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Subject: Response to Request for Additional Information on CRDM Nozzle Examinations

Attached are responses for NRC Requests for Additional Information (RAIs) on a Westinghouse Electric Company submittal, dated February 18, 2002, pertaining to alternate weld repair techniques for reactor vessel head penetrations. The RAIs were provided in an email from Girijah Shukla (NRC) to Hank Sepp (Westinghouse), dated Thursday, June 13, 2002.

If there are any questions, please call Warren H. Bamford at 412-374-6515, or email at bamforwh@westinghouse.com.

Very truly yours,

H. A. Sepp, Manager
Regulatory & Licensing Engineering

cc: G. S. Shukla

Attachments: RAI Responses

T010
Add: G. Shukla

Responses to Requests for Additional Information Pertaining to Alternate Weld Repair Techniques for Reactor Vessel Head Penetrations

In a letter dated February 18, 2002 (LTR-NRC-02-6, Reference 1) Westinghouse submitted a relief request for an alternate flaw repair method. In response to this request in an email dated Thursday, June 13, 2002 (Reference 2) the NRC staff has made requests for additional information. The following information is provided in response.

(2) RAIs on Alternative Weld Repair Techniques for Reactor Vessel Head Penetrations by Westinghouse, Attachment to LTR-NRC-02-6 dated 2/18/02.

1. If this is a Topical Report, why is Palo Verde mentioned on Page 2 under Item C.?

   Response:

   Palo Verde was intended as the lead plant for the use of this technique. This repair technique is intended to be used on a generic basis.

2. Provide justification for the use of the Ambient Temperature Temper Bead Method, such as, Procedure Qualification Records, weld test results, hardness results, notch toughness test results, tensile test results, bend test results, etc. The report should discuss the applicability of the data to the relief request.

   Response:

   Research by the Electric Power Research Institute (EPRI) and other organizations on the use of an ambient temperature temper bead operation using the machine GTAW process is documented in EPRI Report GC-111050 (Reference 3). According to the EPRI report, repair welds performed with an ambient temperature temper bead procedure utilizing the machine GTAW welding process exhibit mechanical properties equivalent or better than those of the surrounding base material. Laboratory testing, analysis, successful procedure qualifications, and successful repairs have all demonstrated the effectiveness of this process.

   <u>Mechanical Properties</u>

   The principal reasons to preheat a component prior to repair welding is to minimize the potential for cold cracking. The two cold cracking mechanisms are hydrogen cracking and restraint cracking. Both of these mechanisms occur at ambient temperature. Preheating slows down the cooling rate resulting in a ductile, less brittle microstructure thereby lowering susceptibility to cold cracking. Preheat also increases the diffusion rate of monatomic hydrogen that may have been trapped in the weld during solidification. As an alternative to preheat, the ambient temperature temper bead welding process utilizes the tempering action of the welding procedure to produce tough and ductile microstructures. Because precision bead placement and heat input control is characteristic of the machine GTAW process, effective tempering of weld heat affected zones is possible without the application of preheat. According to Section 2-1 of EPRI Report GC-111050,

   > "the temper bead process is carefully designed and controlled such that successive weld beads supply the appropriate quantity of heat to the untempered heat affected zone such that the desired degree of carbide precipitation (tempering) is achieved. The resulting microstructure is very tough and ductile."

Section 2.1 of the relief request establishes detailed welding procedure qualification requirements. Simulating base materials, filler metals, restraint, impact properties, and procedure variables, the qualification requirements of Section 2.1 provide assurance that the mechanical properties of repair welds will be equivalent or superior to those of the surrounding base material. It should also be noted that the qualification requirements of Section 2.1 are identical to those in ASME Code Section XI, IWA-4530. The ambient temperature temper bead specification was qualified in accordance with the requirements outlined in the relief request. Based upon the procedure qualification test results, the impact properties of the base material heat affected zone were superior to those of the unaffected base material. The mechanical testing results for the procedure qualification are summarized below.

Hydrogen Cracking

The potential for hydrogen induced cracking is greatly reduced by using machine GTAW process. However, should it occur, cracks would be detected by the final nondestructive examinations (NDE) performed after the completed repair weld has been at ambient temperature for at least 48 hours as required in Section 4.0 of the relief request. Regarding this issue, EPRI Report GC-111050, Section 6.0 concluded the following:

> "No preheat temperature or postweld bake above ambient temperature is required to achieve sound machine GTAW temper bead repairs that have high toughness and ductility. This conclusion is based on the fact that the GTAW process is an inherently low hydrogen process regardless of the welding environment. Insufficient hydrogen is available to be entrapped in solidifying weld material to support hydrogen delayed cracking. Therefore, no preheat nor postweld bake steps are necessary to remove hydrogen because the hydrogen is not present with the machine GTAW process."

Cold Cracking

The ambient temperature temper bead process is designed to provide a sufficient heat inventory so as to produce the desired tempering for high toughness. Because the machine GTAW temper bead process provides precision bead placement and control of heat, the toughness and ductility of the heat affected zone will typically be superior to the base material. Therefore, the resulting structure will be appropriately tempered to exhibit toughness sufficient to resist cold cracking. Additionally, even if cold cracking were to occur, it would be detected by the final NDE which is performed after the completed repair weld has been at ambient temperature for at least 48 hours as required in Section 4.0 of the relief request.

Mechanical Properties Summary

In conclusion, no elevated preheat or postweld soak above ambient temperature is required to achieve sound and tough repair welds when performing ambient temperature temper bead welding using the machine GTAW process. This conclusion is based upon strong evidence that hydrogen cracking will not occur with the GTAW process. In addition, automatic or machine temper bead welding procedures without preheat will produce satisfactory toughness and ductility properties both in the weld and weld heat affected zones. The results of previous industry qualifications and repairs further support this conclusion. The use of an ambient temperature temper bead welding procedure will improve the feasibility of performing localized weld repairs with a significant reduction in radiological exposure. EPRI Report GC-111050, Section 6.0 concluded the following:

"Repair of RPV components utilizing machine GTAW temper bead welding at ambient temperature produces mechanical properties that are commonly superior to those of the service-exposed substrate. The risk of hydrogen delayed cracking is minimal using the GTAW process. Cold stress cracking is resisted by the excellent toughness and ductility developed in the weld HAZ (heat affected zone). Process design and geometry largely control restraint considerations, and these factors are demonstrated during weld procedure qualification."

Weld Procedure Qualification

The weld procedure qualification for this repair technique was qualified in accordance with method outlined in the relief request (LTR-NRC-02-6, Reference1). The welding procedure qualification test assembly was 3 inches thick and consisted of SA-533, Grade B, Class 1 (P-No. 3, Group 3) and SB-166, N06690 (P-No. 43) base materials. Prior to welding, the SA-533, Grade B, Class 1 portion of the test assembly was heat treated for 40 hours at 1,200°F. The repair cavity in the test assembly was 1.5 inches deep. The test assembly cavity was welded in the 3G (vertical) position using ERNiCrFe-7 (F-No. 43) filler metal. Results of the welding procedure qualification were documented in a procedure qualification record. Results of mechanical testing – tensile testing, bend testing, Charpy V-notch testing, and drop weight testing – are summarized below. The weld procedure qualification will be used to perform the repair welding activities.

- Tensile test specimens exhibited a tensile strength that exceeded 80,000 psi and were acceptable per ASME Section IX. The bend testing was also acceptable. Test results are as follows:

Tensile Test Results

Specimen No.	Tensile Specimen	Actual Tensile Strength	Failure
Test 1-1	0.505" Turned Specimen	86,600 psi	Ductile/Base
Test 1-2	0.505" Turned Specimen	84,500 psi	Ductile/Base
Test 2-3	0.505" Turned Specimen	82,400 psi	Fusion Line
Test 2-4	0.505" Turned Specimen	86,600 psi	Ductile/Weld Metal

Bend Test Results

Specimen Type and Figure No.	Result
Side Bend 1 QW-462.2	Acceptable
Side Bend 2 QW-462.2	Acceptable
Side Bend 3 QW-462.2	Acceptable
Side Bend 4 QW-462.2	Acceptable

- Drop weight and Charpy V-notch testing of the SA-533, Grade B, Class 1 "unaffected" base material was performed. Based upon drop weight testing of the SA-533, Grade B, Class 1 "unaffected" base material, a nil-ductility transition temperature (T_{NDT}) of -50°F was established. Charpy V-notch testing was also performed at +10°F. All three Charpy V-notch specimens exhibited at least 35 mils and 50 ft-lbs. Based upon the above testing, an RT_{NDT} of -50°F was established for the SA-533, Grade B, Class 1 base material. Test results are as follows:

Drop Weight Test: Unaffected Base Material

Specimen ID	Specimen Type	Test Temperature	Drop Weight Break	T_{NDT}
DW1	P-3	-40°F	No	-50°F
DW2	P-3	-40°F	No	-50°F

Charpy V-Notch Tests: Unaffected Base Material

Specimen ID	Test Temperature	Absorbed Energy (ft-lbs)	Lateral Expansion(mils)	% Shear Fracture
1	+10°F	59.0	50.0	60.0
2	+10°F	51.0	43.0	50.0
3	+10°F	50.0	45.0	50.0
Average	+10°F	*53.3*	*46.0*	*53.3*

- Charpy V-notch testing of the SA-533, Grade B, Class 1 heat affected zone was also performed at +10°F. The absorbed energy, lateral expansion, and percent shear fracture of the heat affected zone test specimens were compared to the test values of the unaffected base material specimens. The average values of the three heat affected zone specimens were greater than those of the unaffected base material specimens. Based upon these results, it is clear that the proposed ambient temperature temper bead process improved the heat affected zone properties. Test results are as follows:

Charpy V-Notch Tests: Heat Affected Zone

Specimen ID	Test Temperature	Absorbed Energy (ft-lbs)	Lateral Expansion(mils)	% Shear Fracture
1	+10°F	85.0	65.0	90.0
2	+10°F	136.0	64.0	75.0
3	+10°F	124.0	49.0	30.0
Average	+10°F	*115.0*	*59.3.0*	*65.0*

Supplemental microstructural evaluations were also performed on the test coupon weld of the procedure qualification. Microstructural evaluations consisted of micro-hardness testing (Vickers) and metallography. Vickers micro-hardness testing was performed at three different locations:

1. 0.125 inch below the surface of the weld,
2. 0.625 inch below the surface of the weld, and
3. 0.125 inch above the root of the weld.

Micro-hardness test values are provided in the table below.

Metallography was performed at 100X and 500X magnifications. There were a few colonies of tempered martensite observed near the root of the weld. These seem to be associated with the slight banding present in the base material. There was no indication of untempered martensite. The remaining areas of the heat affected zone consist of a mixed microstructure of by-products of high temperature pearlite degeneration, bainite and a small amount of ferrite. There was no evidence of massive carbides or carbide networks.

Vickers Micro-Hardness Tests Results

Weld Zone Location	0.125" From Surface		0.625" From Surface		0.125" Above Weld Root	
	Filar	Vickers	Filar	Vickers	Filar	Vickers
Unaffected Base Material	182	224	184	219	182	224
	182	224	185	217	176	240
	183	222	186	214	174	245
	182	224	186	214	181	226
	184	219	182	224	178	234
	184	219	187	212	173	248
HAZ Grain Coarsened Region	167	266	162	283	150	330
	165	273	164	276	144	358
	165	273	169	260	144	358
HAZ Adjacent to Fusion Line	163	279	161	287	149	334
	161	287	161	287	147	343
	159	293	164	276	147	343
Weld Metal	183	222	187	212	190	205
	189	208	192	201	189	208
	184	219	185	217	186	214
	184	219	185	217	182	224
	189	208	183	222	182	224
	193	199	184	219	179	232

3. If ERNiCrFe-7M (Alloy 52 modified) is used, relief should be requested for this non-ASME weld filler metal. Test data, experience, etc., with this filler metal should be submitted with this request.

   Response:

   ERNiCrFe-7M was not included in the weld procedure qualification and will not be used for the alternative weld repair techniques for reactor vessel head penetrations (ambient temperature temper bead method)

References:

1. Westinghouse Letter LTR-NRC-02-6, February 18, 2002, ASME Section XI Inservice Inspection Program Relief Request – Alternative Repair Technique.
2. NRC Email Girija Shukla (NRC) to H. A. Sepp (Westinghouse), Thursday, June 13, 2002.
3. EPRI Report GC-111050, Ambient Temperature Preheat for Machine GTAW Temper Bead Applications.