Enclosure 3
Technical Papers 1

Dated October 1, 2008

NEI/NRC Meeting

Technical Paper: –
Use of Weld Inlays as a PWSCC Mitigation for Reactor Vessel Safe-End-to-Primary Nozzle Welds

American Electric Power Lead Application

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USE OF WELD INLAYS AS A PWSCC MITIGATION FOR REACTOR VESSEL SAFE-END-TO-PRIMARY NOZZLE WELDS

Background: Primary Water Stress Corrosion Cracking (PWSCC) has been observed in Pressurized Water Reactor piping systems. Recently this cracking has been seen in butt welds fabricated with Alloy 82/182. This cracking has been observed in both buttering and the butt weld materials. Steam generators, pressurizers, and reactor vessel heads have been replaced because of this phenomenon. Various repair and mitigation schemes have been proposed or employed to control this cracking.

One mitigation approach is to apply weld inlays on the reactor vessel (RV) safe end-to-primary nozzle dissimilar metal welds (DMWs) to mitigate against the potential occurrence of PWSCC. The process qualification for this mitigation approach is being sponsored by the PWR Owners Group. The inlay process being developed includes the inlay itself. On a contingency basis, it also includes the processes and tooling necessary to remove pre-existing flaws in the DM weld, prior to installation of the inlay. Section 5.1 of this document provides a description of the processes to permit the implementation of mitigative/repair weld inlays During U1C23 (Fall 2009), D.C. Cook, the lead plant for this mitigation approach, intends to pro-actively apply inlays in eight (8) DMWs, four (4) on the hot leg (HL) and four (4) on the cold leg (CL), located at the RV primary nozzles.

In anticipation of plants mitigating Alloy 82/182 in the RV primary nozzles, including D.C. Cook, the NRC has called a public meeting is to "…discuss the regulatory approach related to weld onlay and inlay to mitigate primary water stress corrosion cracking in dissimilar metal welds in pressurized water reactors." Among other items, the agenda calls for the industry to address:

- Onlay/inlay Design and Installation Requirements.
- Applicable ASME Code Requirements and Code Cases Industry

On going communications indicate that the industry input to this meeting should address the following:

- Major aspects of the mitigation technique.
- Identify if the mitigation will be implemented outside of Code space, and if so, identify what assurance there is that the mitigation is sufficiently effective.
- Identify the code applicability rules for the mitigation.
- Identify the pre-inspections to be performed
- Identify the chromium content specification inlay/onlay.
- Identify how it will be assured that the dilution layer is effective and inspected.
- Identify whether the Code provides all the requirements needed, or whether relief from Code would be needed.

The purpose of this document is to provide the necessary input for the aforementioned meeting, as it relates to inlays as a PWSCC mitigation for RV safe end-to-primary nozzle DMWs.

1 ASME Code Components Affected

The components associated with this mitigation technique are ASME Code Class 1 NiCrFe dissimilar metal welds (DMWs) with Alloy 82/182 weld metal in the RV safe end-to-primary nozzle welds. These are butt welds category B-F. They are exposed to reactor coolant (RC) and are susceptible to Primary Water Stress Corrosion Cracking (PWSCC). Both HL nozzles and CL nozzles are targeted to have inlay welds applied to the inside surface of the DMWs. The weld inlays, using nickel alloy ERNiCrFe-7A (Alloy 52M) filler metal, will extend from the stainless steel safe end, across the DMW, to the stainless steel cladding on the inside surface of the HL and CL nozzles, protecting the DMWs from the RC.

1.1 Category and System Details

Code Class: Class 1
Reference:

ASME Code, Section XI
ASME Code Case N-416-1
ASME Section III (Construction, Nondestructive Examination, and Modification Code(s))
ASME Code Case N-638-1
ASME Code Case N-695 (Preservice/Inservice Inspection Qualification Requirements)

Note: Specific code years and addenda will vary by plant.

Examination Categories: B-F
Item Number: B5.10
System Welds: Reactor Coolant System

1.2 Component and Component Materials

The mitigation technique will apply inlay welds on the inside of safe end-to-primary nozzle DMWs for RV HL and CL Nozzles. These nozzles connect the RV to the primary RCS coolant loop. The inlays will extend outward from the stainless steel cladding on the ferritic low alloy steel RV nozzles, across the adjacent DMWs, to the stainless steel safe ends. The general configuration for the nozzle locations is shown in Figures 1 and 2.

1.3 Component Materials

Nozzle materials will have small variations by application. For D. C. Cook Unit 1 the materials are depicted in Table 1.

TABLE 1

HOT LEG AND COLD LEG NOZZLE MATERIALS

Nozzle (P-No. 3, Gr 3)	Nozzle Cladding (A-No. 8)	Safe End-to-Nozzle DMW (F-No. 43)	Nozzle DMW Buttering (F-No. 43)	Safe End (P-No. 8, Gr. 1)	Safe End Cladding (A-No. 8 and F-No. 43)
SA-508, Cl 2	Type 308, 309, and 312	Alloy 82/182	Alloy 182	SA-182, Gr F316	Type 312L (OD & ID) Alloy 82 (OD & ID)

2 Applicable Code Edition and Addenda

Specific code years and addenda will vary by plant. D. C. Cook Unit 1 is currently in the Third Inservice Inspection (ISI) interval scheduled to end on February 28, 2010. The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) of record for the current ISI interval is Section XI, 1989 Edition, no Addenda (Reference 8.2) for the Repair/Replacement Program.

3 Applicable Code Requirement

With the exception of specific code relief, mitigation of RV primary loop DM welds will be installed in accordance with ASME Code requirements, (i.e. Section XI, AWI-4000 and Code Case N-638-1).

The applicable ASME Code requirements for which relief will be required are:

1. ASME Section XI Case N-638-1 (Reference 8.1) with condition as specified in Regulatory Guide (RG) 1.147 Revision 15

Code Case N-638-1 (Reference 8.1), provides requirements for ambient temperature machine gas tungsten-arc dissimilar metal welding using the temper bead technique that is applicable for welding on ferritic low alloy steel.

4 Specific Code Relief Request

The following summary presents the relief request specifics in one location for ease of reference and to clearly identify relief which will be required.

	Code Requirement	Exception	Reason for Request
1	N-638-1, paragraph 1.0(a)	Limit of 500 sq. in. and no depth limit.	Depending on the size of of any pre-existing flaw, significant excavation and repair may be required. Paragraph 1.0(a) may not permit the necessary surface areas on the low alloy ferritic steel nozzle for temper bead welding for repair inlays (see Figure 2). Furthermore, the depth of the repair weld through the ferritic steel base metal thickness is restricted to ½ the ferritic steel thickness which also may not permit temper bead welding for repair inlays (see Figure 2)).
2	N-638-1, paragraph 1.0(c)	No limit on depth to allow for a repair	Paragraph 1.0(c) may not permit the necessary depths into the low alloy ferritic steel nozzle for temper bead welding for repair inlays (see Figure 2).
3	N-638-1, paragraphs 3.0(d) & 4.0(c)	Allow the use of heat flow analysis or mockup verification in lieu of direct measurement	Paragraph 3.0(d) specifies a maximum interpass temperature of 350F and implies temperature monitoring by thermocouples may be required by Paragraph 4.0(c). In any case, direct interpass temperature measurement using thermocouples or any other direct measurement method will be extremely impractical to perform during welding operations from inside the nozzle.
4	N-638-1, paragraph 4.0(b)	The preheated band NDE is not practical given the nozzle configuration. Acceptance NDE will be performed 48 hrs after the third temper bead layer is deposited over the ferritic steel nozzle.	Paragraph 4.0(b) specifies that the final weld surface and the band around the area defined in Paragraph 1.0(d) be examined using surface and ultrasonic methods when the completed weld has been at ambient temperature at least 48 hours. NDE of the nozzle ferritic steel band is unnecessary and the weld integrity on the ferritic steel nozzle can be verified by NDE 48 hours after the third temper bead layer is completed on the nozzle.

5 Proposed Alternative And Basis for Use

Section 5.1 of this document provides a description of the processes to permit the implementation of mitigative/repair weld inlays on the RV safe end-to-primary nozzle DMWs. The application of the alternatives to the requirements of Code Case N-638-1, (Reference 8.1) is included in this section.

Temper bead welding will performed in accordance with Appendix 1 of Enclosure 1 to this document.

The Alternative Requirements shown in Enclosure 1 are proposed for implementation of the mitigative/repair inlay welds for susceptible RV safe end-to-primary nozzle DMWs. The purpose of the weld inlay is to provide PWSCC and corrosion resistant weld material over the inner surface of the DMW so that the PWSCC susceptible Alloy 82/182 material is not exposed to the RCS water environment. This mitigation, in accordance with the Alternative Requirements (Enclosure 1), is first scheduled to be performed at D. C. Cook Unit 1 in the Fall of 2009.

These Alternative Requirements (Enclosure 1) are the result of industry consensus associated with weld inlay modifications to DMWs and the development of these methods for mitigation of DMWs susceptible to PWSCC or repairs to DMWs with PWSCC related flaws.

Specific Justification for relief:

1. The 100 sq. in. restriction is an arbitrary limit. Case N-638-4 specifies a maximum finished surface area of 500 sq. in. over the ferritic material.
2. The flaw depth for planning purposes is assumed to be 2 in. maximum. This is approximately 75% of the pipe wall. If repair is required the depth into the ferritic steel nozzle may need to be greater than 3/8 in. to provide sufficient access for welding. As a part of this mitigation approach contingencies are included, should a flaw of this magnitude be discovered. The depth of the temper bead limit was for minor flaws to allow ease of repair. Modern welding techniques and process controls make this limit obsolete.
3. Welding on the inside of a pipe using automated remote equipment make direct temperature measurement impractical. This mitigation approach proposes to perform mockup testing and heat flow analysis to demonstrate that interpass temperature verification is not required during field welding.
4. Since pre-existing defects are expected to be in the DMW and new defects would not occur therein due to inlay welding, UT and PT of the ferritic steel nozzle preheated band after welding is unnecessary. UT of the inlay and its heat-affected-zone and PT of the inlay will be performed. The ferritic steel nozzle base material is not exposed after inlay welding so PT cannot be performed thereon. UT and PT will be performed no sooner than 48 hrs after completion of the third temper bead layer over the ferritic

steel nozzle. Flaws due to hydrogen cracking are not expected to occur due to the strict controls used during welding.

5.1 General Process Description

The following describes the overall process:

Ultrasonic examination (UT) will be performed on the DMW prior to commencing with mitigation activities. The UT is performed to satisfy the Section XI, IWB-2000 requirement for inservice examination and to provide information to determine the extent of additional machining required in the event that unacceptable flaws are detected.

Based on the UT results, and after determination of the DMW boundaries exposed to the RC, a cavity will be machined around the full inside circumference of the DMW and liquid penetrant examination (PT) performed. The final cavity configuration will be dependent on the geometry of any unacceptable flaws detected in the DMW. The minimum cavity width will be sufficient to provide for the weld inlay to completely cover the exposed DMW inner surface with more than one layer and at least 1/8 in. final thickness using Alloy 52M.

Welding of the cavity will be performed with Alloy 52M. The final weld inlay inner surface contour will be essentially equivalent with the original DMW surface contour and blended with the adjacent surrounding surfaces. (See Figure 1) For DMWs where flaws with significant through wall depths are removed, ERNiCr-3 (Alloy 82) may be used to partially fill the cavity, however Alloy 52M will be used on at least the inner 1/8 in. and more than one layer of the final inlay thickness. (See Figure 2)

Acceptance PT will be performed on the weld inlay and acceptance UT and preservice UT on the final modified DMW, including the weld inlay, will be performed.

5.2 Design

The mitigative/repair weld inlay will satisfy the requirements specified in the Alternative Requirements (Enclosure 1), using PWSCC resistant Alloy 52M filler metal. The weld is deposited into a cavity that is machined across the entire inner surface of the DMW that is exposed to the RC (see Figure 1). For cases using repair weld inlays at depths greater than 1/8 in., Alloy 82 may be used to partially fill the cavity, however Alloy 52M will be used on at least the inner 1/8 in. and more than one layer of the final inlay thickness (see Figure 2).

Stress Analyses

Primary + secondary stress and fatigue analyses for both inlet and outlet nozzles are performed in accordance with NB-3200, Section III (Reference 8.4) for the modified DMW to show compliance therewith. The stress analyses will consider the following final modified configurations:

1) 0.13 in. deep cavity requiring more than one layer and at least 1/8 in. thick weld inlay of Alloy 52M for the full inner circumference (see Figure 1).
2) 2 in. deep local repair weld inlay (see Figure 2) using Alloy 82 or Alloy 52M with at least 1/8 in. and more than one layer of the final inlay thickness of Alloy 52M weld inlay applied thereon.

Flaw Growth Analyses

Flaw growth analyses for postulated flaws are performed in accordance with IWB-3640. Analysis performed to date shows minimal flaw growth occurs for the assumed design life of the modified DMWs and flaw growth in the weld inlay is significantly less than its 1/8 in. minimum thickness, such that the Alloy 82/182 material would not be exposed to the RC during its design life.

Residual stresses for the modified DMW are calculated based on the original DMW configuration. This simulation also assumes a full circumferential 50% through-wall weld repair from the inside surface of the DMW has previously occurred. Also, the residual stress analysis takes into account the effects of the safe end-to-pipe weld. For the mitigative inlay configuration, a 3/16 in. deep cavity is machined in the DMW and the surrounding material (see Figure 1). A single layer of Alloy 82 is deposited therein, then the cavity is filled with Alloy 52M material. For the 2 in. repair configuration, a 2 in. deep cavity (see Figure 2) is machined and filled back with Alloy 82 material with at least ⅛ in. thick and more than one layer Alloy 52M material at the inside surface.

Planar flaws are postulated to exist in the newly applied weld inlay and in the original DMW. Both circumferential and axial flaws are evaluated in conjunction with the maximum size flaw permitted by the inservice examination acceptance standards of Table IWB-3514-2:

For the 1/8 in. Weld Inlay Design Case:
Postulated flaws in weld inlay:
(1) Circumferential surface flaw of 1/16 in. depth through the inlay weld thickness, ID surface connected for the entire circumference of the inlay.
(2) Axial surface flaw of 1/16 in. depth through the inlay weld thickness, ID surface connected for the entire width (axial length) of the inlay.

Postulated flaws in the original DMW:
(1) Full circumferential subsurface flaw of 3/8 in. depth in the remaining DMW, originating at the weld inlay/DMW interface for the entire circumference of the inlay.

(2) Axial subsurface flaw of 3/8 in. depth in the remaining DMW, originating at the weld inlay/DMW interface for the entire width (axial length) of the inlay.

For the Repair Weld Design Case:
Postulated flaws in weld inlay:
(1) Circumferential surface flaw of 1/16 in. depth through the inlay weld thickness, ID surface connected for the entire circumference of the inlay.
(2) Axial surface flaw of 1/16 in. depth through the inlay weld thickness, ID surface connected for the entire width (axial length) of the inlay.

Postulated flaws in the original DMW:
(1) Full circumferential surface flaw postulated to exist from the outside surface of the DMW to the 2-inch boundary depth of the newly deposited weld material.
(2) Axial surface flaw postulated to exist from the outside surface of the DMW to the 2-inch boundary depth of the newly deposited weld material for the entire width (axial length) of the inlay.

Leak-Before-Break (LBB) Evaluation

Since the original geometry and loads are not significantly modified by the weld inlay (see Figure 1), or repair weld inlay (see Figure 2), when applicable, and the replacement weld inlay material (Alloy 52M) has equal or superior fracture toughness than the existing materials, LBB remains applicable at these locations. Furthermore, the machine gas tungsten-arc welding process (GTAW) is used for the weld inlay and repair weld inlay. GTAW exhibits higher fracture toughness properties with either Alloy 82 or Alloy 52M than the shielded metal arc welding process which was the process used for the original DMWs at these locations.

Evaluation of Weld Shrinkage Effects

The axial weld shrinkage caused by the weld inlay (see Figure 1) and repair weld inlay (see Figure 2) has a negligible effect on the attached piping. The radial weld shrinkage has a negligible effect on the nozzle configuration.

5.3 Welding

The welding will be performed in accordance with the Alternative Requirements (Enclosure 1) using the remote machine GTAW process and using the ambient temperature temper bead method (Enclosure 1 and Appendix 1).

During recent DMW overlay activities, where Alloy 52M was used for the filler metal, there were some cases where flaws occurred in the portion of the first layer of the overlay deposited on the austenitic stainless steel items (safe ends, pipe etc.). The flaw characteristics observed are indicative of hot cracking. This phenomenon has not been observed on the ferritic steel or ENiCrFe-3 (Alloy 182) DMWs when welding Alloy 52M thereon.

In those cases where base material chemistry indicates the potential hot cracking, a barrier weld will be used on all the stainless steel items prior to welding being performed. A barrier layer will be used at D. C. Cook Unit 1 and it will use ER309L on the stainless steel and ERNiCr-3 (Alloy 82) on the stainless steel near the DMW to stainless steel fusion zones and on the adjacent DMW surfaces.

The weld inlay filler metal covering the Alloy 82 barrier welds and the balance of the DMW surface, including deep weld repairs where Alloy 82 is used, will be Alloy 52M. The minimum as-deposited Cr content for at least the final 1/8 in. and more than one layer of the weld inlay thickness will be 24%.

The Alternative Requirements (Enclosure 1) specify the maximum finished surface area of the weld inlay over the low alloy ferritic steel base material not to exceed 500 sq. in. This exceeds the 100 sq. in. maximum surface area specified in Case N-638-1 (Reference 8.1) paragraph 1.0(a). However, Section XI Case N-638-4 specifies a maximum finished surface area of 500 sq. in. over the ferritic material.

The Alternative Requirements (Enclosure 1) specify the maximum cavity depth for weld repair is 2 in. That exceeds the depth on low alloy ferritic steel of ½ the ferritic steel thickness at the nozzle interface permitted by Case N-638-1 (Reference 8.1), paragraph 1.0(a), for temper bead welding. Analysis shows that the nozzle low alloy ferritic steel that is replaced by the Alloy 82/52M weld material does not adversely affect the structural integrity of the DMW region.

The Alternative Requirements (Enclosure 1) does not specify the maximum permitted depth into the low alloy ferritic steel for weld repair using nonferritic weld material whereas the maximum depth into the low alloy ferritic steel nozzle material is 3/8 in. permitted by Case N-638-1 (Reference 8.1), paragraph 1.0(c), for temper bead welding. In order to establish an appropriate bounding case for flaw removal, it was assumed that flaw removal of up to a 2 in. depth, near the buttering to nozzle fusion zone might be required, thereby resulting in a maximum depth of nozzle low alloy ferritic steel material being replaced by the Alloy 82/52M weld. Analysis shows that the nozzle low alloy ferritic steel that is replaced by the Alloy 82/52M weld material does not adversely affect the structural integrity of the DMW region.

Code Case N-638-1 (Reference 8.1), Paragraph 3.0(d) specifies a maximum interpass temperature of 350F and implies temperature monitoring by thermocouples may be required by Paragraph 4.0(c). Since direct temperature measurement methods will be extremely impractical to perform during welding operations from inside the nozzle, the Alternative Requirements (Enclosure 1, Appendix 1) specify interpass temperature shall be determined by either:

- Performing heat flow calculations using the variables listed therein, or
- Measurement of the maximum interpass temperature on a test coupon that is equal to or less than the thickness of the item to be welded using the maximum permitted heat input specified on the applicable welding procedure specification.

Section XI Cases N-638-2 through -4 specify these alternatives in lieu of direct interpass temperature measurement.

5.4 Examination

Prior to machining, UT will be performed on the DMW in accordance with Section XI (Reference 8.2) and procedures, personnel, and equipment that have been qualified in accordance with Case N-695 (Reference 8.5). The results of this examination will determine if there are PWSCC related flaws or other adverse pre-existing conditions.

Following machining and prior to inlay welding (see Figure 1) and repair welding (see Figure 2), PT will be performed in accordance with NB-5000, Section III (Reference 8.4). IWB-3514-2, Section XI (Reference 8.2) acceptance criteria will be applicable.

Following welding, acceptance/preservice PT (see Figure 1) will be performed thereon in accordance with NB-5000, Section III (Reference 8.4) and IWA-2222, Section XI (Reference 8.2). Because ambient temperature temper bead welding is used, the examination will be conducted at least 48 hours after the completion of the third temper bead layer over the low alloy ferritic steel base material. The acceptance criteria of NB-5352, Section III (Reference 8.4) will apply with the additional requirement that rounded indications with major dimensions greater than 1/16 in. are unacceptable. For areas outside of the inlay, the inservice examination acceptance standards of Table IWB-3514-2 shall apply.
Acceptance UT will be performed on the weld inlay (see Figure 1) in accordance with Section V (2004 Edition), Article 4, Cladding – Technique One using calibration blocks in accordance with Fig. T-434.4.2.2. Because ambient temperature temper bead welding is used, the examination will be conducted at least 48 hours after the completion of the third temper bead layer over the low alloy ferritic steel base material. The acceptance criteria will be in accordance with NB-5330, Section III (Reference 8.4). When deep repair welding is performed (see Figure 2), acceptance UT of the repair weld below the weld inlay will be performed in accordance with Section V (2004 Edition), Article 4, and the

acceptance criteria will be in accordance with NB-5330, Section III (Reference 8.4).

The requirement for NDE of the 1 ½ T band in Case N-638-1 (Reference 8.1) is specified to assure all flaws in the area of the repair have been removed or addressed, since these flaws may be associated with the original flaw and may have been overlooked. In this case, the repair welding is being performed as a result of PWSCC concerns occurring in the DMW and not for defects in the nozzle ferric steel.

Preservice UT of the modified DMW, including the weld inlay (see Figure 1) and repair weld/weld inlay (see Figure 2), when applicable, will be performed in accordance with Section XI (Reference 8.2) and procedures, personnel, and equipment that have been qualified in accordance with Case N-695 (Reference 8.5). The inservice acceptance standards of IWB-3514.4 (Reference 8.2) will be applicable. UT will be performed no sooner than 48 hours after completion of the third temper bead layer over the low alloy ferritic steel nozzle base material.

The 48 hour delay is intended to provide time for delayed hydrogen cracking occurrence. The Alternative Requirements (Enclosure 1) requires the machine GTAW process to be used for temper bead welding thereby eliminating the use of welding processes requiring flux for arc shielding.

The machine GTAW temper bead process uses a welding process that is inherently free of hydrogen. The GTAW process relies on bare welding electrodes and bare wire filler metal with no flux to absorb moisture. An inert gas blanket provides shielding for the weld and surrounding metal, which protects the region during welding from the atmosphere and the moisture it may contain and typically produces porosity free welds. In accordance with the associated weld procedure qualification, welding grade argon is used for the inert gas blanket. To further reduce the likelihood of any hydrogen effects, specific controls will be used to ensure the welding electrodes, filler metal, and weld region are free of all sources of hydrogen. In addition, the use of the machine GTAW temper bead process provides precise control of heat input, bead placement, bead size and contour. The very precise control over these factors provides effective tempering of the nozzle low alloy ferritic steel HAZ resulting in achievement of lower hardness and tempered martensite. This further reduces susceptibility to hydrogen induced cracking.

Temperbead Welding Applications, 48 Hour Hold Requirements for Ambient Temperature Temperbead Welding, EPRI, Palo Alto, CA: 2006. 1013558. (Reference 8.6) provides justification for reducing the 48 hour hold time on P-No. 3, Group No. 3 low alloy ferritic steel base material to start after completion of the third temper bead layer, as specified in the Alternative Requirements (Enclosure 1). This report addresses microstructural issues, hydrogen sources, tensile stress and temperature, and diffusivity and solubility of hydrogen in steels. Past industry experience with the use of the machine GTAW process has resulted in no detection of hydrogen induced cracking after the 48 hours hold nondestructive examination or subsequent in-service inspections.

a. Inservice examination volumetric and surface examinations will be performed on all modified DMWs as specified in the Alternative Requirements (Enclosure 1).

5.5 Conclusion

The proposed Alternative Requirements (Enclosure 1) result from industry PWSCC mitigation development programs for DMWs. This mitigation approach will require the granting of relief form certain aspects of AMSE Code Case N-638-1. The Alternative Requirements (Enclosure 1) provide an acceptable level of quality and safety consistent with provisions of 10 CFR 50.55a(a)(3)(i). This conclusion is based on the following:

- The filler metal in contact with the RC being highly resistant to PWSCC
- The substantial stress analysis and flaw growth analyses as specified in the Alternative Requirements (Enclosure 1)
- Other information contained in this document

6 Precedents

Weld inlay or corrosion resistant clad on Arkansas Nuclear One Unit 1 Reactor Vessel (Ref. 8.8) safe end-to-core flood nozzle DMWs.

7 Duration of Proposed Alternative

The duration of the proposed alternative is the remaining service life of the component including the period of extended operation. Future inservice examination requirements will be as described in section 5.4.

8 References

8.1 Case N-638-1, 2, 3, and 4 “Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique,”.

8.2 ASME Boiler & Pressure Vessel Code, Section XI.

8.3 Materials Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guidelines (MRP-139), EPRI, Palo Alto, CA: 2005. 1010087.

8.4 ASME Boiler & Pressure Code Section III.

8.5 Case N-695, “Qualification Requirements for Dissimilar Metal Piping Welds.”

8.6 Temperbead Welding Applications: 48-Hour Hold Requirements for Ambient Temperature Temperbead Welding. EPRI, Palo Alto, CA: 2006. 1013558.

8.7 (ML081130173) Arkansas Nuclear One, Unit No. 1 - Approval Of Relief Request ANO1-R&R-011 To Use A Proposed Alternative To The American Society Of Mechanical Engineers Boiler And Pressure Vessel Code Requirements For Weld Overlay Repairs (TAC NO. MD6958)

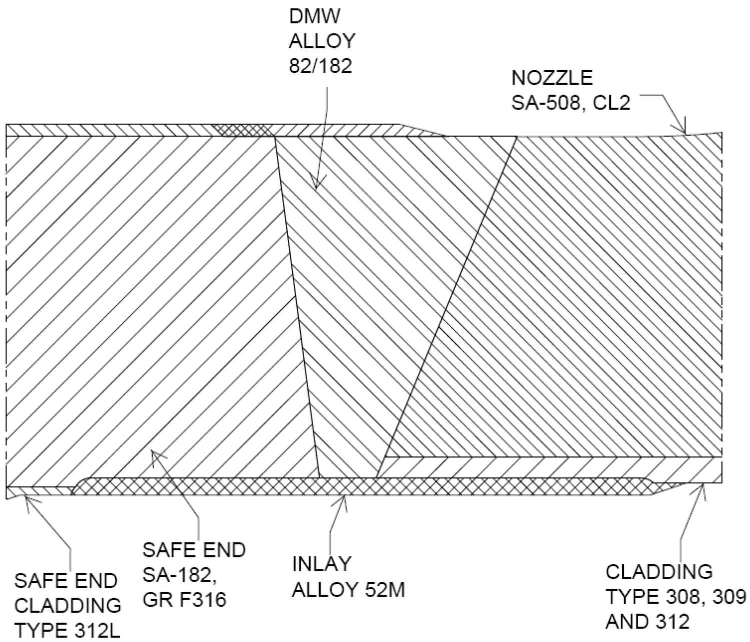


Figure 1 – Typical Weld Inlay Configuration

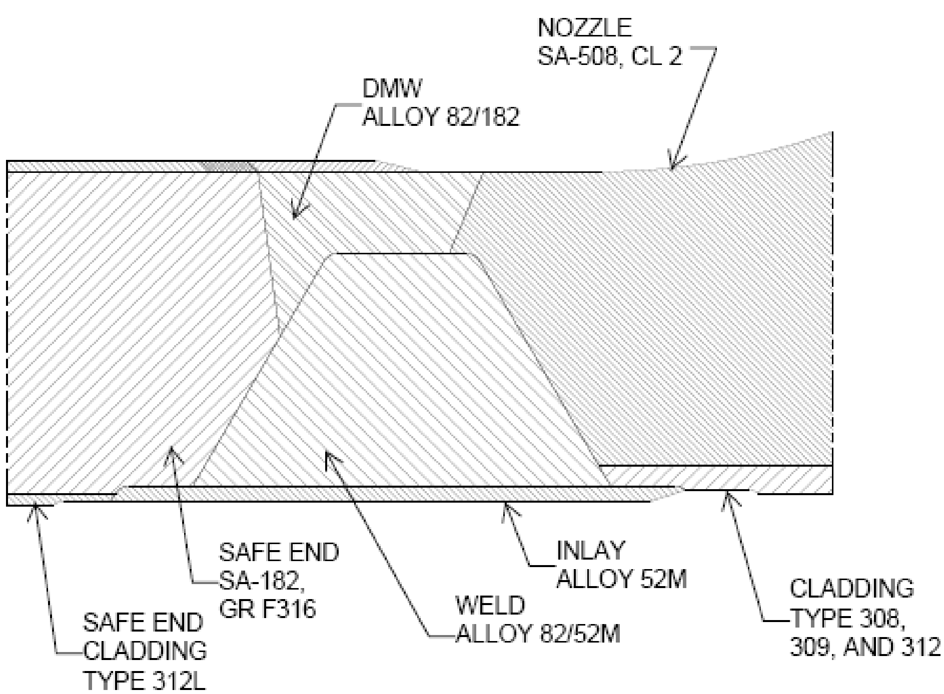


Figure 2 – Typical Weld Inlay Repair Configuration
(1/8 in. and more than one layer minimum thick Alloy 52M cover on inner surface over all Alloy 82)

Enclosure 1

Alternative Requirements for Reactor Vessel Safe End-to-Primary Nozzle Alloy 82/182 Dissimilar Metal Weld Modification Using Weld Inlay

1.0 GENERAL

a. The weld inlay shall be applied on the inside surface of the full penetration circumferential austenitic nickel alloy welds (DMWs) on the low alloy steel components, including nozzles (P-No. 3) to safe ends or piping components (P-No. 8 or 43), inclusive of the UNS N06082 or W86182 DMWs that join the two items.
b. Enclosure 1 shall apply to DMWs and adjacent component nozzles, cladding, piping and their austenitic stainless steel welds, if applicable, consisting of the following materials and combinations thereof:
    i. P-No. 8 and P-No. 43.
    ii. P-No.8 or 43 and P-No.3.
c. The location of the DMW fusion zones shall be determined.
d. All welding shall use Welding Procedure Specifications qualified in accordance with Appendix 1.
e. Ambient temperature temper bead welding shall be performed in accordance with Appendix 1.
f. The final 1/8 in. inlay thickness shall contain at least 24% Cr as deposited. The Cr content of the deposited weld metal shall be determined by chemical analysis of a coupon from a mockup representative of the materials on which the inlay will be deposited using the applicable production weld parameters and the same production weld metal classification. The weld filler metal used for the mockup shall have Cr content no greater than that to be used for the inlay. The results shall be documented.
g. Welding shall be performed using the machine GTAW process. ERNiCrFe-7A (Alloy 52M) filler metal shall be used for at least the final 1/8 in. thickness and more than one layer (inlay). ERNiCr-3 (Alloy 82) may be used for repair welding, when applicable, beyond at least 1/8 in. and more than one layer thickness from the inside final surface.
h. To reduce the potential of hot cracking when applying an austenitic nickel alloy over P-No. 8 base metal, austenitic stainless steel welds or cladding, it shall be permissible to apply ER309L austenitic stainless steel filler material and Alloy 82 near the DMW fusion zones, over the austenitic stainless steel material. The Alloy 82 shall be subsequently covered with at least 1/8 in. thick and more than one layer of Alloy 52M complying with 1.0(f) and (g).

i. Unless otherwise specified, all Section III and Section XI references in this enclosure shall be the 1989 Edition, no Addenda.

2.0 DESIGN, STRESS ANALYSES AND FLAW GROWTH ANALYSES

a. Design
   The thickness of the inlay over the exposed portion of the original DMW at the inner surface shall comply with the following.
   i. The minimum final thickness of the inlay shall consist of at least 1/8 in. of Alloy 52M at the inner surface.
   ii. The minimum thickness of the inlay using Alloy 52M in accordance with 2.0a.i. shall extend over and beyond the final inner surface DMW fusion zones by at least twice the demonstrated accuracy of the locating technique of 1.0c or 1/4 in., whichever is greater.
   iii. The maximum thickness of the repair weld, if required, including the weld inlay shall be 2 in.
   iv. The design life of the modified DMWs shall be 30 additional years and shall be verified by the stress analyses specified in 2.0b and the flaw growth analyses specified in 2.0c considering the postulated flaws.
b. Stress Analyses
   i. Stress and fatigue analyses shall be performed in accordance with NB-3200. The stress analyses evaluate the following modified DMW configurations.
      1. 0.13 inch deep cavity requiring a 0.13 in. thick weld inlay for the full inner circumference.
      2. 2 in. thick, local cavity repair weld inlay with weld inlay thereon.
c. Flaw Growth Analyses
   i. Flaw growth analyses for postulated flaws shall be performed in accordance with IWB-3640. The residual stress analyses shall assume a full circumferential 50% through-wall weld repair from the inside surface of the original DMW has previously occurred.
   ii. Planar flaws shall be postulated to exist in the newly applied weld inlay and in the original DMW as follows.
      1. Circumferential flaw of 1/16 in. depth through the inlay weld thickness, surface connected for the entire circumference of the inlay.
      2. Axial flaw of 1/16 in. depth through the inlay weld thickness, surface connected for the entire width (axial length) of the inlay.
      3. Circumferential flaw of depth equal to the maximum acceptable flaw depth per Table IWB-3514-2, in the remaining DMW, originating at the weld inlay/DMW interface for the entire circumference of the inlay.

4. Axial flaw of depth equal to the maximum acceptable flaw depth per Table IWB-3514-2, in the remaining DMW, originating at the weld inlay weld inlay/DMW interface for the entire width (axial length) of the inlay.

d. Any changes in applied loads, as a result of weld shrinkage from the inlay, or deep weld repair, when applicable, on the other items in the piping system (e.g., support loads and clearances and nozzle loads, shall be evaluated. Existing flaws previously accepted by analytical evaluation shall be evaluated in accordance with IWB-3640, as applicable.

3.0 EXAMINATION

a. General
   i. The examination requirements of this Enclosure shall be applicable in lieu of all other examination requirements.
   ii. Nondestructive examination procedures shall be in accordance with NB-5000 for acceptance examinations and IWA-2200 for preservice and inservice examinations and as specified herein.
   iii. Nondestructive examination personnel shall be qualified in accordance with IWA-2300, and as specified herein.
   iv. The final surface of the inlay shall be suitable for surface and volumetric examination.
   v. Examinations required after inlay welding shall be performed no sooner than 48 hours after completion of the third temper bead layer over the ferritic steel nozzle.
   vi. All flaws detected that are not associated with the DMW modification activity shall meet the requirements of IWB-3000.

b. Examination Prior to Application of the Inlay
   i. Prior to machining and inlay welding, the applicable DMW volume shall be ultrasonically examined using procedures, personnel, and equipment that have been qualified in accordance with Case N-695. Ultrasonic examination acceptance criteria shall be in accordance with the inservice examination acceptance standards of IWB-3514.
   ii. After machining and prior to welding, the area to be welded shall be examined using the liquid penetrant examination method. The acceptance criteria shall be in accordance with IWB-3514-2.

c. Acceptance Examination of the Inlay
   i. The inlay surface, including at least 1/2 in. of adjacent material, shall be examined using the liquid penetrant examination method in accordance with NB-5000. Acceptance criteria for the weld inlay shall be in accordance

with NB-5352 with the additional requirement that rounded indications with major dimension greater than 1/16 in. shall not be permitted. Criteria for the balance of the surface examination area shall be in accordance with the inservice examination acceptance standards of Table IWB-3514-2.

   ii. The inlay volume, at least 1/8 in. thickness, including the fusion zones shall be ultrasonically examined in accordance with Section V, Article 4, using Cladding Technique One. Calibration standards shall be in accordance with Fig. T-434.4.2.2. The acceptance criteria of NB-5330 shall apply. The repair weld volume, when applicable, shall be ultrasonically examined in accordance with Section V, Article 4. The acceptance criteria of NB-5330 shall apply.

d. Preservice Examination
   i. Surface examination is required of the inlay surface. Examination requirements and acceptance criteria shall be as specified in 3.0c.i.
   ii. The modified DMW examination volume (see Figure E1) shall be ultrasonically examined using procedures, personnel, and equipment that have been qualified in accordance with Case N-695. Ultrasonic examination acceptance criteria shall be in accordance with the inservice examination acceptance standards of IWB-3514.

e. Inservice Examination
   i. Volumetric and surface examination shall be performed on all the modified DMWs no sooner than the third refueling outage and no later than 10 years following inlay welding.

      1. Ultrasonic examination shall be performed using procedures, personnel and equipment that have been qualified in accordance with Case N-695. The inservice examination acceptance standards of IWB-3514 shall be applicable.

   ii. Examination volumes that show no indications of cracking shall be placed into a population to be examined on a sample basis. Twenty-five percent of this population shall receive a volumetric examination performed from the outside diameter surface, or a volumetric examination and a surface examination performed from the weld inside diameter surface. The 25% sample shall be added to the ISI Program in accordance with IWB-2410 and shall be examined once each inspection interval.
   iii. If inservice examinations reveal crack growth, or new cracking, meeting the acceptance standards of IWB-3132.3, the DMW examination volume shall be reexamined during the first refueling outage following discovery of the growth or new

cracking. The weld examination volume shall be subsequently examined during each of the next two refueling outages.

iv. Any volumetric examinations that reveal crack growth or new cracking, meeting the acceptance standards shall also be subject to a surface examination. The acceptance standards of 3.0c.i. shall be applicable. This surface examination shall also be required in any subsequent examinations required by 3.0e.iii.

1. If the examinations required by (3.0e.iii or 3.0e.iv. reveal that the flaw(s) remain essentially unchanged for three successive examinations, the weld examination schedule may revert to the sample and schedule of examinations. This DMW shall be included in the 25% sample population.

v. For volumetric examinations performed from the outside surface if new cracking or the growth of existing cracking is detected, additional surface examinations shall also be performed from the inside surface in the same outage and in subsequent outages as applicable for volumetric examinations.

f. The 25% sample shall consist of the same welds in the same sequence during successive intervals to the extent practical provided the 25% sample contains the welds that experience the highest operating temperature in the Item. If hot leg and cold leg welds are included in the same item, the initial 25% sample does not need to include the cold leg welds. Those welds not included in the 25% sample shall be examined prior to the end of the evaluation period if the plant is to be operated beyond that time.

g. The above inservice and preservice examinations will be performed and scheduled in accordance with Code Case N-770.

4.0 PRESSURE TESTING

A system leakage test shall not be required for a weld inlay thickness of 10% or less of the original DMW thickness. A system leakage test shall be performed in accordance with IWA-5000 for weld inlays greater than 10% of the original DMW thickness.

5.0 DOCUMENTATION

Use of this Enclosure 1 shall be documented on Form NIS-2.

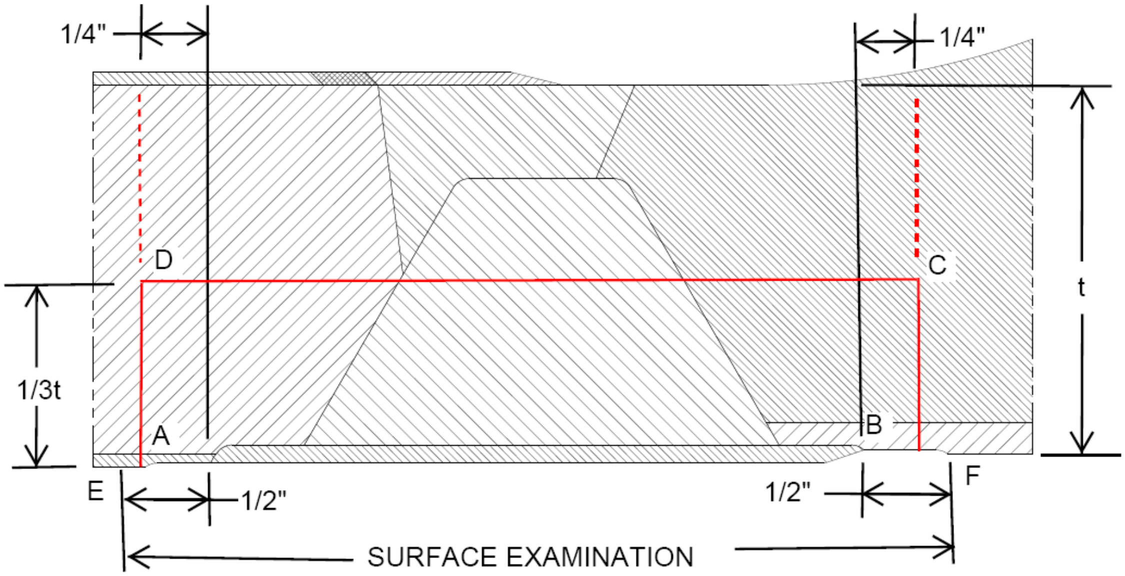


Figure E1 – Examination Volume
Volumetric Examination A-B-C-D
Surface Examination E-F

APPENDIX 1

AMBIENT TEMPERATURE TEMPER BEAD WELDING

1.0 GENERAL REQUIREMENTS

1.1 The maximum area of an individual inlay weld based on the finished surface over the ferritic base material shall be 500 sq. in.
1.2 Repair/replacement activities on a DMW in accordance with this Appendix shall be limited to those along the fusion line of a nonferritic weld to ferritic base material on which 1/8 in. or less nonferritic weld deposit exists above the original fusion line.
1.3 Prior to welding the area to be welded and a band around the area of at least 1-1/2 times the component thickness or 5 in, whichever is less, shall be at least 50F.

2.0 WELDING QUALIFICATIONS

The welding procedures and the welding operators shall be qualified in accordance with Section IX and the requirements of 2.1 and 2.2.

2.1 Procedure Qualification

(a) The base materials for the welding procedure qualification shall be of the same P-Number and Group Number as the materials to be welded. The materials shall be postweld heat treated to at least the time and temperature that was applied to the materials to be welded.
(b) The root width included angle of the cavity in the test assembly shall be no greater than the minimum specified for the barrier weld.
(c) The maximum interpass temperature for the first three layers of the test assembly shall be 150F.
(d) The test assembly cavity depth shall be at least 1 in. The test assembly thickness shall be at least twice the test assembly cavity depth. The test assembly shall be large enough to permit removal of the required test specimens. The test assembly dimensions surrounding the cavity shall be at least the test assembly thickness and at least 6 in. The qualification test plate shall be prepared in accordance with Figure 1-1.
(e) Ferritic base material for the procedure qualification test shall meet the impact test requirements of the Construction Code and Owner's Requirements. If such requirements are not in the Construction Code and Owner's Requirements, the impact properties shall be determined by Charpy V-notch impact tests of

the procedure qualification base material at or below the lowest service temperature of the item to be repaired. The location and orientation of the test specimens shall be similar to those required in (f) below, but shall be in the base metal.

(f) Charpy V-notch tests of the ferritic heat-affected zone (HAZ) shall be performed at the same temperature as the base metal test of (e) above. Number, location, and orientation of test specimens shall be as follows:

(1) The specimens shall be removed from a location as near as practical to a depth of one-half the thickness of the deposited weld metal. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. When the material thickness permits, the axis of a specimen shall be inclined to allow the root of the notch to be aligned parallel to the fusion line.

(2) If the test material is in the form of a plate or a forging, the axis of the weld shall be oriented parallel to the principal direction of rolling or forging.

(3) The Charpy V-notch test shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. The test shall consist of a set of three full-size 10 mm X 10 mm specimens. The lateral expansion, percent shear, absorbed energy, test temperature, orientation and location of all test specimens shall be reported in the Procedure Qualification Record.

(g) The average lateral expansion value of the three HAZ Charpy V-notch specimens shall be equal to or greater than the average lateral expansion value of the three unaffected base metal specimens. However, if the average lateral expansion value of the HAZ Charpy V-notch specimens is less than the average value for the unaffected base metal specimens and the procedure qualification meets all other requirements of this appendix, either of the following shall be performed:

(1) The welding procedure shall be requalified.

(2) An *Adjustment Temperature* for the procedure qualification shall be determined in accordance with the applicable provisions of NB-4335.2 of Section III, 2001 Edition with 2002 Addenda. The RT_{NDT} or lowest service temperature of the materials for which the welding procedure will be used shall be increased by a temperature equivalent to that of the Adjustment Temperature.

2.2 Performance Qualification

Welding operators shall be qualified in accordance with Section IX.

3.0 WELDING PROCEDURE REQUIREMENTS

The welding procedure shall include the following requirements.

3.1 The area to be welded shall be buttered with a deposit of at least three layers to achieve at least 1/8 in. (3mm) and more than one layer at the final inner surface of inlay weld thickness using Alloy 52M with the heat input for each layer controlled to within ±10% of that used in the procedure qualification test. The heat input of the first three layers shall not exceed 45,000 J/in. (1,800 J/mm) under any conditions. Particular care shall be taken in the placement of the weld layers of the austenitic inlay weld filler material at the toe of the inlay weld to ensure that the HAZ and ferritic base metal are tempered. Subsequent layers shall be deposited with a heat input not exceeding that used for layers beyond the third layer in the procedure qualification.

3.2 The maximum interpass temperature for field applications shall be 350F for all weld layers regardless of the interpass temperature used during qualification. The interpass temperature limitation of QW-406.3 need not be applied.

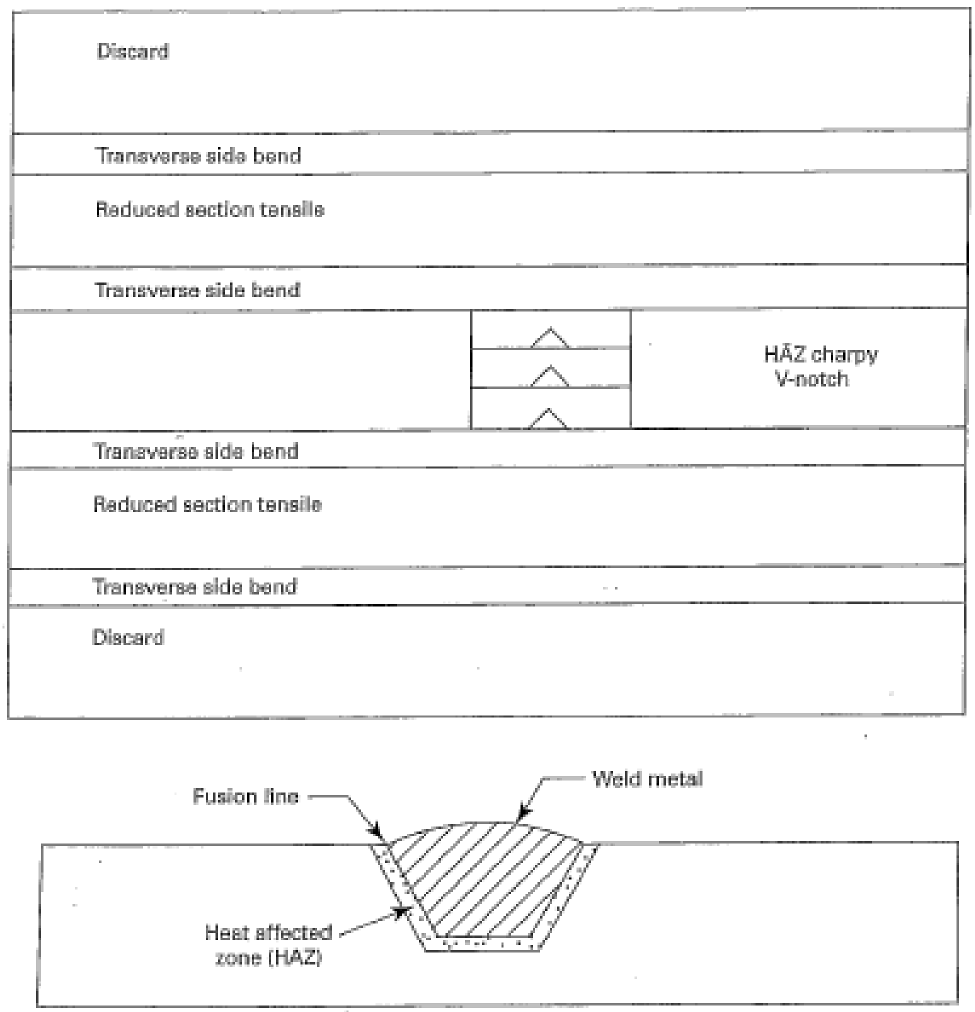
3.3 The interpass temperature shall be determined by one of the following methods:

(a) Heat flow calculations using the variables listed below as a minimum:

(1) welding heat input
(2) initial base material temperature
(3) configuration, thickness, and mass of the item being welded
(4) thermal conductivity and diffusivity of the materials being welded
(5) arc time per weld pass and delay time between each pass
(6) arc time to complete the weld

(b) Measurement of the maximum interpass temperature on a test coupon that is equal to or less than the thickness of the item to be welded. The maximum heat input of the welding procedure shall be used in the welding of the test coupon.

3.4 Particular care shall be given to ensure that the weld region is free of all potential sources of hydrogen. The surfaces to be welded, filler metal and shielding gas shall be suitably controlled.



GENERAL NOTE: Base metal Charpy impact specimens are not shown. This figure illustrates a similar-metal weld.

Fig. 1-1 QUALIFICATION TEST PLATE

GENERAL NOTE: Base metal Charpy impact specimens are not shown. This figure illustrates a similar-metal weld.