a) when using the temper bead welding procedure on nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53.

Code Case N-638-11 Paragraph 4(a)(2) states:

> When ferritic materials are used, the weld shall be nondestructively examined after the completed weld has been at ambient temperature for at least 48 hr. When austenitic materials are used, the completed weld shall be nondestructively examined after the three tempering layers (i.e., layers 1, 2, and 3) have been in place for at least 48 hr. Examination of the welded region shall include both volumetric and surface examination methods.

Elimination of the 48-hour hold time is based on Attachment 2, which is a white paper based on PVP2023-107489, "Elimination of the 48-hour Hold Time for Ambient Temperature Temper Bead Welding with Austenitic Weld Metal." Removal of the 48-hour hold time is supported by the white paper that was developed for the proposed change to ASME Code Case N-888-1. Although this ASME Case is not approved in Reg. Guide 1.147, Revision 21, it has been approved by the ASME Section XI Standards Committee. Since Code Case N-888 is the culmination of temper bead code cases that have been produced over the years, combining requirements from Code Cases N-638 and N-839 and Appendix I in cases such as Code Cases N-740 and N-754, etc., the justification is also applicable to the planned use of Code Case N-638-11 at PNP.

4.2 IDTB Modification Acceptance Examinations

ASME Section III, 2019 Edition, NB-5245, specifies progressive surface examination of partial penetration welds. The Construction Code requirement for progressive surface examination, in lieu of volumetric examination, was because volumetric examination is not practical for the conventional partial penetration weld configurations. Therefore, the following combination of UT and PT examinations are proposed.

For a modified VHP, the weld is suitable for UT examination and the structural portion of the weld is accessible from both the top and bottom sides (Refer to Figure 4 through Figure 8).

UT volumetric examination of the modified configuration will be performed as specified in ASME Code Case N-638-11, 4(a)(2) and 4(a)(3). The acceptance criteria of NB-5331, in ASME Section III, 2019 Edition, apply to all flaws identified within the examined volume.

The UT examination system is capable of scanning from cylindrical surfaces with inside diameters of approximately 2.79-inch. The scanning is performed using a 0° L-wave transducer, 45□ S-wave transducer aimed axially downward 45° L-wave transducers in two opposed axial directions, and 70° L-wave transducers in two opposed axial directions as well as 45° L-wave transducers in two opposed circumferential directions. Additionally, the low alloy steel extending to ¼-inch beneath the weld into the low alloy steel base material (see Figure 3) will be examined using the 0° L-wave transducer searching for evidence of under bead cracking and lack of fusion in the heat-affected zone. The structural weld volume receives essentially 100% UT examination coverage as shown in Figure 4 through Figure 8.

In addition to the UT examinations, a surface PT examination will be performed on the entire weld as shown in Figure 3. The acceptance criteria of NB-5350 in ASME Section III, 2019 Edition shall apply.

The combination of performing PT and UT examinations depicted in Figure 3 during the IDTB modification provides assurance of structural integrity. Thus, Holtec requests relief from the progressive surface examination requirements specified in NB-5245.

4.3 Triple Point Anomaly

ASME Section III, 2019 Edition, NB-5331(b) states:

> Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

An artifact of ambient temperature temper bead welding is an anomaly in the weld at the triple point. There are two triple points in the modification. The upper triple point is the point in the modification weld where the low alloy steel RVCH base material, the Alloy 600 nozzle, and the Alloy 52M weld intersect. The lower triple point is the point in the modification weld where the low alloy steel RVCH base material, the Alloy 690 replacement nozzle, and the Alloy 52M weld intersect. The locations of the upper and lower triple points for the VHP modification are shown in Figure 2.

The anomaly consists of an irregularly shaped very small void. Mock-up testing has verified that the anomalies are common and do not exceed 0.10-inches in through wall extent and are assumed to exist, for purposes of analysis, around the entire bore circumference at the triple point elevation.

The outermost CRDM penetration and the ICI penetration were modeled due to the applied loading conditions being representative and bounding relative to all other locations in the RVCH. The initial flaw size for the triple point anomaly analysis is 0.10-inches. Crack growth analysis determines the future flaw size and concludes that it is acceptable for the stated life. The outermost hillside nozzle is explicitly modeled, meaning that both extremes of interaction between the IDTB weld and the original J- groove weld are considered (i.e., these welds are very close to each other on the uphill side, and are relatively far away from each other on the downhill side).

Two fracture mechanics analyses were performed for the design configurations to provide justification, in accordance with ASME Section XI, for operating with the postulated triple point anomaly. One analysis for the ICI VHPs and one analysis for the outermost CRDM VHPs. The anomaly is modeled as a 0.10-inch deep crack-like defect, initiating at the triple point location, considering the most susceptible material for propagation. Postulated flaws could be oriented within the anomaly such that there are two possible flaw propagation paths, as shown in Figure 12 and discussed below.

Circumferential and Axial Flaws: Flaw propagation is across the nozzle wall thickness from the outside diameter (OD) to the inside diameter (ID) of the nozzle housing.

> By using a fatigue crack growth rate twice that of the rate of in-air austenitic stainless-steel material, that is used to bound the Alloy 600/690 nozzle and Alloy 52M weld materials, it is ensured that another potential path through the HAZ between the new modification weld and the Alloy 600 nozzle material is also bounded.
>
> For completeness, two types of flaws are postulated at the outside surface of the nozzle IDTB modification weld. A 360-degree continuous circumferential flaw, lying in a horizontal plane, is considered to be a conservative representation of crack-like defects that may exist in the weld triple point anomaly. This flaw is subjected to axial stresses in the nozzle. An axially oriented semi-circular outside surface flaw is also considered since it would lie in a plane normal to the higher circumferential stresses. Both of these flaws would propagate toward the inside surface of the nozzle.

Cylindrical Flaw: Flaw propagation extends up the outside surface of the modification weld between the upper and lower triple points.

> A cylindrically oriented flaw is postulated to lie along this interface, subjected to radial stresses with respect to the nozzle. This flaw may propagate through either the new Alloy 52M weld material or the low alloy steel RVCH base material.

The results of the analyses demonstrate that a 0.10-inch weld anomaly is acceptable, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension following a VHP nozzle ID temper bead weld modification. Acceptable design margins have been demonstrated for all flaw propagation paths considered in the analysis. The minimum fracture toughness margin has been shown to be 2.5 for the cylindrical flaw propagations, as compared to the required margin of $\sqrt{2}$ (1.41) for normal operating conditions per ASME Section XI, IWB-3613. Fatigue crack growth is negligible. A limit load analysis was also performed considering the ductile Alloy 600/Alloy 690 materials along flaw propagation of circumferential and axial flaws. This analysis showed a limit load margin of 1.11 for normal operating conditions, as compared to the required margin of 1.0 per ASME Section XI, C-5320 and C-5410.

Since the postulated OD flaw in the weld anomaly at the upper triple point is not exposed to the primary coolant and the air environment is benign for the materials at the triple point, the time-dependent crack growth rates from PWSCC are not applicable. The crack-like defects due to the weld anomaly at the lower triple point are exposed to primary coolant however, the materials at the lower triple point are Alloy 52M, Alloy 690, and low alloy steel, therefore are only subject to fatigue crack growth.

These evaluations are prepared in accordance with ASME Section XI 2007 Edition including Addenda through 2008 and demonstrates that for the intended service life of the modification, the fatigue crack growth is acceptable and the crack-like indications remain stable. This satisfies the ASME Section XI criteria.

Holtec requests relief from the acceptance criteria specified in NB-5331(b) of ASME Section III to permit anomalies, as described herein, at the triple point area to remain in service.

4.4 Flaw Characterization and Successive Examinations – RVCH Original J-Groove Weld

The assumptions of IWB-3600 of ASME Section XI are that cracks are fully characterized in accordance with IWB-3420 in order to compare the calculated parameters to the acceptable parameters addressed in IWB-3500. There are no qualified UT examination techniques for examining the original nozzle-to-RVCH J-groove welds. Therefore, since it is impractical to characterize the flaw geometry that may exist therein, it is conservatively postulated that a radial-axial corner flaw exists through the entire J-groove weld and butter, and then propagates into the low alloy steel RVCH material by fatigue crack growth under cyclic loading conditions. Although galvanic corrosion, hydrogen embrittlement, PWSCC, and crevice corrosion are not expected to be a concern for the exposed low alloy RVCH base metal resulting from the IDTB modification, general corrosion of the exposed base metal may occur and is therefore included in the present flaw evaluation as a conservative approach.

The J-groove flaws were evaluated using the worst-case CRDM outermost nozzle penetration and the ICI configuration with postulated flaws on uphill and downhill sides of the J-groove weld. The initial flaw size for the J-groove weld is conservatively assumed to include all of the weld and buttering. This is highly conservative since the buttering sees PWHT, which would tend to reduce welding residual stresses, making it less susceptible to PWSCC. Fatigue crack growth for cyclic loading conditions using operational stresses from pressure and thermal loads, and crack growth rates from ASME Section XI, Nonmandatory Appendix A, Subarticle A-4300 for ferritic material in a primary water environment was calculated. The results of this evaluation show that, based on a linear elastic fracture mechanics (LEFM) analysis that the postulated flaw growth is acceptable, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension.

The transients applicable for the "as-left" J-groove weld are those due to normal, upset and test conditions only. The controlling transient for the ICI locations was the end of cooldown (uphill side flaw), with a safety margin on the applied stress intensity factor of 1.52 compared to the required safety margin of $\sqrt{2}$. The controlling transient for the CRDM locations was the end of the cooldown (downhill side flaw), with a safety margin on the applied stress intensity factor of 2.39 compared to the required safety margin of $\sqrt{2}$.

It is likely that the flaws detected by UT examination would be removed when the lower portion of the nozzle is machined away from the J-groove weld. However, as discussed above, flaws are postulated to exist in the remaining portion of the J-groove weld and shown in the evaluation to be acceptable, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension based on the detailed LEFM analysis that was performed.

Following the detailed LEFM analysis, per IWB-3610(d)(2) requirements which states that a flawed component must meet the primary stress limits of NB-3000 assuming a local area reduction of the pressure retaining membrane that is equal to the area of the flaw, a primary stress evaluation using limit load analysis is performed to demonstrate the operational life of the modification through the remainder of the operational life of the PNP.

Successive examinations required by IWB-3132.3 will not be performed on the modified nozzles for the duration of the life of the modifications because analytical evaluation of the worst-case postulated flaw is performed to demonstrate the acceptability for continued operation. A reasonable assurance of the RVCH structural integrity is maintained without the successive examination by the fact that evaluation has shown the worst-case flaw to be acceptable, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension.

In summary, the fatigue crack growth and fracture mechanics evaluation for a postulated flaw in the as-left J-groove weld demonstrates based on LEFM analysis per IWB-3612, and limit load analysis per IWB-3610(d)(2) that the postulated flaw growth shows acceptability of the RVCH ICI and CRDM nozzle modifications, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension. While similar repairs at other plants may be limited by crack growth in the available reinforcement area at the as-left J-groove weld, this is not the case for PNP. The greater thickness of the PNP RVCH combined with the smaller diameter of the nozzles and greater distance between nozzle penetrations results in greater available reinforcement area such that this is not limiting for PNP.

Relief is requested from flaw characterization specified in IWB-3420 and subsequent examination requirements specified in IWB-2420(b) and IWB-2420(c).

The potential for debris from a cracked J-groove weld remnant was considered. Radial cracks (relative to the nozzle axis) were postulated to occur in the J-groove weld due to the dominance of higher hoop stresses relative to axial stresses. The possibility of transverse cracks occurring that could subsequently intersect the radial cracks is considered remote as there are minimal driving forces for cracks in the transverse direction. The radial cracks would relieve the driving forces for any potential transverse cracks. There are no known service conditions that could drive radial cracks and transverse cracks to intersect to produce a loose part. There is extensive operating experience with remnant J-groove welds for which there are no known cases of debris generation (loose parts) due to PWSCC of the remnant J-groove weld. Therefore, cracking of the J-groove weld resulting in debris (loose parts) is not expected.

4.5 Preservice Inspection (PSI) / Baseline and Inservice Inspection (ISI) of Modified VHP's

Nozzles 25, 33, and 36 underwent rotary peening mitigation in 2018. As part of the current modification, all remaining RVCH VHPs will be mitigated by the same rotary peening process. T he residual plus operating surface stresses on peened CRDM and ICI nozzles repaired by the IDTB process have been evaluated and meet the requirements of EPRI Topical Report MRP-335, Rev. 3-A, (Reference 6). Follow-up ISI is required during the second refueling outage after peening mitigation per MRP-335, Rev. 3-A, (Reference 6). PSI of each CRDM and ICI nozzle that are part of the current modification will be performed prior to rotary peening as required by MRP-335, Rev. 3A, (Reference 6).

Prior to peening nozzles 25, 33, and 36 in 2018, PSI liquid penetrant surface examination was performed as required by MRP-335, Rev. 3A, (Reference 6). After peening, visual examination of the peened surface was performed. In 2020, follow up ISI volumetric examinations of nozzles 25, 33, and 36 were performed using UT. There were no flaws detected during the successive volumetric examinations one refueling cycle after the peening application. Prior to restarting plant operations, ISI will be performed for nozzles 25, 33, and 36 utilizing the surface exam plus UT leak path techniques discussed below.

Code Case N-729-6 as approved by the NRC in 10 CFR 50.55a specifies requirements for performing PSI and ISI examinations of RVCHs with nozzles having partial penetration welds. Prior to modification of the CRDM and ICI nozzles, the nozzles were examination category B4.20 of Code Case N-729-6, Table 1. Post modification, the exam requirements of B4.60 of Code Case N-729-6, Table 1, modified for the IDTB weld geometries as shown in Figure 9 and Figure 10, will be applied to the CRDM and ICI nozzles. Code Case N-729-6 Table 1, Item B4.60, permits either volumetric or surface examination. Item B4.60 examination coverage is specified in Figure 2 of Code Case N-729-6.

In lieu of the surface examination region that extends 1.5-inch above and below the J-groove weld shown in Figure 2 of Code Case N-729-6, an alternative examination region will be interrogated for the structural and non-structural portions of the modification weld for nozzles 1-16, 18-24, 26-28, 31, 32, 35, and 37-53. The lower extent of the new pressure boundary (structural weld) jurisdiction will be located at the transition point between the inside diameter and taper of the lower replacement nozzle as shown in Figure 2. The portion of the modification weld above the jurisdictional boundary is classified as a pressure-retaining structural weld, and the portion of the modification weld below the jurisdictional boundary is classified as a permanent, nonstructural attachment weld. The structural weld will be subject to PSI and ISI examinations. The PSI and ISI examination surfaces will extend up to 0.81-inches above the roll transition (greater than 1.5-inch above the modification weld), and 1.5-inch below the structural weld as shown in Figure 9. This examination coverage includes the rotary peened surfaces. Examination coverage below the structural weld will extend 1.5-inch below the structural weld and will obtain the maximum surface practical.

For previously repaired nozzles 17, 25, 29, 30, 33, 34 and 36, the PSI and ISI examination surfaces will extend up to 0.81-inches minimum above the roll transition (greater than 1.5-inch above the modification weld), and 1-inch minimum below the structural weld as shown in Figure 10. This examination coverage includes the rotary peened surfaces. Examination coverage below the structural weld will extend 1-inch below the structural weld and will obtain the maximum surface practical.

Examination coverage of 1-inch and 1.5-inch, as applicable, minimum below the structural weld is considered sufficient due to the following:

- The modification weld material (Alloy 52M) is highly resistant to PWSCC
- The replacement nozzle material (Alloy 690) is highly resistant to PWSCC
- The replacement nozzle is not pressure-retaining

Prior to restarting plant operations, the PSI for the modified VHPs, and ISI examinations for nozzles 25, 33, and 36, will be performed using a surface examination method followed by a UT leak path examination as shown in Figure 9 and Figure 10, as applicable. Future ISI examinations of all RVCH CRDM and ICI nozzles will be performed using the same methods.

The future ISI examinations will comply with Code Case N-729-6 as modified by 10 CFR 50.55a(g)(6)(ii)(D) and as depicted in Figure 9 and Figure 10, as applicable.

4.6 General Corrosion Impact on Low Alloy Steel

The IDTB nozzle modification leaves an annular crevice between the RVCH and the replacement lower nozzle, wherein a small area of low alloy steel in the RVCH will be exposed to primary coolant. An evaluation was performed for similar prior repairs, evaluating corrosion concerns for the RVCH low alloy steel wetted surface. Galvanic corrosion, hydrogen embrittlement, SCC, and crevice corrosion are not expected to be a concern for the exposed low alloy steel base metal. General corrosion of the exposed low alloy steel base metal will occur within the crevice between the IDTB weld and the original J-groove weld. As corrosion products pack the crevice, RCS flow will be restricted, resulting in decreased corrosion rate. However, a conservative, sustained, corrosion rate will be assumed and the resultant increase in bore diameter will be considered in the reinforcement calculation (per NB-3330) as part of the ASME Section III analysis.

Galvanic Corrosion

The results of the NRC's boric acid corrosion program have shown that the galvanic difference between SA-533 Grade B Class 1, Alloy 600, and Type 308 stainless steel (nominal chemistry of RVCH cladding) is not significant enough to consider galvanic corrosion as a strong contributor to the overall boric acid corrosion process, (Reference 8). Therefore, it was judged that galvanic corrosion between the exposed RVCH low alloy steel, Alloy 600, Alloy 690, or their weld metals is not a concern for this modification configuration. This is supported by studies documented in (References 9 – 11).

Hydrogen Embrittlement

Hydrogen embrittlement degrades material properties in the presence of hydrogen, usually occurring in combination with an applied stress. High pressure hydrogen environments are not typical of PWRs. Furthermore, lower strength, high toughness carbon and low alloy steels are not particularly susceptible to hydrogen stress cracking at normal operating temperatures. Therefore, it was determined that hydrogen embrittlement is not a concern for the exposed RVCH low alloy steel in the modified configuration. This conclusion is supported by many cases of low alloy steels being exposed to primary coolant without any observed cracking due to hydrogen embrittlement.

Stress Corrosion Cracking

There is extensive Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) operating experience related to low alloy steels being exposed to the reactor coolant environment. This operating experience has not identified any known occurrence of stress corrosion cracking of the low alloy steel of RVCHs. Likewise, there are no existing ASME Section XI Code rules or NRC regulations addressing this issue in RVCH low alloy steels in PWR reactor coolant environment. Therefore, it has been determined that stress corrosion cracking of the low alloy steel of the RVCH is not a concern for this modification configuration.

Crevice Corrosion

The geometry of the gap between the RVCH and replacement nozzle could create conditions for crevice corrosion. However, operating experience for PWRs shows that crevice corrosion of low alloy steels associated with these half nozzle modifications is not a problem in PWR systems due to expected low oxygen contents. Furthermore, the surface of the low alloy steel material will passivate with time, decreasing the rate of corrosion within the crevice. Therefore, it was determined that crevice corrosion of the low alloy is not a concern.

General Corrosion

Corrosion of the exposed low alloy steel is not expected to be a concern based on existing operating experience. The surface of the low alloy steel material will passivate with time, decreasing the rate of general corrosion. As corrosion products fill the gap between the RVCH and the replacement nozzles, they will isolate the low alloy steel surface from the reactor coolant system, thereby, impeding the transport of oxygen which is necessary to sustain continued corrosion. Due to the reduced amount of oxygen, tight geometry, passivated surface, and restriction of RCS flow at the exposed low alloy steel, general corrosion is expected to decrease over the life of the modification.

4.7 PWSCC Evaluation of Modified VHP's

An evaluation of PWSCC initiation and growth was performed for each of the VHP modification configurations, with two cases for each modification: 1) no surface stress improvement and 2) surface stress improvement rotary peening remediation. Primary water stress corrosion cracks were conservatively assumed to initiate instantly in the absence of the compressive stress layer created by rotary peening remediation. For case (1), this corresponds to crack initiation and growth immediately following plant restart. For case (2), the removal of the compressive stress layer, in the absence of any other viable degradation mechanism, was considered to occur by general corrosion; crack initiation and growth was modeled as occurring upon complete removal of the compressive stress layer. Crack growth was assumed to progress at a constant rate that was determined from in-service Alloy 600 VHP PWSCC crack growth measurements. The 75% through- wall flaw acceptance criterion was used.

The results of this evaluation indicate that if the Alloy 600 remnant nozzles following the modifications are not treated with any surface remediation, the remnant nozzles could exhibit a PWSCC flaw through 75% of the original wall thickness relatively quickly. Without surface remediation, a design life of the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension cannot be justified.

The results of this evaluation indicate that if rotary peening remediation is utilized, the modified surfaces could exhibit a PWSCC flaw through 75% of the original wall shortly following the degradation of the compressive stress layer. However, the estimated time to remove the compressive stress layer by general corrosion greatly exceeds the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension. Therefore, the rotary peening remediation that will be used in the modifications to the PNP RVCH penetrations is expected to sufficiently mitigate damage to the remnant Alloy 600 RVCH nozzles by PWSCC.

4.8 Conclusions

Implementation of an IDTB modification to the RVCH nozzle penetrations will produce an effective modification that will restore and maintain the pressure boundary integrity of the PNP VHPs. Similar modifications have been performed successfully and were in service for several years without any known degradation [e.g., Shearon Harris (2012, 2013, 2015, 2016 and 2018), Arkansas Nuclear 1 (2021 and 2024), and Palisades (2004, 2018, and 2020)]. This alternative provides improved structural integrity and reduced likelihood of leakage for the primary system. Accordingly, the use of the alternative provides an acceptable level of quality and safety in accordance with 10 CFR 50.55a(z)(1).

5.0 DURATION OR PROPOSED ALTERNATIVE

The acceptable life of the modified design is based on the most limiting life predicted by three evaluations: the weld anomaly analysis, the as-left J-groove analysis, and the PWSCC evaluation of the original Alloy 600 nozzle. Per the Life Assessment Summary (Reference 4) and the conclusions of the analyses presented herein, the results of the analyses performed to establish the overall acceptable life of the modification design demonstrate that the designs of all CRDM and ICI VHP modifications, including nozzles previously repaired in 2004, 2018, and 2020, are acceptable for continued operation, at a minimum, for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension.

The duration of this relief request is for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life extension. The modifications have been designed to meet the requirements of ASME Code, Section III, (Reference 12) and Section XI, (Reference 13). The design considers operation for the remainder of the 60-year licensed operational life (until 2031) plus an additional 20-year operational life.

In accordance with N-729-6 as conditioned by 10 CFR 50.55a(g)(6)(ii)(D), the modified penetrations require examination in the second refueling outage after peening. Then, the inspection frequency will not exceed one inspection interval (nominally 10 calendar years). The modifications installed in accordance with the provisions of this relief shall remain in place for the remaining operational life of the plant/modification.

6.0 ADDITIONAL INFORMATION

Palisades Relief Request RR 5-8 (ML20267A386) documents the qualification of the repaired geometry for CRDM nozzles 17 and 34 without rotary peening. This qualification was limited to a duration not to exceed 20-months or one operating cycle. Submittal of Relief Request RR 5-9 extends the qualified life of the repair for CRDM nozzles 17 and 34 after remediation to cover the remainder of the 60-year licensed operating life (through 2031) plus an additional 20-year life extension. Additionally, RR 5-9 updates the qualified life of repair after rotary peening for CRDM nozzles 29 and 30, similarly extending their qualification through 2031 and into the additional 20-year extended operational period.

The evaluations performed to qualify the life of modification for the CRDM geometries began their life assessment in 2004, which is representative of the time that the first CRDM nozzle modification occurred at PNP. Beginning the CRDM nozzle modification life evaluation in 2004 bounds all nozzles repaired or modified in the years after. The evaluations performed herein to qualify the life of modification for the new ICI nozzle geometries began their life assessment in 2025.

7.0 PRECEDENTS

1. Palisades Nuclear Plant, Relief Request #1 and Relief Request #2, October 11, 2005, ADAMS Accession Number ML043090191

2. Davis-Besse Nuclear Power Station Relief Request RR-A34, September 20, 2010, ADAMS Accession Number ML102571569

3. Calvert Cliffs Nuclear Power Plant Relief Request RR-PZR-01, December 9, 2011, ADAMS Accession Number ML113360526

4. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I3R-09, October 2, 2012, ADAMS Accession Number ML12270A258

5. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I3R-11, September 13, 2013, ADAMS Accession Number ML13238A154

6. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I3R-13, April 11, 2014, ADAMS Accession Number ML14093A075

7. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I3R-15, September 18, 2015, and January 6, 2016, Safety Evaluation, ADAMS Accession Numbers ML15203A702 and ML15342A043

8. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I3R-16, December 27, 2016, ADAMS Accession Number ML16343A220

9. Shearon Harris Nuclear Power Plant, Unit 1, Relief Request I4R-18, April 18, 2018, ADAMS Accession Number ML18108A094

10. Palisades Nuclear Plant, Relief Request RR 5-7, November 26, 2018, ADAMS Accession Number ML 24113A150

11. Palisades Nuclear Plant, Relief Request RR 5-8, September 24, 2020, ADAMS Accession Number ML 20365A001

12. Arkansas Nuclear One, Unit 2, Relief Request RR-23-001, December 31, 2022, ADAMS Accession Number ML 22073A095

13. Arkansas Nuclear One, Unit 2, Relief Request RR-24-001, October 21, 2024, ADAMS Accession Number ML 25107A057

8.0 REFERENCES

1. ASME Code Case N-638-11 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique, Section XI, Division 1

2. NRC Regulatory Guide 1.147, Revision 21, Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1

3. ASME Code Case N-729-6 Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial- Penetration Welds, Section XI, Division 1

4. Framatome Evaluation 51-9384372 Revision 000, "Life Assessment Summary for Palisades CRDM, ICI, and Vent RVCH Nozzle Mitigation" (Proprietary)

5. EPRI Report 1014351, "Repair and Replacement Applications Center: Topical Report Supporting Expedited NRC Review of Code Cases for Dissimilar Metal Weld Overlay Repairs", December 2006

6. EPRI Topical Report 3002009241, MRP-335, Revision 3-A, "Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," November 2016

7. EPRI Report 1025169, "Welding and Repair Technology Center: Welding and Repair Technical Issues in ASME Section XI", December 2013

8. NUREG-1823, "U.S. Plant Experience with Alloy 600 Cracking and Boric Acid Corrosion of Light-Water Reactor Pressure Vessel Materials", April 2005

9. Whitman G.D., Robinson, G.C., and Savolainen, A.W., "A Review of Current Practice in Design, Analysis, Materials, Fabrication, Inspection, and Test," ORNL-NSIC-21, ORNL, December 1967.

10. "Evaluation of Yankee Vessel Cladding Penetrations," Yankee Atomic Electric Company to the U.S. Atomic Energy Commission, WCAP-2855, License No. DPR-3, Docket No. 50-29, October 15, 1965.

11. Ruther, W.E., and Hart, R.K., "Influence of Oxygen on High Temperature Aqueous Corrosion of Iron," Corrosion, Vol 19(4), April 1963, p. 127t.

12. ASME Section III, "Nuclear Power Plant Components", Subsection NB, Division 1, Class 1 Components, 2019 Edition.

13. ASME Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components", 2007 Edition, including Addenda through 2008

Figure 1

Nozzle Machining

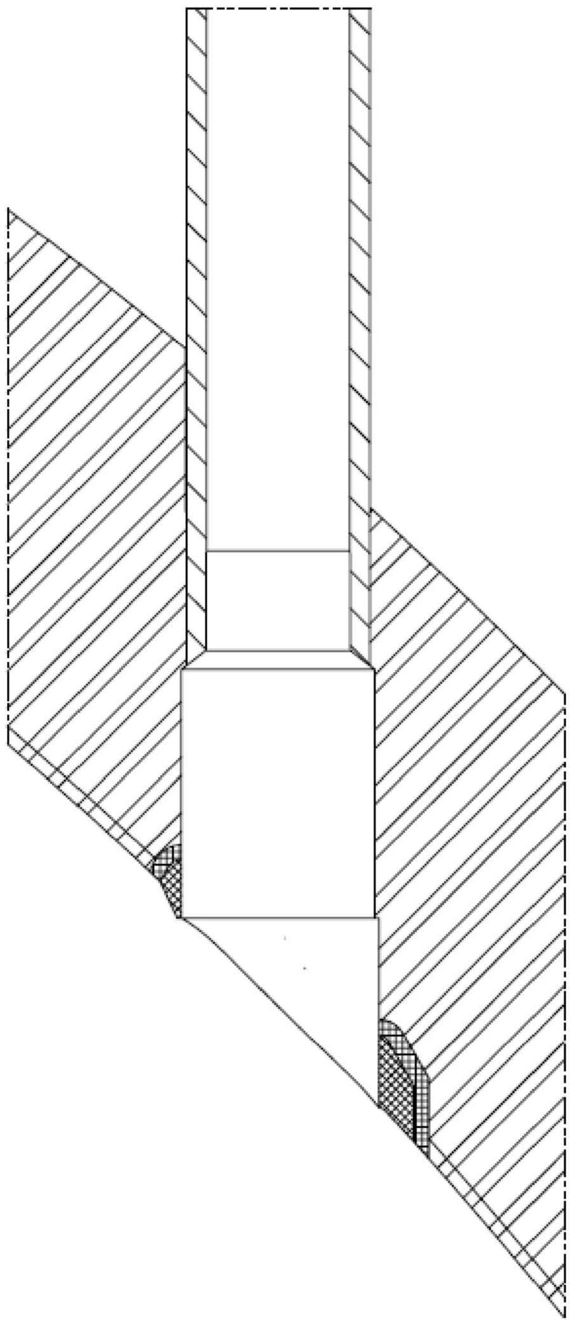


Figure 2

Nozzle Weld

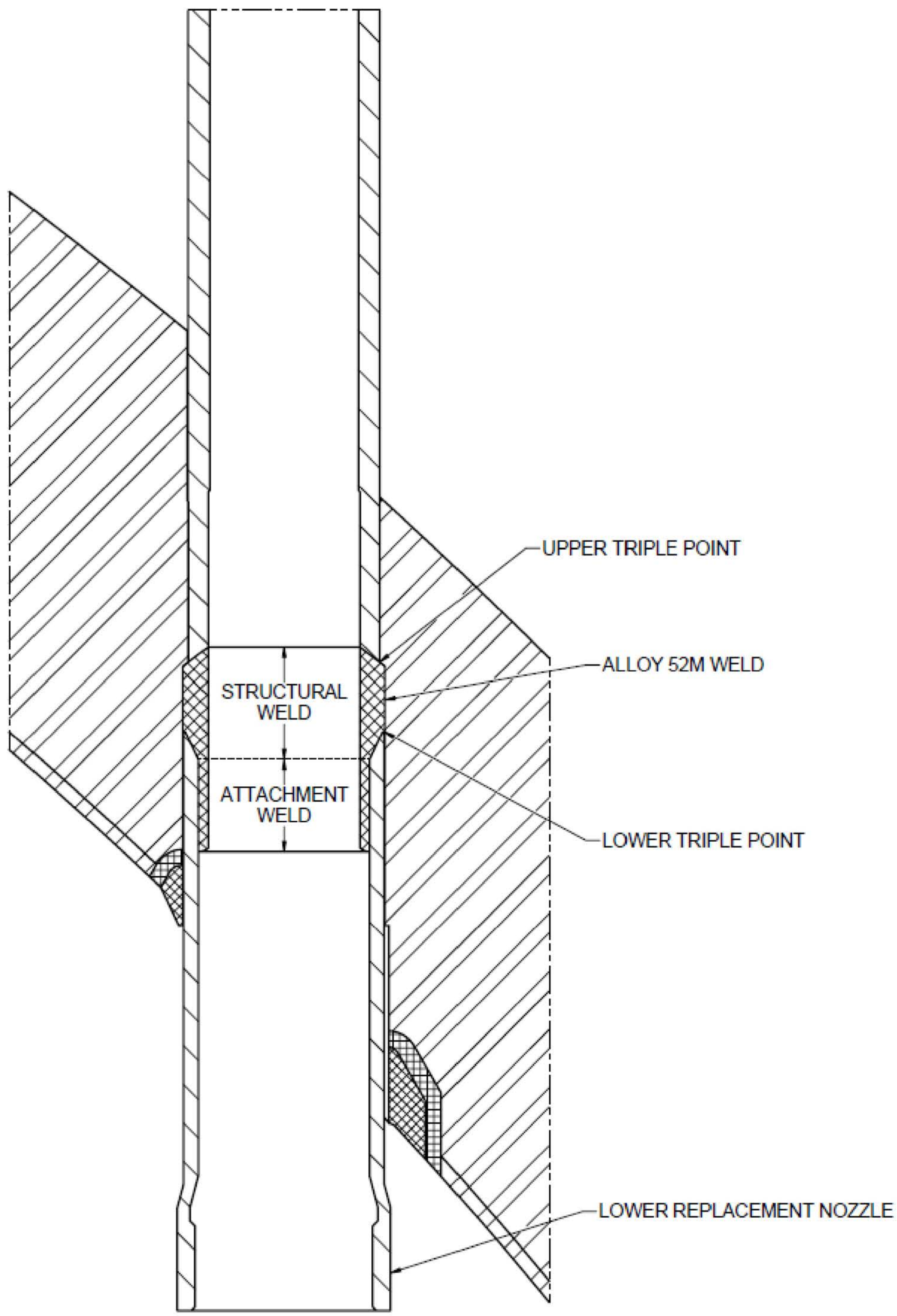
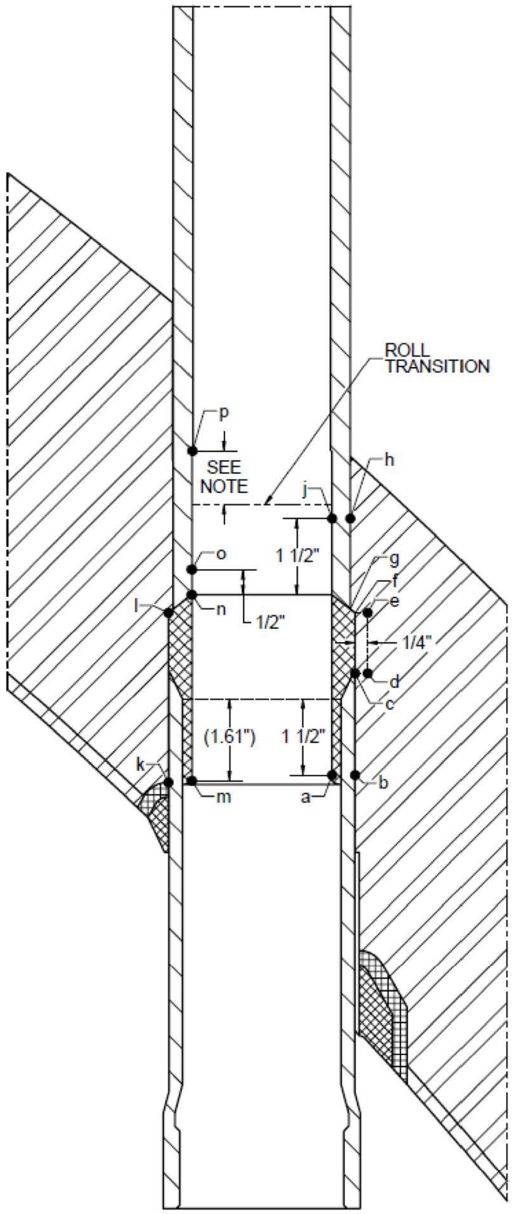


Figure 3

Nozzle Examination



Pre-Weld PT	k-i-n-o-p
Post-Weld PT	m-n-o-p
Post-Weld UT	a-b-c-d-e-f-g-h-j-a

NOTE: For Post – Weld PT, extent of examination above and below the weld is 1-1/2”. In addition, the examination shall include a minimum of 0.81” above the rolled transition area. Point “m” is the location where the nozzle ID meets the bottom of the weld.

Figure 4

Nozzle UT 0° and 45° L Beam Coverage Looking Clockwise and Counter-Clockwise

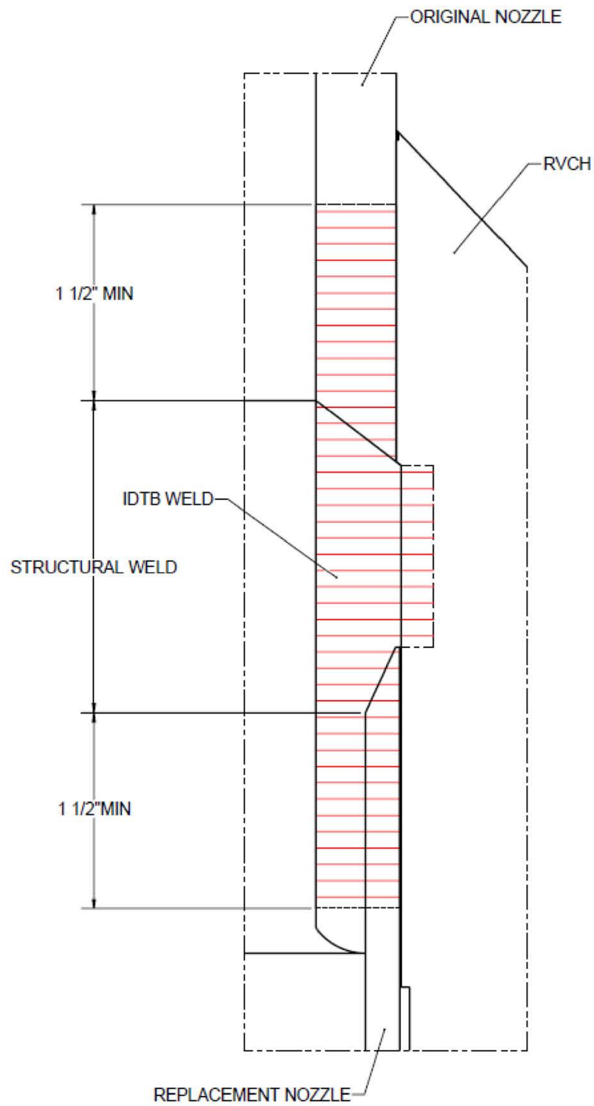


Figure 5

Nozzle 45° L UT Beam Coverage Looking Down

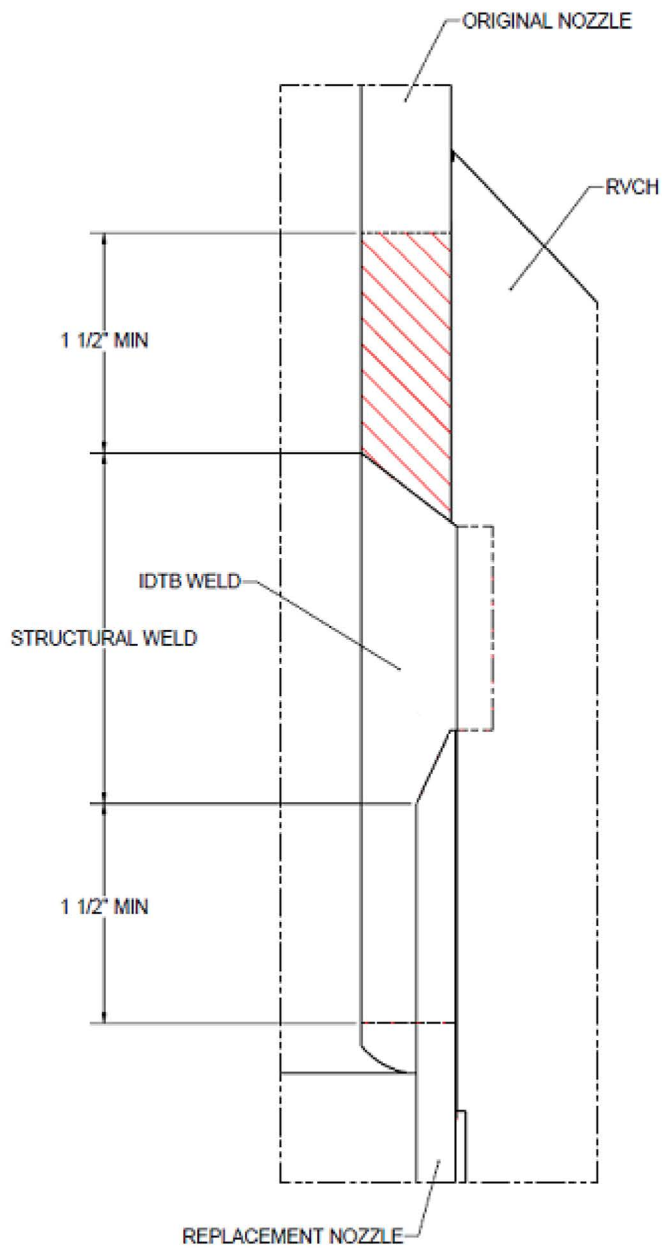


Figure 6

Nozzle 45° L UT Beam Coverage Looking Up

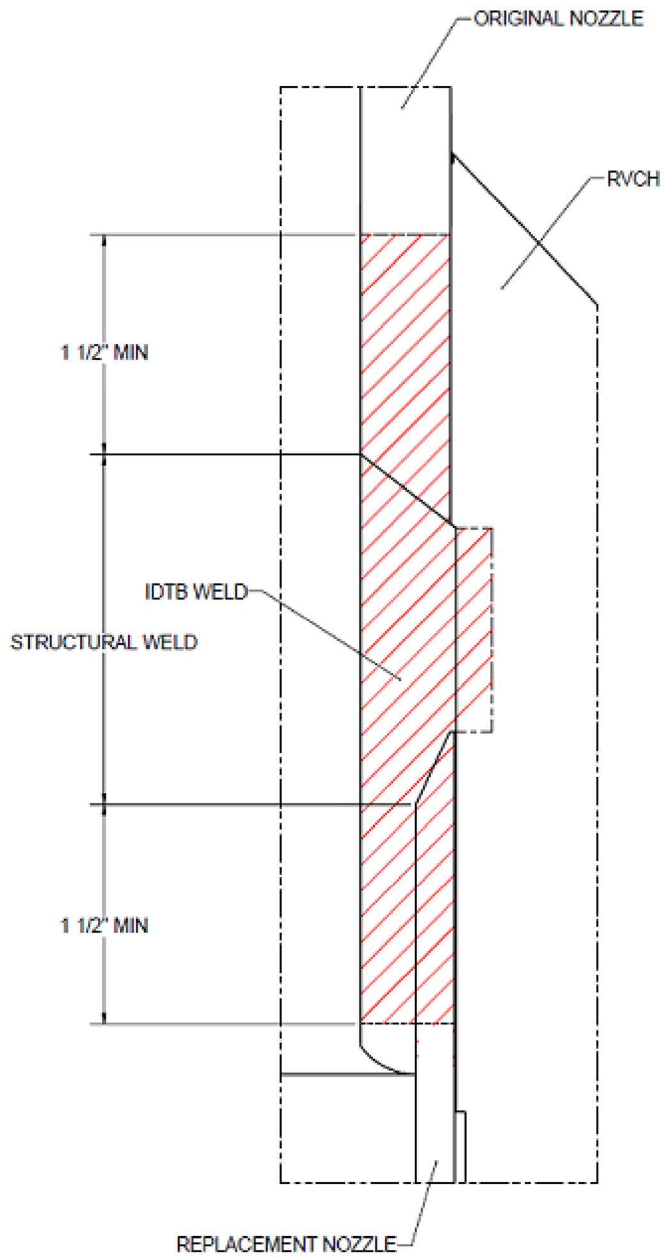


Figure 7

Nozzle 70° L UT Beam Coverage Looking Down

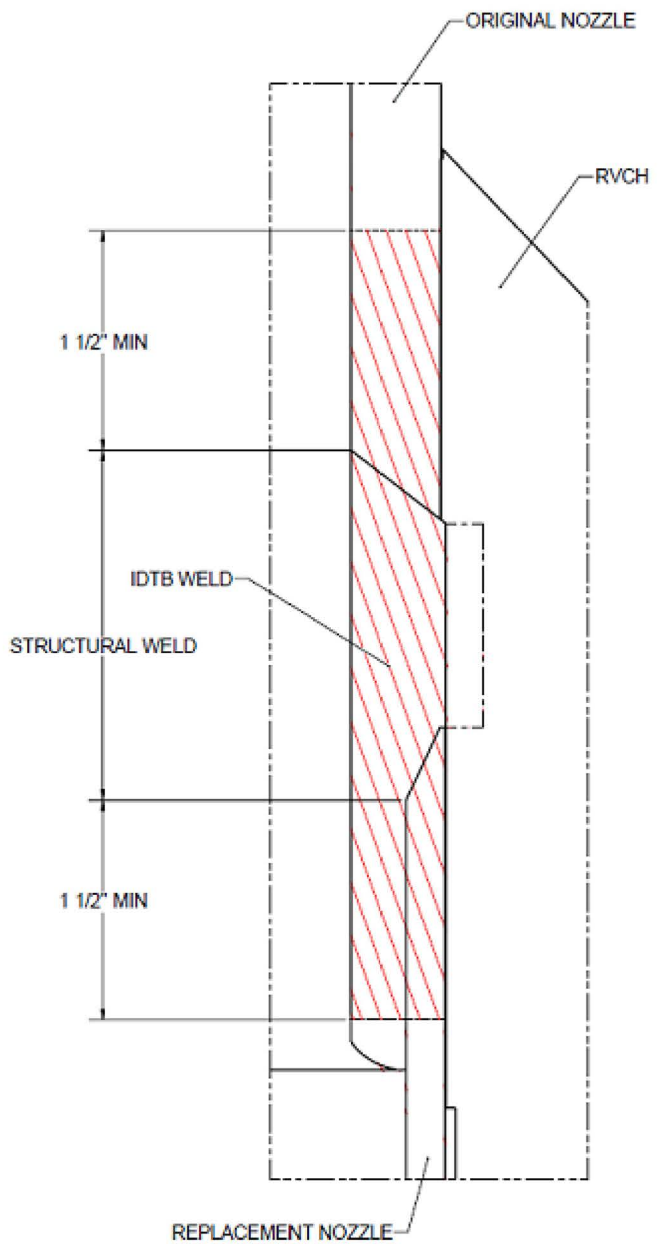


Figure 8

Nozzle 70° L UT Beam Coverage Looking Up

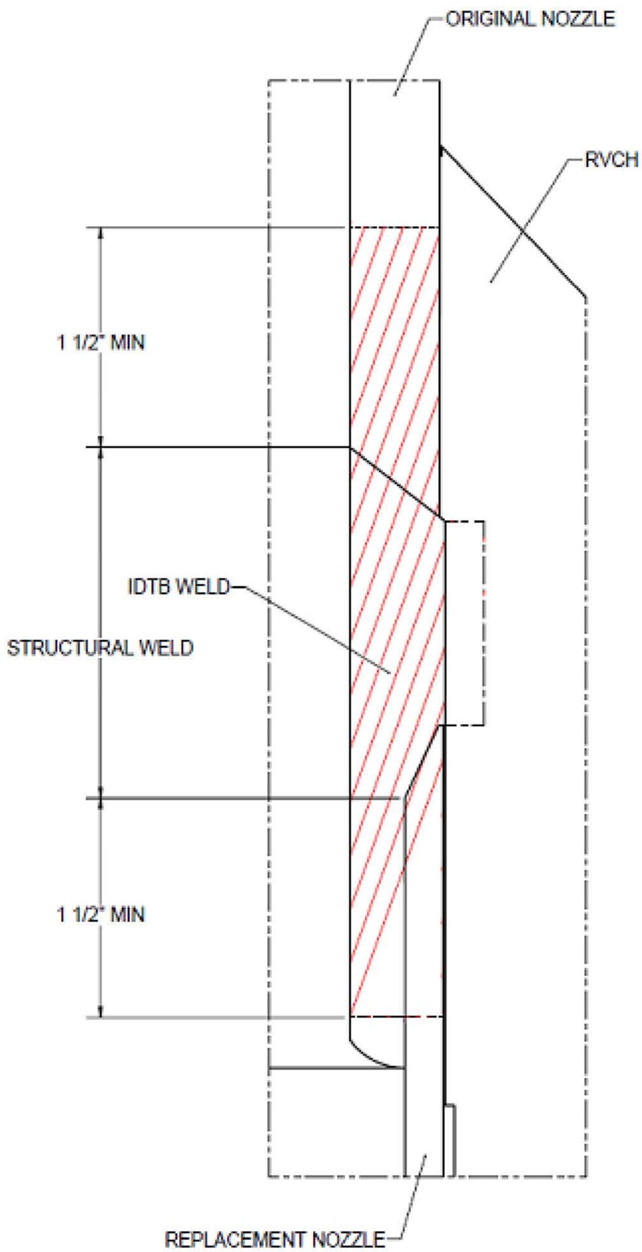
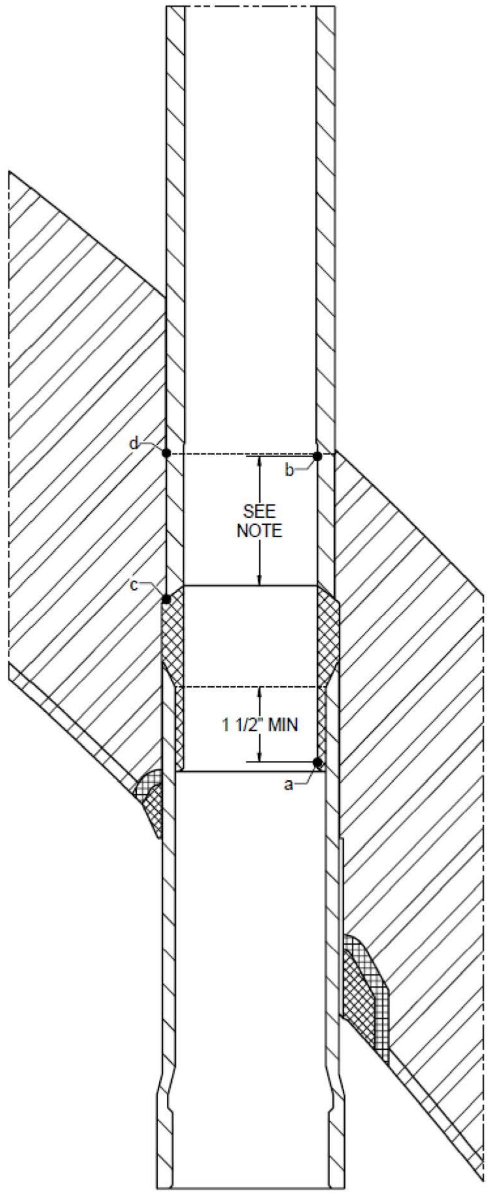


Figure 9

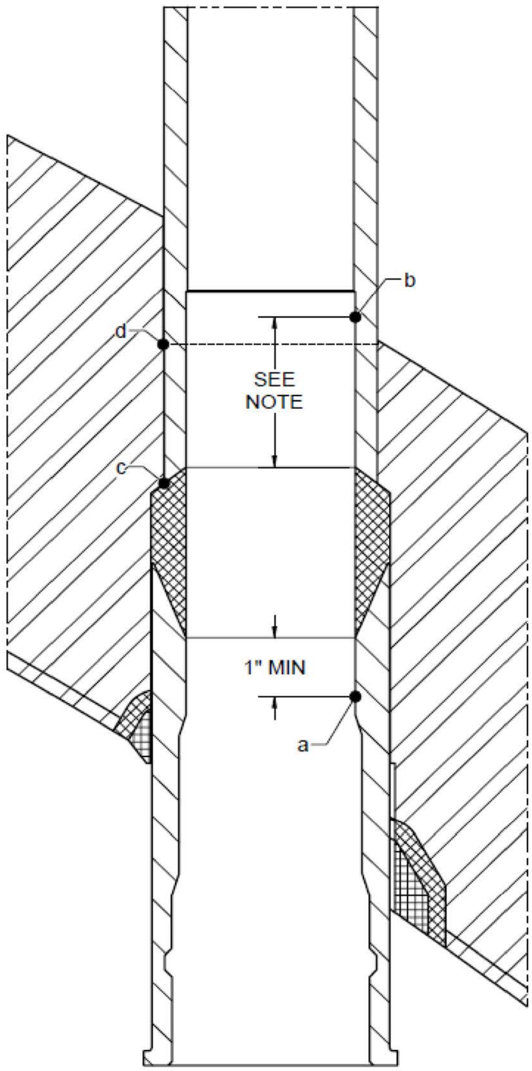
Nozzle PSI / ISI Examination
(Applicable for All CRDM / ICI Nozzles Except Those Identified in Figure 10)



ET	a-b
UT	c-d (leak path)

Note: Extent of examination below the weld is 1-1/2" and the extent of examination above the weld is 0.81" above the roll transition. UT leak path examination will be performed for PSI only. ISI examination will consist of the ET surface examination. Point "d" is the location where the nozzle exits the RVCH penetration-to-nozzle interference fit.

Figure 10
Nozzle PSI / ISI Examination
(CRDM Nozzles 17, 25, 29, 30, 33, 34, and 36)

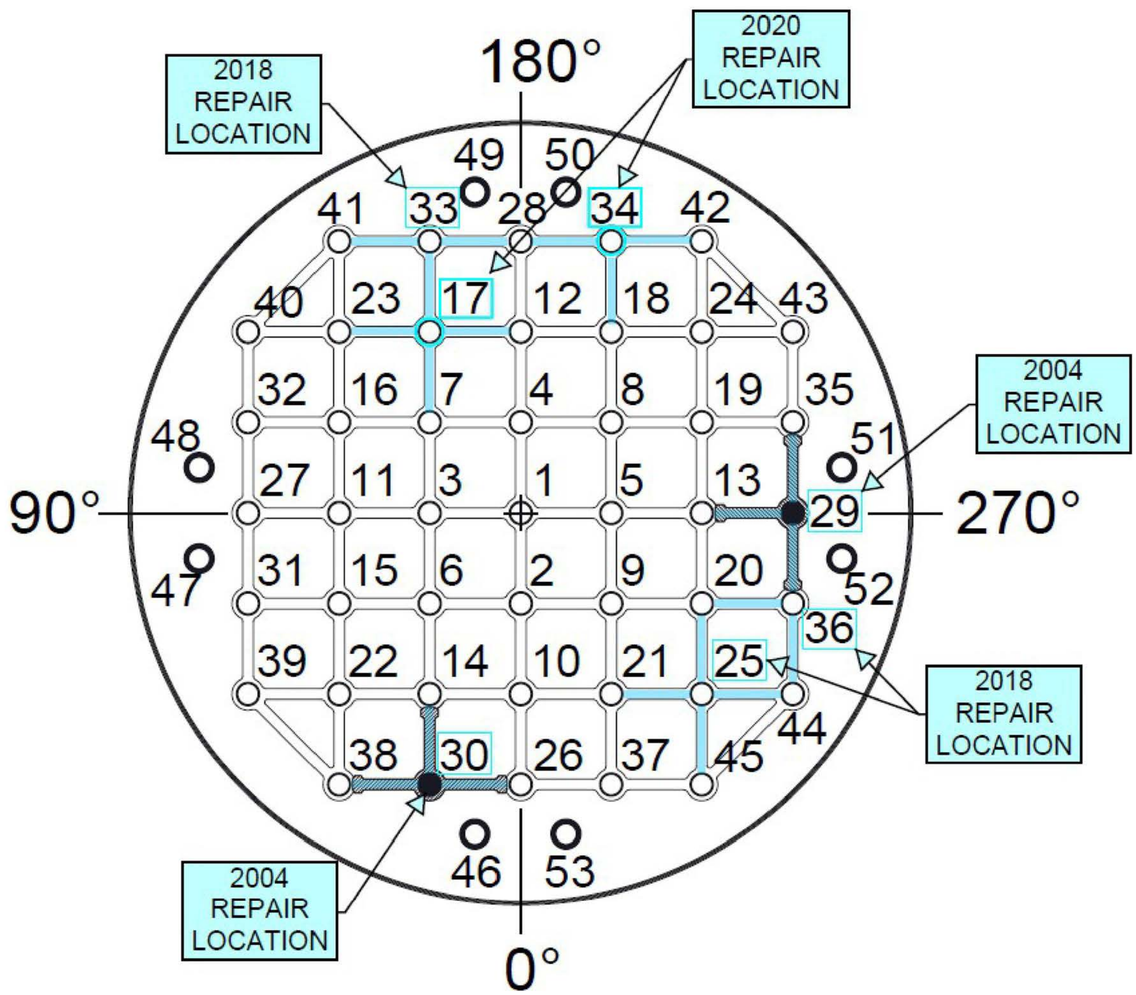


ET	a-b
UT	c-d (leak path)

Note: Extent of examination below the weld is 1" minimum and the extent of examination above the weld is 0.81" minimum above the roll transition. PSI and ISI examination will consist of the ET surface examination and UT leak path. Point "d" is the location where the nozzle exits the RVCH penetration-to-nozzle interference fit.

Figure 11

Reactor Vessel Head Penetration Locations



(Plan View Looking Down)

1-45 CRDM Nozzles
46-53 ICI Nozzles

<u>Notes</u>:

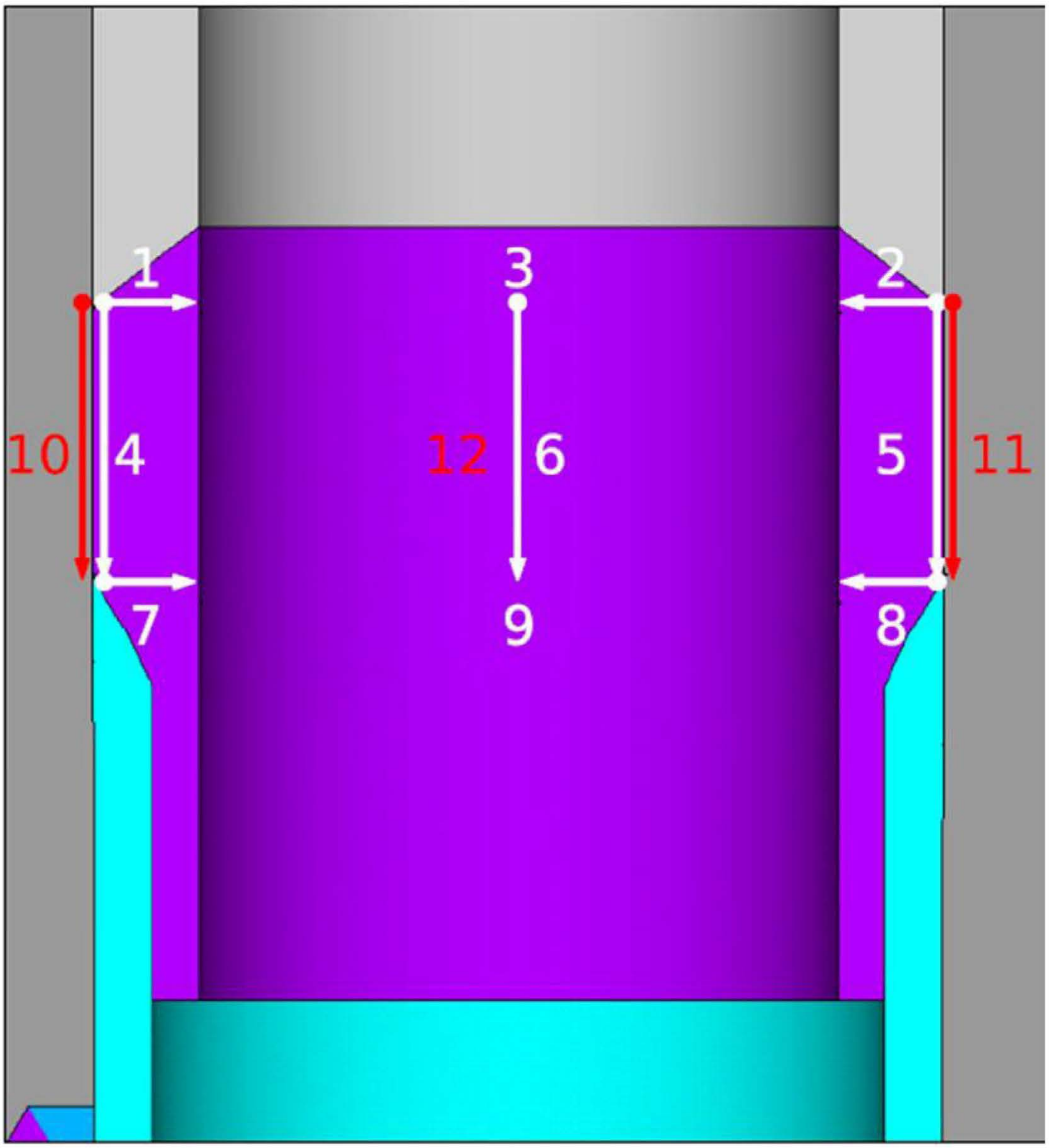
1. Penetrations 29 and 30 were repaired during the Fall 2004 Refueling Outage. The nozzles at penetrations 29 and 30 will undergo rotary peening remediation prior to startup of the PNP.

2. Penetrations 25, 33 and 36 were repaired during the Fall 2018 Refueling Outage.

3. Penetrations 17 and 34 were repaired during the Fall 2020 Refueling Outage. The nozzles at penetrations 17 and 34 will undergo rotary peening remediation prior to startup of the PNP.

Figure 12

Crack Propagation Paths



ATTACHMENT 2

White Paper

Ambient Temperature Temper Bead- Elimination of 48-Hour Hold Time from N-888 When using Austenitic Filler Material

1. Introduction and Background

In welding, the presence of hydrogen in the weld metal or heat affected zone (HAZ) can cause hydrogen-induced cracking (HIC) occurring phenomena that occurs after the weldment has cooled to at or near room temperature. HIC is largely dependent upon three main factors, diffusible hydrogen, residual stress and susceptible microstructure. There are many theories on the mechanism for HIC, however, it is well understood that HIC requires simultaneous presence of a threshold level of hydrogen, a susceptible brittle microstructure and tensile stress. Additionally, the temperature must be in the range of 32 to 212°F (0 to 100°C). Elimination of just one of these four contributing factors will prevent HIC (Reference 1).

Two early overlay (WOL) repairs involving temper bead welding were applied to two core spray nozzle-to-safe end joints at the Vermont Yankee boiling water reactor (BWR) in 1986 to mitigate intergranular stress corrosion cracking (Reference 2). To avoid post weld heat treatment, temper bead was deployed when installing the repair overlay on the low alloy steel SA-508 Class 2 (P- No. 3 Group 3) reactor pressure vessel nozzle. This early application of temper bead welding required elevated preheat and a post weld hydrogen bake.

As the industry experienced an increased need for temper bead welding the requirement for preheating and post weld bake made temper bead welding complicated. EPRI responded to the industry concern and conducted studies that demonstrated that repair to low alloy steel pressure vessel components could be made without the need for preheat or post weld bake (References 3 and 4]. As a result of these studies the preheat and post weld bake requirements were not included in American Society of Mechanical Engineers (ASME) Code Case N-638 for ambient temperature temper bead welding with machine GTAW.

Deployment of the ambient temperature temper bead technique has been highly successful for many years with no evidence of HIC detected by nondestructive examination (NDE). During the past twenty years, many temper bead weld overlay repairs were successfully performed on BWRs and PWRs using ambient temperature temper bead technique, as illustrated in Table 1. The operating experience shows that with hundreds of ambient temperature temper bead applications; there has not been a single reported occurrence of hydrogen induced cracking.

Code Case N-888 is the culmination of temper bead code cases that have been produced over the years, combining requirements from Code Cases N-638 and N-839 and Appendix I in cases such as Code Cases N-740 and N-754, etc. Code Case N-888 applies to temper bead of P-No. 1 or P-No. 3 materials and their associated welds or welds joining P-No. 8 or P-No. 43 materials to P-No. 1 or P-No 3 materials. Additionally, Code Case N-888 provides provisions to allow for ambient temperature preheat with no post weld bake. However, the post weld 48-hour hold at ambient temperature has remained as a requirement in Code Case N-888. This 48-hour delay between welding completion and cooling to ambient temperature and the final NDE of the fully welded component is intended to assure detection of delayed hydrogen cracking that is known to occur up to 48-hours after the weldment is at ambient temperature.

The post weld 48-hour delay following cooling to ambient temperature has resulted in a considerable cost burden to utilities. As there are significant economic advantages associated with eliminating the 48-hour hold time and immediately performing NDE following the completed weld, it is important to determine the technical advantages and disadvantages of making such a change.

Table 1: Successfully Implemented Repairs Completed Using Temper Bead Technique from 2002-2021

Date	Plant	Component (Qty.)
2002	Oconee[1]	Mid-Wall RVH Repair (15)
2002	ANO[1]	Mid-Wall RVH Repair (6)
2002	Oyster Creek[2]	Recirculation outlet nozzle (1)
2002	Peach Bottom Units 2 & 3[2]	Core spray, recirculation outlet, and CRD return nozzles
2002	Calvert Cliff[2]	Heater Sleeve Repairs (Pads) (~50)
2002	Oconee[1]	Mid-Wall RVH Repair (2)
2002	Davis-Besse[1]	Mid-Wall RVH Repair (5)
2002	Millstone[1]	Mid-Wall RVH Repair (3)
2003	Palo Verde 1[2]	Heater Sleeve Repairs -Pads (36)
2003	Pilgrim[2]	Core spray nozzle and CRD return nozzle
2003	TMI Unit 1[2]	Hot leg and Surge line nozzle
2003	Ringhals[1]	1/2 Nozzle with Structural Pad (2)
2003	Crystal River[1]	1/2 Nozzle with Structural Pad (3)
2003	South Texas[1]	1/2 Nozzle with Structural Pad (2)
2003	Millstone[1]	Mid-Wall RVH Repair (8)
2003	St. Lucie[1]	Mid-Wall RVH Repair (2)
2004	Palo Verde 2[2]	Heater Sleeve Repairs -Pads (34)
2004	Susquehanna Unit 1[2]	Recirculation inlet and outlet nozzles
2004	Hope Creek[1]	SWOL (1)
2004	Palisades[1]	Mid-Wall RVH Repair (2)
2004	Point Beach[1]	Mid-Wall RVH Repair (1)
2004	ANO[1]	Mid-Wall RVH Repair (1)
2005	Palo Verde 3[2]	36 Heater Sleeve Repairs – Pads (36)
2005	ANO[2]	Mid Wall heater sleeve repair
2005	Waterford[2]	Mid Wall heater sleeve repair
2005	Calvert Cliffs Unit 2[2]	Hot Leg Drain and Cold Leg Letdown Nozzles
2005	DC Cook Unit 1[2]	Pressurizer Safety Nozzle
2005	TPC Kuosheng[2]	N1 Nozzle
2005	SONGS 3[2]	Heater Sleeve Repairs -Pads (~29)
2005	Three Mile Island[1]	SWOL (1)
2005	St. Lucie[1]	Mid-Wall RVH Repair (3)
2006	SONGS 2[2]	Heater Sleeve Repairs -Pads (~30)
2006	Davis Besse[2]	Hot and Cold Leg
2006	SONGS 2[2]	Pressurizer Nozzles (6)
2006	Millstone 3[2]	Pressurizer Nozzles (6)
2006	SONGS 3[2]	Pressurizer Nozzles (6)
2006	Oconee 1[2]	Pressurizer Nozzles (6)
2006	Beaver Valley 2[2]	Pressurizer Nozzles (6)
2006	Byron 2[3]	Pressurizer Nozzles (6)
2006	Wolf Creek[3]	Pressurizer Nozzles (6)
2006	McGuire[2]	Pressurizer Nozzles (6)
2006	DC Cook[1]	SWOL (4)
2007	Callaway[3]	Pressurizer Nozzles (6)
2007	St. Lucie[1]	SWOL (4)
2007	Crystal River[1]	SWOL (4)
2007	Three Mile Island[1]	SWOL (4)
2007	North Anna[1]	SWOL (4)
2008	Prairie Island[1]	SWOL (1)
2008	Diablo Canyon[1]	SWOL (6)

2008	Diablo Canyon[1]	SWOL (4)
2008	Seabrook[1]	SWOL (4)
Date	**Plant**	**Component (Qty.)**
2009	Three Mile Island[1]	SWOL (1)
2009	Three Mile Island1	Full Nozzle with Structural Pad (1)
2009	Crystal River1	SWOL (1)
2009	Palisades1	Mid-Wall RVH Repair (2)
2010	Oconee4	U3 Letdown WOL (1)
2010	Krsko1	SWOL (5)
2010	Tihange1	SWOL (1)
2010	Davis-Besse1	Mid-Wall RVH Repair (24)
2011	Hatch4	Nozzle WOL (1)
2011	Talen Energy Corporation4	N5 core spray nozzles
2011	Monticello4	Emergent WOL (1)
2011	Three Mile Island4	TMI PZR Spray Nozzle (1)
2011	Doel1	SWOL (1)
2011	Tihange1	SWOL (1)
2011	St. Lucie1	1/2 Nozzle with Structural Pad (30)
2012	North Anna4	SG Nozzle WOLS (3)
2012	Palo Verde4	Small Bore CL Nozzles WOL
2012	Grand Gulf4	Reactor Vessel Nozzle Contouring and N6 Weld Overlay
2012	Doel1	SWOL (1)
2012	Calvert Cliffs1	Mid-Wall Przr Heater Repair (119)
2012	Quad Cities1	1/2 Nozzle with Structural Pad (1)
2012	Harris Nuclear Plant1	Mid-Wall RVH Repair (4)
2013	Farley4	Unit 2 FAC Pipe Replacement and WOL
2013	Oconee4	Hot/Cold Leg Small Bore Alloy 600
2013	Hope Creek4	Emergent N5A WOL
2013	Three Mile Island1	SWOL (1)
2013	Palo Verde1	1/2 Nozzle with Structural Pad (1)
2013	Harris Nuclear Plant1	Mid-Wall RVH Repair (2)
2015	Harris Nuclear Plant1	Mid-Wall RVH Repair (3)
2015	Hatch4	N4A WOL
2015	Millstone4	2" Drain WOL
2015	Hatch4	Recirc (N2) WOL
2016	Harris Nuclear Plant1	Mid-Wall RVH Repair (4)
2017	Fitzpatrick4	RHR WOL
2017	Limerick1	1/2 Nozzle with Structural Pad (1)
2018	Waterford4	Emergent Drain Nozzle WOLs (2)
2018	Palisades1	Mid-Wall RVH Repair (3)
2018	Doel1	Mid-Wall RVH Repair (16)
2018	Harris Nuclear Plant1	Mid-Wall RVH Repair (1)
2018	Brunswick1	SWOL (2)
2020	Peach Bottom1	1/2 Nozzle with Structural Pad (1)
2020	Palisades1	Mid-Wall RVH Repair (2)
2021	Oconee4	Complex nozzle pads on RCS piping
2021	ANO-21	Mid-Wall RVH Repair (1)

Notes: Operating experience provided by Steve McCracken (EPRI), Darren Barborak (EPRI, formerly with AZZ) and Travis Olson (Framatome)

(1) Framatome
(2) Unknown
(3) PCI
(4) AZZ Specialty Welding

2. Objective

The objective of this white paper is to provide technical justification to eliminate the 48- hour delay when using austenitic filler materials in the temper bead welding process for P-No. 1 and P-No. 3 ferritic materials. The industry and regulatory technical concerns related to this change are examined and the technical bases for changing the requirements for the 48-hour delay are presented. Discussion from white paper for *Ambient Temperature Temper bead Weld Overlay Gas Tungsten Arc Welding* by Hermann and Associates (Reference 9) are included in this white paper.

If adopted, it is expected that the change in the 48-hour delay requirement will become part of a revision to the current ASME Section XI Case N-888 that currently allows for ambient temperature temper bead repairs but requires 48-hour delay after the initial three temper bead layers prior to final NDE.

3. Technical Issues Related to the 48-Hour Delay

The reasons for performing the final NDE after the 48-hour delay is the recognition that alloy steels can become susceptible to HIC. There are two primary weld cracking mechanisms of concern for low alloy steels during cooling or after reaching ambient temperature. These are cold cracking of high restraint geometries (weld shrinkage- induced) and hydrogen induced cracking (HIC), often referred to as hydrogen delayed cracking. Cold cracking occurs immediately as the weldment cools to ambient temperature. In contrast, HIC can occur immediately during cooling to ambient temperature or up to 48-hours after reaching ambient temperature. Cold cracking that occurs with high restraint weldments would therefore be detected by NDE performed immediately after the weldment is complete.

EPRI studies (Reference 4) have indicated that cold cracking occurs under conditions of high geometrical restraint especially where low toughness HAZs are potentially present.

Restraint mechanisms can occur either hot (resulting in intergranular or interdendritic cracking), or cold (resulting in transgranular cracking of material having marginal toughness). Cold cracking occurs immediately as the weld deposit cools to ambient temperature. Proper joint design, appropriate welding procedures and bead sequences, are practical solutions that avoid critical cold cracking conditions. This form of cracking is addressed effectively by the ASME code guidance including welding procedure qualification testing and by in-process and or post-weld inspections.

The other form of cracking at ambient temperature, which is the focus of this white paper, is HIC. This cracking mechanism manifests itself as intergranular cracking of prior austenite grain boundaries and in contrast to cold cracking generally occurs during welding, but also up to 48-hours after cooling to ambient temperature. It is produced by the action of internal tensile stresses acting on low toughness HAZs (generally characterized by inadequate tempering of weld related transformation products). The most widely accepted theory suggests that the internal stresses will be produced from localized buildup of monatomic hydrogen. Monatomic

hydrogen can be entrapped during weld solidification, and will tend to migrate, over time, to prior austenite grain boundaries or other microstructure defect locations. As concentrations build, the monatomic hydrogen will recombine to form molecular hydrogen, thus generating highly localized internal stresses at these internal defect locations. Monatomic hydrogen is produced when moisture or hydrocarbons interact with the welding arc and molten weld pool.
The concerns with and driving factors that cause hydrogen induced cracking have been identified. These issues are fundamental welding and heat treatment issues related to temper bead welding, requiring a technical resolution prior to modification of the current ASME Code Cases N-888 by the ASME Code and the technical community. Specific concerns relate to the following issues:

-Microstructure

-Sources for Hydrogen Introduction

-Diffusivity and Solubility of Hydrogen

In the following discussion of this white paper each of these factors is briefly described to provide insight into the impact and proper management of these factors that cause HIC.

4. Discussion of Technical Issues Related to the 48-Hour Delay

Microstructure:

C-Mn and low alloy steels can have a range of weld microstructures which is dependent upon both specific composition of the steel and the welding process/parameters used. Generally, untempered martensitic and untempered bainitic microstructures are the most susceptible to hydrogen cracking. These microstructures are produced when rapid cooling occurs from the dynamic upper critical (A_{c3}) transformation temperature (Reference 1). Generally, a critical Rockwell hardness (Rc) level necessary to promote hydrogen cracking is on the order of Rc 35 for materials with high hydrogen and Rc 45 for low level of hydrogen. Maintaining hardness levels below these thresholds generally avoids hydrogen cracking (Reference1).

EPRI has examined in detail the effects of welding on the hardening of low alloy steels. The microstructure evaluations and hardness measurements discussed in EPRI reports References 4, 5 and 6) have described the effects of temper bead welding on the toughness and hardness of P-No. 3 materials. The research results have illustrated that the microstructure in the low alloy steel (P-No. 3) beneath the temper bead WOL in the weld HAZ consists of a structure that is tempered martensite or tempered bainite and has maximum hardness at a distance of 2 to 3 mm (80 to 120 mils) beneath the surface of the order of 280 to 300 KHN (28 to 30Rc) or lower. The research outlines that the microstructure resulting from temper bead welding is highly resistant to HIC. Additionally, hardness would not be a concern provided there are adequate hydrogen controls in place.

Furthermore, materials having face-centered-cubic (FCC) crystal structures such as austenitic stainless steels (300 series) and nickel base alloys such as Inconel are not susceptible to hydrogen induced cracking. The reason is that FCC atomic structures have ample unit cell volume space to accommodate atomic (diffusible) hydrogen. It is noted that the diffusion of hydrogen at a given temperature is slightly higher in body-centered- cubic (BCC) materials, ferritic steels, than it is in FCC austenitic materials. The FCC crystal structure has increased capacity to strain significantly without cracking (ductility) providing acceptable levels of toughness capable of resisting HIC. The inherent ability to deform and accommodate diffusible hydrogen are the reasons austenitic stainless steel and nickel base coated electrodes do not have low hydrogen designators that are found for ferritic weld materials (Reference 6). Since the ferritic HAZ is in a tempered condition and an FCC filler material is used, a susceptible microstructure susceptible to HIC is highly unlikely.

Presence/sources of Hydrogen:

Hydrogen can be introduced into the weld from several sources. These include 1) hydrogen in the original base material, 2) moisture in electrode coatings and fluxes, 3) organic contaminants (grease or oils), 4) hydrogen in the shielding gas and 5) humidity in the atmosphere.

The reduction of diffusible hydrogen in temper bead and non-temper bead weldments begins with implementing low hydrogen weld practices. These practices originate with Federal requirements that nuclear utilities control special processes such as welding and design and fabricate components to various codes and standards. These requirements, when followed, will effectively eliminate the contamination, and minimize the environment pathways.

Cleanliness of surfaces to be welded are mandated by Code and subsequently implemented via adherence to sound welding programs. The controls and requirements for cleanliness of the welded surface at nuclear utilities significantly reduce the likelihood of hydrogen entering the weld from surface contamination. Furthermore, repair and replacement applications typically deal with components that have been at operating temperatures above 390°F (200°C) for many years and any hydrogen present in the base material would have diffused from the steel and escaped to the atmosphere. Thus, surface contaminants and the base materials are not expected to be a significant source of diffusible hydrogen.

For Shielded Metal Arc Welding (SMAW), main pathway for diffusible hydrogen to enter the weldment will be the electrode coating. Welding programs primarily maintain low moisture in electrode coatings through procurement via an approved supplier, controlled storage conditions, and conservative exposure durations. The conservative exposure duration and coatings that resist moisture uptake minimize the amount of additional moisture in the coated electrode taking into consideration that moisture uptake is a function of time, temperature, and relative humidity. Extensive testing by the EPRI Welding and Repair Technology Center shows there is an extremely low probability of HIC with H4 and H4R electrodes. EPRI performed diffusible hydrogen analysis per American Welding Society (AWS) A4.3 via gas chromatography on thirteen commercially available electrodes. Electrodes with AWS E7018, E8018 and E9018 from multiple vendors exposed at 27°C at 80% relative humidity (HR) for exposure times from 0 to 72 hours. Many of the electrodes did not have "R" moisture resistant coating.

Figure 1 shows EPRI diffusible hydrogen test results for the thirteen lots of low hydrogen electrodes. All H4R electrodes exhibited < 16ml/100g of diffusible hydrogen at 72 hours of exposure. Figure 3 shows that new electrodes without exposure have < 2ml/100g diffusible hydrogen. Only one of the electrodes tested at the extremely aggressive 27°C and 80% Relative Humidity (HR) 72-hour exposure had diffusible hydrogen > 4 ml/100g. This demonstrates that exposure limits in the field of 24 hours or less is adequate to assure electrodes maintain the H4R limit. Ferritic electrodes were verified to have less than 4ml/100g diffusible hydrogen (Reference 6). Testing verifies that ambient temperature is acceptable, post weld hydrogen bakeout is not needed, and a 48 hour hold at ambient temperature prior to performing final NDE is unnecessary and diffusible hydrogen levels will be below any susceptibility threshold that supports HIC.

For GTAW, EPRI performed studies investigating the diffusion of hydrogen into low alloy pressure vessel steels (Reference 4). Due to the little information published at the time, EPRI decided to generate experimental data that would provide information on the levels of diffusible hydrogen associated with GTAW welding. The experimentation included individual sets of diffusible hydrogen tests as follows:

1. determination of diffusible hydrogen levels for the GTAW process under severe welding and environmental conditions simulating (or exceeding) repair welding conditions which may be expected in a nuclear plant.

2. measurement of diffusible hydrogen levels for various shielding gas dew point temperatures

3. examination of diffusible hydrogen levels for modern off-the-shelf filler wires

Discussion of these items can be found in the EPRI documents and will not be reiterated in this report. The results demonstrate that introducing hydrogen is unlikely with the GTAW process. The typical hydrogen content for the GTAW process is less than 1.0mL/100g. Therefore, hydrogen cracking is extremely unlikely.

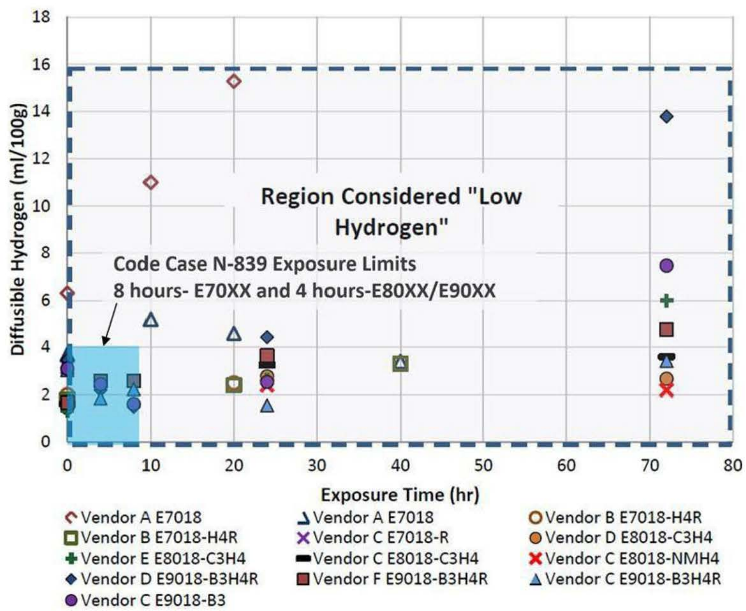


Figure 1. Results of EPRI diffusible hydrogen testing at 27°C 80% Relative Humidity (HR) for zero to 72 hours of exposure (Reference 6)

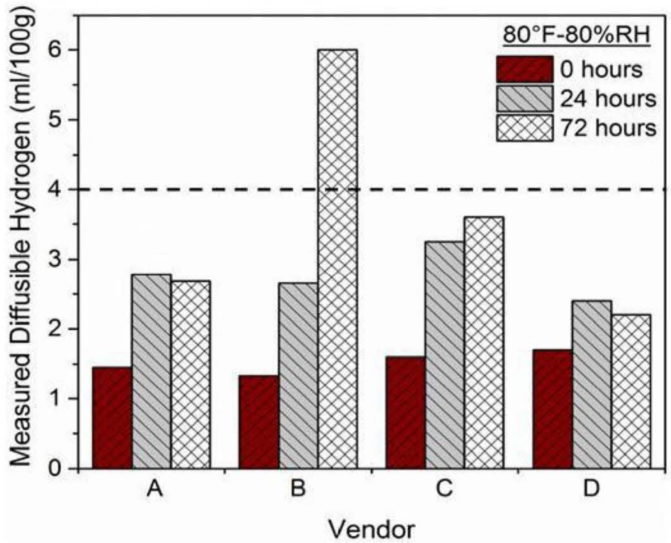


Figure 2. Graph showing sight increase of diffusible hydrogen after exposure to 24 and 72 hours (Reference 6)

Diffusivity and Solubility of Hydrogen

Diffusivity and solubility of hydrogen in ferritic, martensitic, and austenitic steels is an important factor to consider. Materials having face-centered-cubic (FCC) crystal structures such as austenitic stainless steels (300 series) and nickel base Inconels generally are not considered to be susceptible to hydrogen delayed cracking as discussed in the microstructure section, above. Additionally, due to the temperatures expected during the welding of the temper bead layers, and during the welding of any non-temper bead layers, the temperature should be sufficient for the hydrogen to diffuse out of the HAZ, either escaping the structure or diffusing into the austenite, where it can be held in much greater quantities. The diffusion rate is clearly from the ferrite to the austenite and whatever hydrogen remains will reside in the austenite, which has little to no propensity to hydrogen related cracking.

Use of fully austenitic weld metal on ferritic base material is a technique that has been used for decades to install welds on ferritic base materials with high potential of HIC. Austenitic filler materials are used in applications where preheat or post weld bake out is not possible because hydrogen (H^+) has high solubility, Figure 3, and low diffusivity, Figure 4, in austenite relative to other phases and acts as a trap for hydrogen to prevent HIC. Figure 3 show the solubility of hydrogen in α-Fe and γ-Fe. Note that α-Fe is at the saturation limit at ~4ml/100g of hydrogen. At temperatures above ~1700° C the solubility of hydrogen in austenite (γ-Fe) is nearly five times that of ferrite (α-Fe). The benefit regarding HIC is the hydrogen stays in the austenite and is not available to promote HIC. Figure 4 shows the overall difference in hydrogen diffusion between ferritic and austenitic materials. The diffusion of hydrogen in ferritic material is orders of magnitude greater compared to austenite. Again, the obvious advantage regarding HIC prevention is the hydrogen is slow to diffuse out of the austenitic material. When comparing how hydrogen behaves in ferritic versus austenitic weldments the hydrogen stays within the austenitic material whereas in ferritic welds, it tends to diffuse into the base material. For a weld made with ferritic electrodes, the H^+ is absorbed in the molten weld puddle and as the weld solidifies, it transforms from austenite to ferrite and the H^+ is rejected and diffuses into the HAZ of the base material. When the HAZ transforms from austenite to martensite, the H^+ becomes trapped in the brittle microstructure and causes cracking, Figure 5. However, with an austenitic electrode, H^+ is absorbed in the molten weld puddle and there is no solid state transformation in the solidified weld metal so the H^+ stays in the austenitic weld material. No diffusion of the H^+ into the brittle martensite, thus avoiding the possibility of HIC, Figure 6. Schematics in Figure 5 and Figure 6 are adapted from Lippold and Granjon as shown in draft chapters 2 & 4 for Temper Bead Welding Process in Operating NPP's, International Atomic Energy Agency (References 1 and 8).

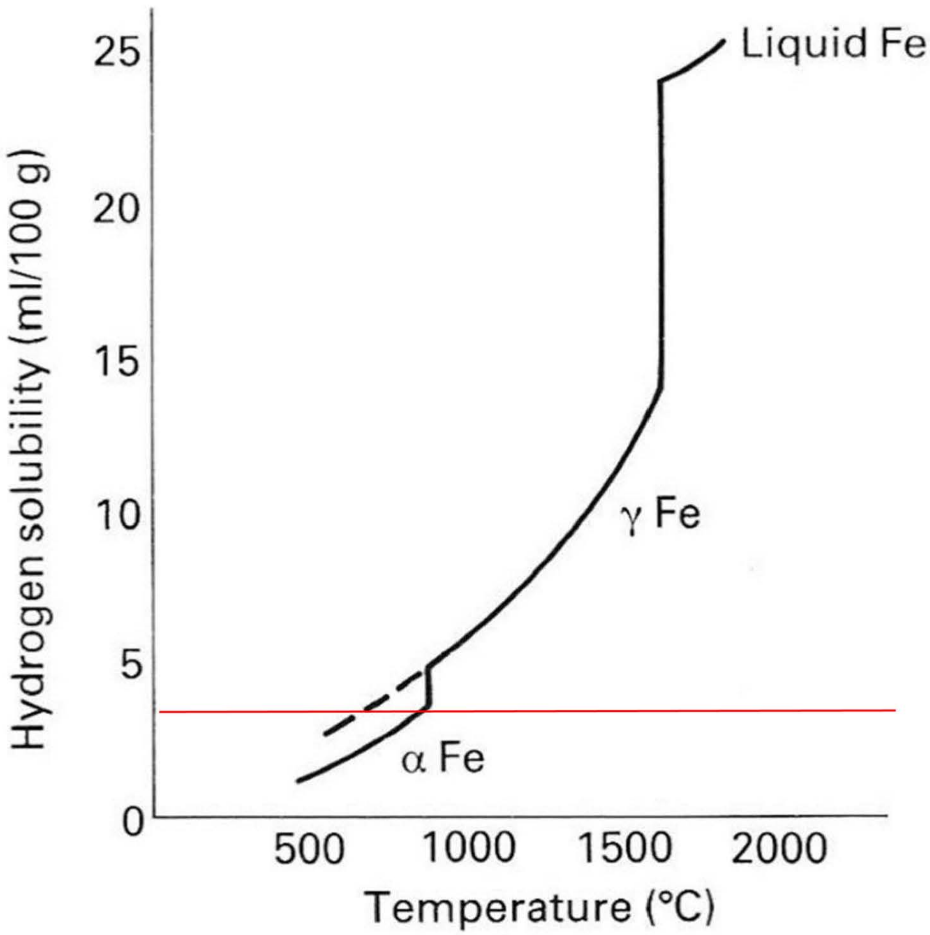


Figure 3 – Hydrogen solubility in ferritic and austenitic materials as a function of temperature

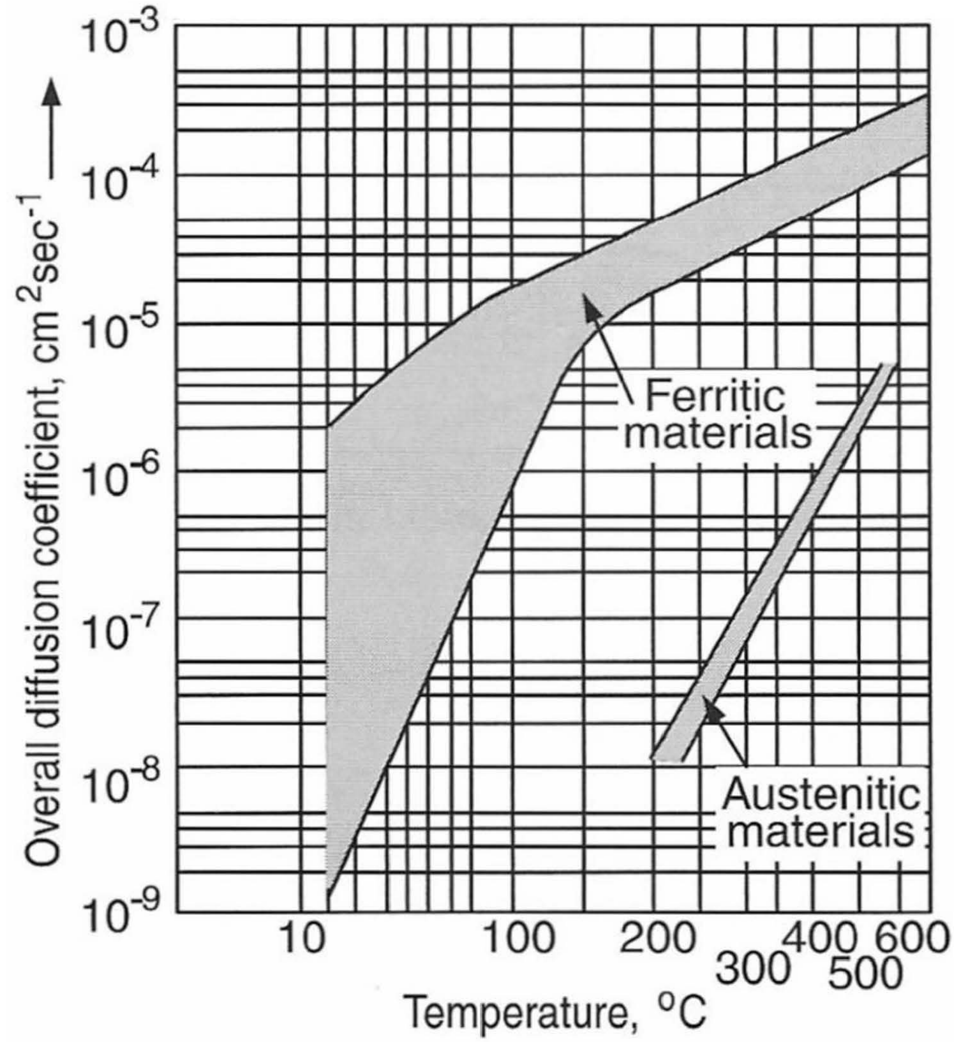


Figure 4 – Diffusion Coefficient of Hydrogen

In ferritic and austenitic materials as a

Function of temperature

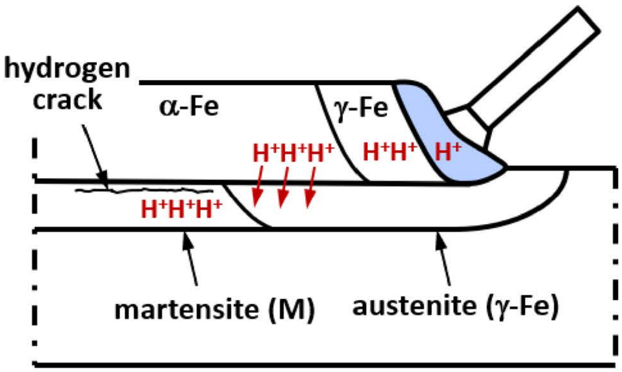


Figure 5 – Hydrogen movement with ferritic electrodes (Reference 8)

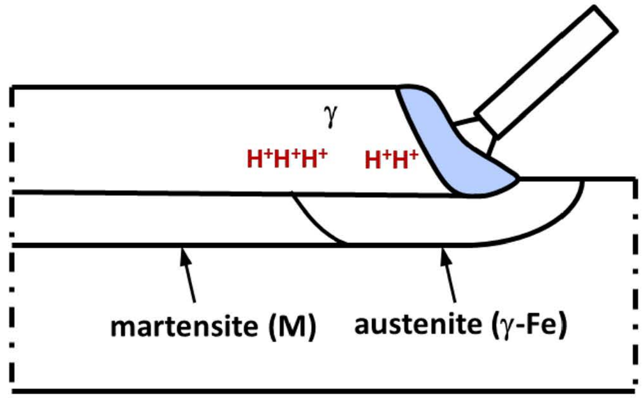


Figure 6 – Hydrogen movement with austenitic electrodes (Reference 8)

5. Conclusion

The temper bead technique has become an increasingly effective tool for performing repairs on carbon and low alloy steel (P-No. 1 and P-No. 3) materials. ASME Code Case N-888 provisions allow for ambient temperature temper bead welding with no post weld bake. However, the 48-hour hold at ambient temperature prior to performing the final weld acceptance NDE has remained a requirement. This white paper summarizes the technical basis to eliminate the 48-hour delay for temper bead welding when using austenitic filler materials. The data and testing by EPRI and other researchers show that when austenitic weld metal is used the level of diffusible hydrogen content in the ferritic base metal HAZ is too low to promote HIC. The 48-hour hold requirement in Code Case N-888 can therefore be removed.

Lastly, field experience applying austenitic filler materials to hundreds of dissimilar metal weld overlays using the ambient temperature temper bead procedures has never experienced hydrogen delayed cracking nor would it be expected. The reason is simply that the final diffusible hydrogen content is low – well below any threshold level that would be required for hydrogen induced cracking. Table 1 outlines the last 20 years of temper bead weld repairs in the nuclear industry with no reported occurrence of HIC when using austenitic weld metal.

6. References

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8. S.L. McCracken and N. Mohr, Draft Chapters 2 and 4 prepared for: Temper Bead Welding Process in Operating NPP’s, International Atomic Energy Agency, Vienna, 2022.

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