energy harbor

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April 28, 2023
L-23-129

10 CFR 50.55a

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

SUBJECT:
Beaver Valley Power Station, Unit No. 2
Docket No. 50-412, License No. NPF-73
10 CFR 50.55a Request 2-TYP-4-RV-06 for Alternative Repair Methods for Reactor Pressure Vessel Head Penetrations

In accordance with 10 CFR 50.55a(z)(2), Energy Harbor Nuclear Corp. hereby requests Nuclear Regulatory Commission (NRC) approval of a proposed alternative to certain requirements associated with reactor vessel weld repairs for the Beaver Valley Power Station, Unit 2 (BVPS-2). Energy Harbor Nuclear Corp. plans to use approved American Society of Mechanical Engineers (ASME) Code Case N-638-10 to repair two unacceptable flaw indications discovered in the reactor head vent penetration tube material and its weld with relief requested from two criteria. Relief is requested to eliminate the 48-hour hold time for final inspection and use a liquid penetrant test in lieu of a volumetric inspection due to hardship without a compensating increase in quality or safety. The attachments identify the affected component, the applicable code requirements, the description and basis of the proposed relief request, and the proposed alternative for the relief request. The repair is proposed for the duration of the life of the reactor vessel head.

To support the startup from its current refueling outage and the need for critical generation of power from BVPS-2, Energy Harbor Nuclear Corp. requests approval of the proposed alternative by May 12, 2023.

There are no regulatory commitments contained in this submittal. If there are any questions or if additional information is required, please contact Mr. Phil H. Lashley, Manager – Fleet Licensing, at 330-696-7208.

Sincerely,

Barry Blair

Attachments:

1. Beaver Valley Power Station, Unit No. 2, 10 CFR 50.55a Request 2-TYP-4-RV-06
2. Ambient Temperature Temper Bead Elimination of 48-hour Hold Time from N-888 When Using Austenitic Filler Material

cc: NRC Region I Administrator
NRC Resident Inspector
NRC Project Manager
Director BRP/DEP
Site BRP/DEP Representative

Proposed Alternative
In Accordance with 10 CFR 50.55a(z)(2)

-- Hardship or Unusual Difficulty
Without Compensating Increase in Quality or Safety --

1.0 ASME Code Components Affected

Component Numbers:	2RCS-REV21 Reactor Vessel Head Vent Line Penetration and Weld
Code Class:	Class 1
Examination Category:	Class 1 PWR Reactor Vessel Head (ASME Code Case N-729-6)
Item Number:	B4.10, B4.20

2.0 Applicable Code Edition and Addenda

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code), Section XI, 2013 Edition with no Addenda is the code of record for inservice inspection and repair/replacement programs.

The construction code for BVPS-2 is ASME Section III, 1971 Edition, 1973 Winter Addenda, and the BVPS 2 Reactor Vessel construction code is ASME Section III, 1971 Edition, Summer 1972 Addenda.

3.0 Applicable Code Requirement

ASME Code Case N-638-10 (Code Case) details requirements for repair activities on pressure retaining components that utilize the ambient temperature temper bead welding technique. The specific Code Case requirements that are the subject of this request are contained in Section 4, paragraph (a)(2), which states:

> *(2) 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.

4.0 Reason For Request

Energy Harbor conducts inspections of the Beaver Valley Power Station, Unit No. 2 (BVPS-2) reactor vessel head in accordance with ASME Code Case N-729-6 with conditions specified in 10 CFR 50.55a(g)(6)(ii)(D). Additionally, penetrations that have been previously repaired using the embedded flaw technique are inspected in accordance with the relief request previously approved by the NRC letter dated August 27, 2018 (ADAMS Accession No. ML18227A733). During the reactor vessel head inspections conducted during the spring 2023 refueling outage, unacceptable flaw indications were discovered in the head vent penetration tube material (SB-167, Alloy 600) and its J-groove attachment weld (Inconel 82/182, Alloy 600). Two special interest indications were identified by the eddy current inspection on the head vent penetration tube. One indication at the 38-degree circumferential location measures 0.200 inches long and the second indication at the 236-degree location measures 0.160 inches long. A subsequent liquid penetrant (LP) test confirmed the flaws. The first indication is contained within the tube metal, extending from the inside diameter (ID) in the direction of the outside diameter (OD). The second indication extends from the tube OD into the weld. Figures 1 and 2 show the described indications.

Figure 1 – Two indications identified at the surface of the Reactor Vessel Level Indication System vent line.

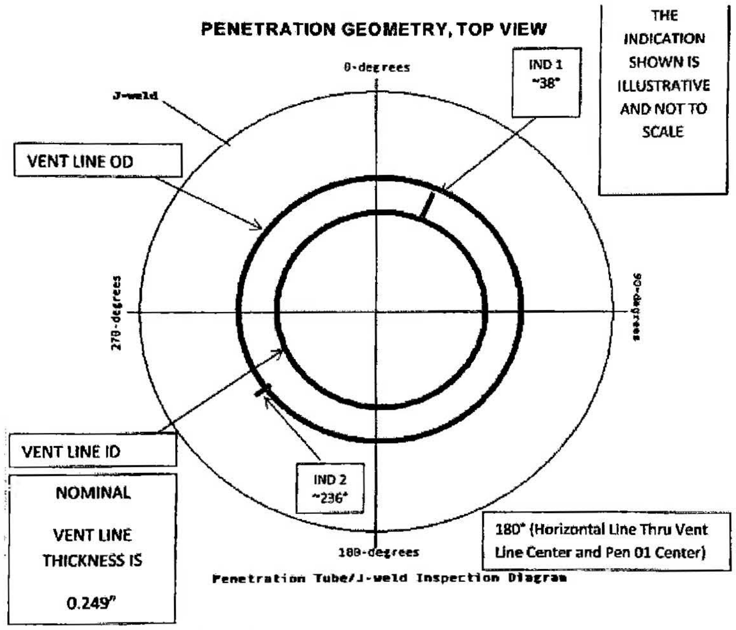

Figure 2 – Diagram from Inspection Report

These indications could not be removed by grinding. As mentioned in Section 3 above, they will be repaired in accordance with the Code Case. Section 4(a)(2) of the Code Case requires final inspection by both volumetric and surface examination methods to be performed 48 hours after the three tempering layers are in place. Energy Harbor Nuclear Corp. requests relief to remove the 48-hour hold based on Attachment 2, which is a white paper based on PVP2023-107489, "Elimination of the 48-hour Hold for the Ambient Temperature Temper Bead Welding with Austenitic Weld Metal," as well as the volumetric inspection of the completed weld based on Precedent 1. With the indications being in a high radiological dose area, following the Code Case requirement without relief causes a hardship with no compensating increase in level or quality of safety.

5.0 Proposed Alternative and Basis for Use

The repair plan will include removal of the buttering, J-groove weld, and a portion of the vent piping using the Electro Discharge Machining (EDM) process. The excavation process uses an electrode that is slightly larger than the original weld prep to fully remove the existing weld material while maintaining the structural integrity of the component. The Ambient Temper Bead (Temper Bead) process, qualified in accordance with the Code Case using machine Gas-Tungsten Arc Welding (GTAW), will be used to apply weld metal to the excavation in the SA-553, Grade 1 reactor vessel head (RVH) material and remaining vent tube penetration length. Additional material will be applied in the area adjacent to the tube, and Temper Bead weld metal which forms a partial penetration groove, to supply the necessary weld throat to support service operation conditions.

The original configuration of the weld can be seen in Figure 3 on the left side. The orange color depicts the original butter and J-groove weld material. The vent penetration tube is shown in green. EDM will be used to remove the original weld material to slightly more than the original excavation as well as to remove approximately 1/2 inch of the end of the tube. The surface area of the exposed RVH material will not exceed the 500 in^2 requirement as listed in the Code Case. Following the excavation, a minimum of 1/32 inch of material will be removed by grinding to eliminate the recast layer produced by the EDM process.

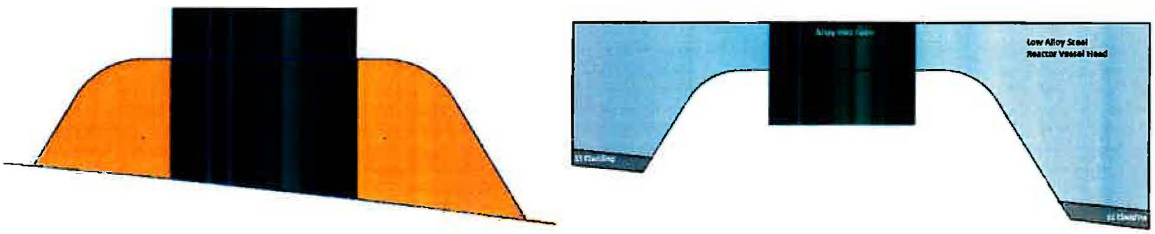

Figure 3 – Picture on the left shows the existing tube, butter, and J-Weld. Picture on the right shows the final excavation after EDM.

After the recast layer is removed, a seal weld will be made between the excavation and the remaining tube to prevent LP material from entering the gap between the tube and head materials. The cavity will be inspected using LP examination. Inspection criteria is from ASME Section III NB-5300 1971 edition through Summer 1972 addenda (Section III).

The first welds will be applied to the clad surface around the excavation using ER309L filler metal as shown in Figure 4. This is to provide isolation from contaminants in the cladding from affecting weld quality when applying Inconel 52M (ERNiCrFe-7A).

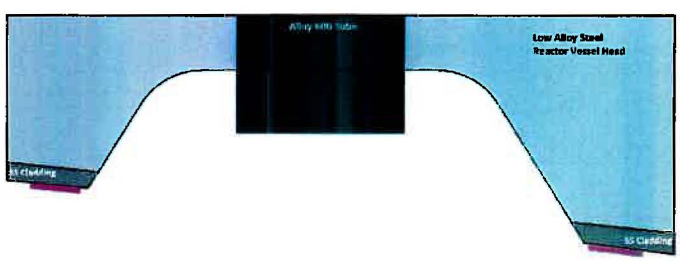

Figure 4 – Stainless Steel Buffer beads installed on Clad surface.

The first layer of Temper Bead will be applied in accordance with the requirements of the Code Case using Inconel 52M filler metal. This layer will start at the seal weld progressing around the excavation. The beads will progress down the excavation surface with approximately a 50 percent overlap. The final first layer beads will extend onto the surface of the previously deposited ER309L material as shown in Figure 5.

Figure 5 – First Layer Temper Bead

The LP examination will be performed on the first layer of Temper Bead in accordance with Section III acceptance criteria.

The second and third layers of Temper Bead will be applied following the same progression as the first layer with LP examination being performed after each layer as shown in Figure 6. The final LP examination will be performed as proposed without the 48-hour hold based on Attachment 2, which is a white paper based on PVP 2023-107489, "Elimination of the 48-hour Hold for Ambient Temperature temper Bead Welding with Austenitic Weld Metal," if relief is granted.

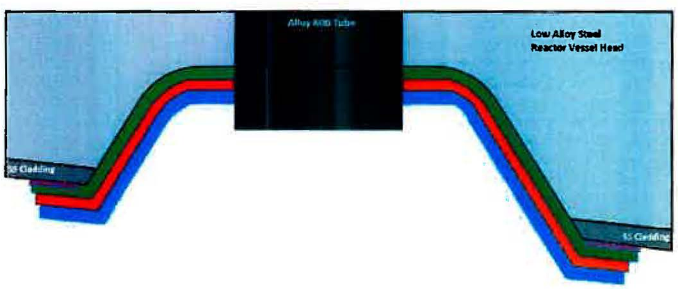

Figure 6 – Final Temper Bead weld layer illustration.

The final planned welding is to complete partial penetration groove weld formed by the remaining pipe section and applied Temper Bead as shown in Figure 7. The final weld will be flush with the end of the tube encapsulating the OD of the tube. A LP examination will be performed after 3/16 inch weld depth has been deposited. It is anticipated that only one inspection will be required prior to final examination. Should additional examinations be required, they will be performed at each 3/16 inch deposit layer thickness as specified.

Final inspection will include both a LP examination in accordance with Section III acceptance criteria and a VT-1 visual exam in accordance with the requirements of the Code Case, Section 4(b), performed on the completed weld.

Figure 7 – Final Weld Configuration.

With three layers of Temper Bead applied to the surface of the excavation, the final thickness of the material deposited will exceed 3/16 inch.

Currently, LP examination is the planned surface inspection in addition to the required VT-1 inspection. Eddy current examination was considered as an alternative surface NDE examination in place of LP examination. However, the tooling to perform the examination has not been developed and would require qualification. It is estimated that this would take approximately 18 months to complete. Additionally, this is a high dose area. Recent surveys show approximately 2000 mREM/hr at the cladding and approximately 970 mREM/hr at one foot from the cone.

In accordance with Section XI IWA-4311 any change made to original design configuration must meet the Construction Code requirements. The proposed modification for the vent line partial penetration weld has been evaluated and determined to meet the requirements of NB-3200 of Section III and final configuration of the attached J-weld will be similar to original configuration. The new configuration would not become more limiting than the outermost penetrations for fatigue and would not be a concern for continued operation.

Future examinations of the repaired BVPS-2 head vent penetration will be examined in accordance with regulatory requirements. Currently, the requirements are defined by ASME Code Case N-729-6 (N-729-6). The requirements of N-729-6 require volumetric or surface examination on essentially 100% of the required volume or equivalent surfaces of the nozzle tube. The original and repaired configurations of the BVPS-2 reactor vessel head vent line penetration and the associated J-groove weld do not accommodate volumetric inspection with current NDE techniques. This requirement for the original configuration was met by performing a surface examination of the head vent penetration ID utilizing an internal eddy current probe combined with a surface examination of the attaching J-groove weld utilizing a surface-riding eddy current technique.

The ID surface of the repaired BVPS-2 head vent penetration will continue to be examined using an internal eddy current probe. The surfaces of the new structural weld and the encapsulated portion of the head vent penetration outside diameter will be examined by the LP technique.

The original owner's code requirement for the reactor vessel head vent line penetration was ASME Section III Division 1, 1971 Edition with Addenda up to and including summer 1972. Later editions of this code allow for progressive surface examination for temper bead repairs to partial penetration welds, in lieu of volumetric examination if meaningful results cannot be obtained. This provides a precedent for the suitability of progressive surface exams in lieu of volumetric exams for partial penetration joints when meaningful results cannot be obtained with volumetric methods. The PT examination will be accomplished using the applicable acceptance criteria specified in the 1971 edition through summer 1972 addenda of the ASME Boiler and Pressure Vessel Code, Section III Subsection NB-5350.

Based on the information provided above, the Code Case requirements present a hardship with no compensating increase in quality or safety. Removal of the 48-hour hold, as well as the volumetric inspection of the completed weld, provides an acceptable alternative.

6.0 Duration of Proposed Alternative

The duration of the proposed alternative is until the reactor vessel head is replaced.

7.0 Precedents

1. Seabrook Station, Unit No. 1 – Relief Request 4RA-22-01, Relief from the Requirements of the ASME Code, ADAMS Accession No. ML23073A156

2. Verbal Authorization for NMP1 [Nine Mile Point Nuclear Station, Unit 1] Proposed Alternative Weld Overlay N2E Safe-end to nozzle DM [dissimilar metal] Weld, ADAMS Accession No. ML23090A130

8.0 References

1. ASME Boiler and Pressure Vessel Code, Section XI, 2013 Edition with no Addenda

2. PVP2023-107489, "Elimination of the 48-hour Hold for Ambient Temperature Temper Bead Welding with Austentitic Weld Metal," McCracken and Patel

3. ASME Section III, 1971 Edition, Summer 1972 Addenda

4. ASME Section III, 1971 Edition, 1973 Winter Addenda

5. Case N-638-10, Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique, Section XI, Division 1, Approved May 6, 2019

1.0 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. [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 [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 [3,4]. As a result of these studies, the preheat and post-weld bake requirements were not included in 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.

Case N-888 is the culmination of temper bead code cases that have been produced over theyears, combining requirements from N-638, N-839, and Appendix I in cases such as N-740 and N-754, etc. 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, 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 N-888. This 48-hour delay between welding completion and cooling to ambient temperature and the final nondestructive examination (NDE) of the fully welded component is intended to assure detection of delayed hydrogen cracking that isknown 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 followingthe 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)
2009	Three Mile Island[1]	SWOL (1)
2009	Three Mile Island[1]	Full Nozzle with Structural Pad (1)

Date	Plant	Component (Qty.)
2009	Crystal River[3]	SWOL (1)
2009	Palisades[1]	Mid-Wall RVH Repair (2)
2010	Oconee[4]	U3 Letdown WOL (1)
2010	Krsko[1]	SWOL (5)
2010	Tihange[1]	SWOL (1)
2010	Davis-Besse[1]	Mid-Wall RVH Repair (24)
2011	Hatch[4]	Nozzle WOL (1)
2011	Talen Energy Corporation[4]	N5 core spray nozzles
2011	Monticello[4]	Emergent WOL (1)
2011	Three Mile Island[4]	TMI PZR Spray Nozzle (1)
2011	Doel[1]	SWOL (1)
2011	Tihange[1]	SWOL (1)
2011	St. Lucie[1]	1/2 Nozzle with Structural Pad (30)
2012	North Anna[4]	SG Nozzle WOLS (3)
2012	Palo Verde[4]	Small Bore CL Nozzles WOL
2012	Grand Gulf[4]	Reactor Vessel Nozzle Contouring and N6 Weld Overlay
2012	Doel[1]	SWOL (1)
2012	Calvert Cliffs[1]	Mid-Wall Przr Heater Repair (119)
2012	Quad Cities[1]	1/2 Nozzle with Structural Pad (1)
2012	Harris Nuclear Plant[1]	Mid-Wall RVH Repair (4)
2013	Farley[4]	Unit 2 FAC Pipe Replacement and WOL
2013	Oconee[4]	Hot/Cold Leg Small Bore Alloy 600
2013	Hope Creek[4]	Emergent N5A WOL
2013	Three Mile Island[1]	SWOL (1)
2013	Palo Verde[1]	1/2 Nozzle with Structural Pad (1)
2013	Harris Nuclear Plant[1]	Mid-Wall RVH Repair (2)
2015	Harris Nuclear Plant[1]	Mid-Wall RVH Repair (3)
2015	Hatch[4]	N4A WOL
2015	Millstone[4]	2" Drain WOL
2015	Hatch[4]	Recirc (N2) WOL
2016	Harris Nuclear Plant[1]	Mid-Wall RVH Repair (4)
2017	Fitzpatrick[4]	RHR WOL
2017	Limerick[1]	1/2 Nozzle with Structural Pad (1)
2018	Waterford[4]	Emergent Drain Nozzle WOLs (2)
2018	Palisades[1]	Mid-Wall RVH Repair (3)
2018	Doel[1]	Mid-Wall RVH Repair (16)
2018	Harris Nuclear Plant[1]	Mid-Wall RVH Repair (1)
2018	Brunswick[1]	SWOL (2)
2020	Peach Bottom[1]	1/2 Nozzle with Structural Pad (1)
2020	Palisades[1]	Mid-Wall RVH Repair (2)
2021	Oconee[4]	Complex nozzle pads on RCS piping
2021	ANO-2[1]	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

2.0 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 [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.

3.0 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 [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 bythe ASME code guidance including welding procedure qualification testing and by in-processand 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 tomigrate, 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 toprovide insight into the impact and proper management of these factors that cause HIC.

4.0 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 (Ac3) transformation temperature [1]. Generally, a critical hardness 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 [1].

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 [4, 5, 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 are 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 basecoated electrodes do not have low hydrogen designators that are found for ferritic weld materials [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) hydrogenin 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 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 AWS A4.3 via gas chromatography on thirteen commercially availableelectrodes. 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 less than 16ml/100g of diffusible hydrogen at 72 hours of exposure. Figure 2 shows that new electrodes without exposure have less than 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 greater than 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 [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 [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 shieling 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 inthis 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.

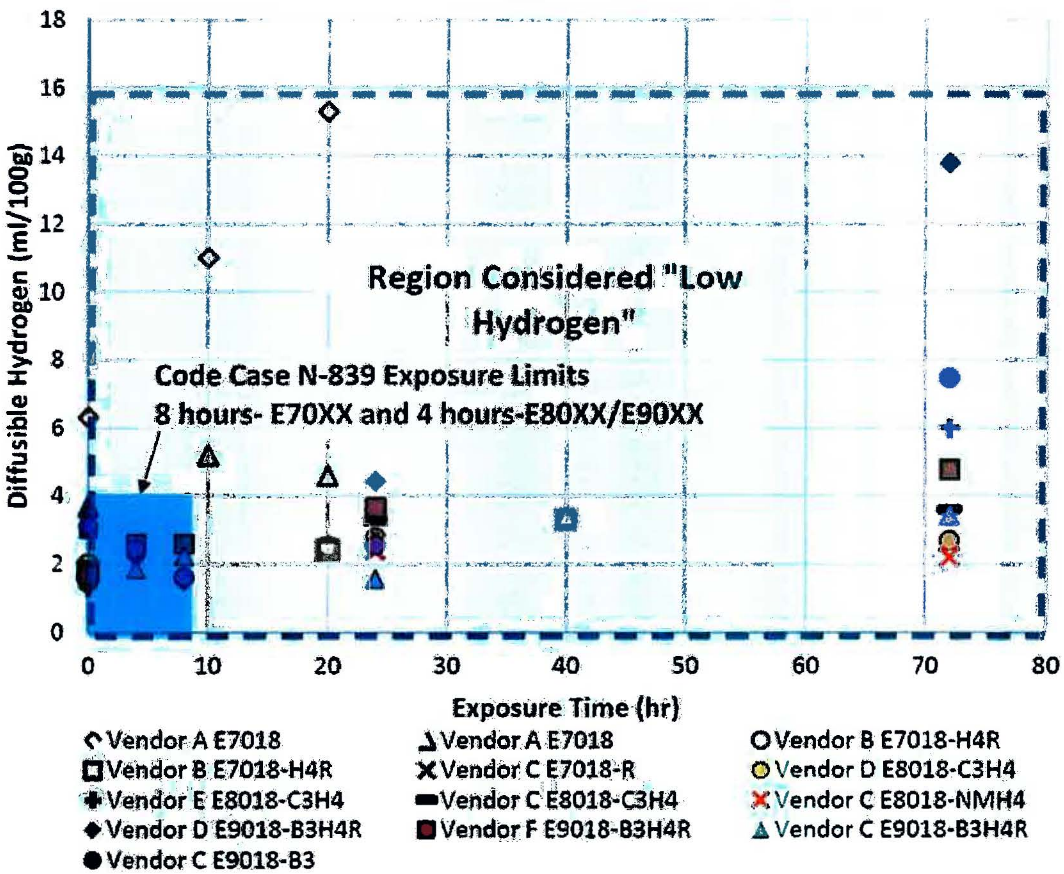

Figure 1. Results of EPRI diffusible hydrogen testing at 27°C 80% Relative Humidity (HR) for zero to 72 hours of exposure [6]

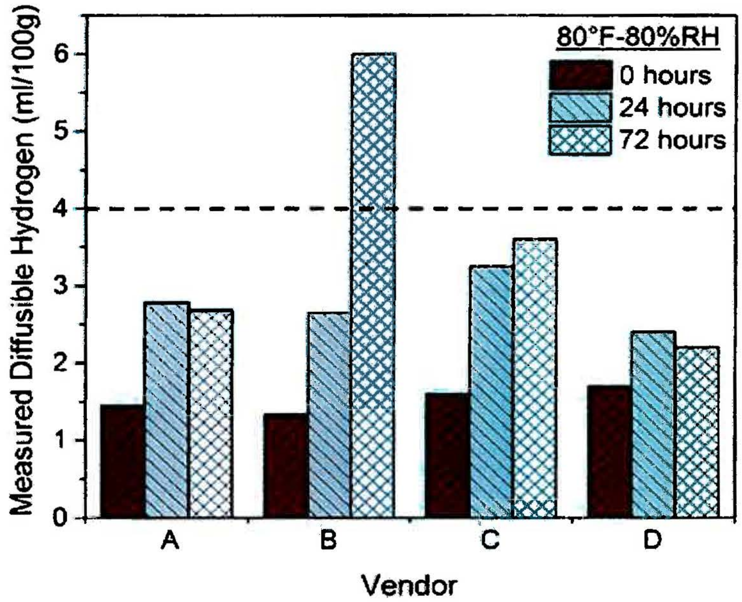

Figure 2. Graph showing slight increase of diffusible hydrogenafter exposure of 24 and 72 hours [6]

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, [1, 8].

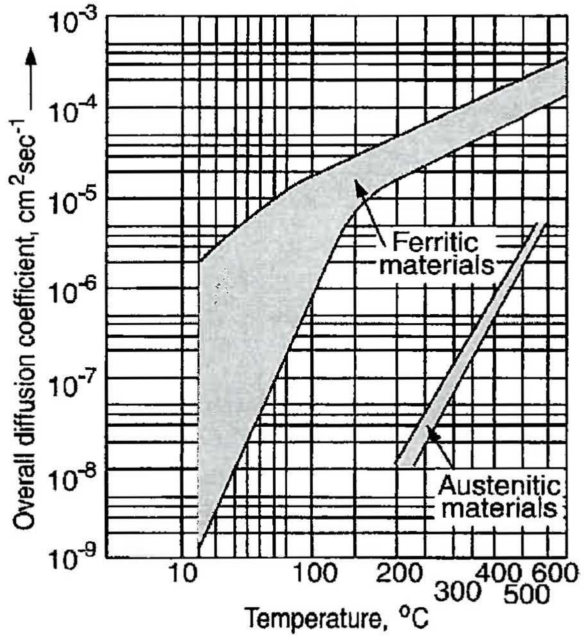

Figure 3 - Hydrogen solubility in ferritic and austenitic materials as a function of temperature

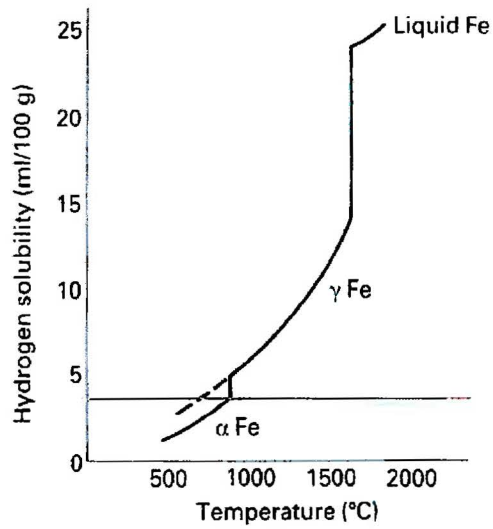

Figure 4 - Diffusion Coefficient of hydrogen in ferritic and austenitic materials as a function of temperature

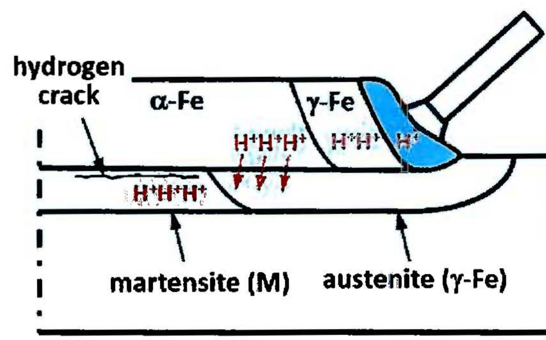

Figure 5 - Hydrogen movement with ferritic electrodes [8]

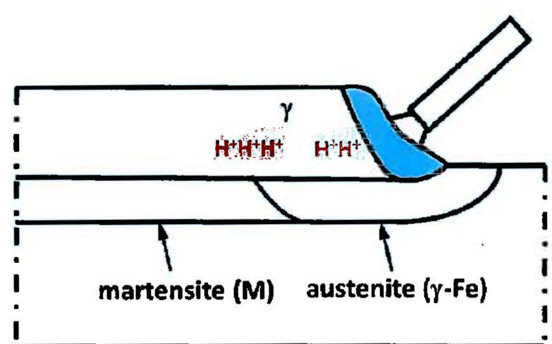

Figure 6 - Hydrogen movement with austenitic electrodes [8]

5.0 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. 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 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.

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