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Exelon Nuclear

10 CFR 50.55a

April 28, 2006

LTR: Byron 2006-0050
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United States Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Third 10-Year Inservice Inspection Interval, Relief Request I3R-08, Structural Weld Overlays on Pressurizer Spray, Relief, Safety and Surge Nozzle Safe-ends and Associated Alternative Repair Techniques

Pursuant to 10 CFR 50.55a(a)(3)(i), Exelon Generation Company, LLC (EGC), is proposing an alternative to the repair/replacement requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, 2001 Edition, through 2003 Addenda, IWA-4000, for the structural weld overlays on pressurizer spray, relief, safety and surge nozzle safe-ends.

During the next Byron Station Unit 1 refueling outage (B1R14) and Byron Station Unit 2 refueling outage (B2R13), EGC will be performing full structural weld overlays (SWOLs) on all pressurizer nozzle safe-end to nozzle welds where Alloy 182 was originally used to butter the nozzle face and used to weld the stainless steel safe-ends to nozzles.

The alternative is proposed under the provisions of 10 CFR 50.55a(a)(3)(i), an alternative that provides an acceptable level of quality and safety.

EGC requests that the review of this relief request be completed by September 11, 2006. If you have any questions regarding this letter, please contact William Grundmann at (815) 406-2800.

Respectfully,

David M. Hoots
Site Vice President
Byron Nuclear Generating Station

DMH/JL/rah

Enclosure: Byron Station Relief Request I3R-08

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Request for Relief for Alternative Requirements of Structural Weld Overlays (SWOLs) of the Pressurizer Surge, Spray, Safety and Relief Nozzles, Dissimilar Welds including the SWOLs of the Safe-End to Pipe, Reducer and Elbow Welds on Pressurizer Surge, Spray, Safety and Relief Nozzles In Accordance with 10 CFR 50.55a(a)(3)(i)

1.0 ASME CODE COMPONENT(S) AFFECTED

Code Class:	1
Reference:	IWA-4000, " Repair/Replacement Activities"
Examination Category:	R-A
Item Number:	See Table 1 for listing
Description:	Alternative Structural Weld Overlays (SWOLs) of the Pressurizer Surge, Spray, Safety and Relief Nozzles, Dissimilar Welds and also including the SWOLs of the Safe-End to Pipe, Reducer and Elbow Welds on Pressurizer Surge, Spray, Safety and Relief Nozzles
Component Number(s):	See Table 1 for listing
Drawing Number(s):	Unit 1: 1PZR-1-ISI (Pressurizer), 1RC-1-ISI Sheet 5 (Surge Line), 1RC-1-ISI Sheet 16 (Spray Line), 1RC-1-ISI Sheet 32 (Relief Lines), and 1RC-1-ISI Sheet 35 (Safety Line) Unit 2: 2PZR-1-ISI (Pressurizer), 2RC-1-ISI Sheet 5 (Surge Line), 2RC-1-ISI Sheet 16 (Spray Line), 2RC-1-ISI Sheet 32 (Relief Lines), and 2RC-1-ISI Sheet 35 (Safety Line)

2.0 APPLICABLE CODE EDITION AND ADDENDA

The Inservice Inspection program is based on the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, 2001 Edition through the 2003 Addenda.

3.0 APPLICABLE CODE REQUIREMENT

ASME Section XI, 2001 Edition, through 2003 Addenda, IWA-4000 requires that repairs be performed in accordance with the owner's original construction Code of the component or system, or later editions and addenda of the Code. The pressurizer Code of Construction is ASME Section III, 1971 Edition through Summer 1973 Addenda, with Code Case NB-4643, 1493-1. The proposed alternative activities are supported by the requirements presented in:

ASME Code Case N-638-1 "Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique" conditionally approved in

Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.147 Revision 14.

ASME Code Case N-504-2 “Alternative Rules for Repair of Classes 1, 2, and 3 Austenitic Stainless Steel Piping” conditionally approved in RG 1.147 Revision 14.

In addition, ASME Code, Section XI, 1995 Edition including Addenda through 1996, Appendix VIII Supplement 11 is used for examination qualification requirements of the final welded overlays.

4.0 REASON FOR THE REQUEST

Dissimilar metal welds (DMWs), typically consisting of Alloy 182 weld are frequently used in pressurized water reactors (PWR) construction to connect stainless steel pipe and safe ends to vessel nozzles, generally constructed of carbon or low alloy ferritic steel. These welds have shown a propensity for primary water stress corrosion cracking (PWSCC) degradation, especially in components subjected to higher operating temperatures, such as the pressurizer (PZR).

Exelon Generating Company, LLC (EGC), Byron Station Units 1 and 2 is proposing to take a proactive approach on the Byron Station Unit 1 and 2 Pressurizer and apply a preemptive Structural Weld Overlay (SWOL) on the Pressurizer Nozzle Safe-end to Nozzle Dissimilar Metal Welds to mitigate the occurrence of PWSCC prior to detectable evidence of PWSCC. Structural Weld Overlays (SWOL) have been used for several years on both boiling water reactors (BWR) and pressurized water reactors (PWR) to arrest existing flaws from propagating while establishing a new structural pressure boundary. In some cases, SWOLs have been used to reestablish structural integrity of the DMW containing through wall leaking flaws. The SWOLs will also facilitate ultrasonic examination of the DMWs by providing a more consistent outer surface configuration from which scanning can be performed.

The welding will be performed using a remote mechanized Gas Tungsten-Arc Welding (GTAW) process and using the ambient temperature temper bead method with AWS Classification ERNiCrFe-7 (Alloy 52 or Alloy 52M*) weld metal. Manual GTAW, using Alloy 52 or Alloy 52M, will only be permitted subsequent to the SWOLs being essentially completed or to repair indications detected in base materials prior to overlay initiation. Also, Manual GTAW may be used if local repairs of weld defects are necessary or additional weld metal is required locally to form the final SWOL contour. Shielded Metal Arc Welds (SMAW), using AWS Classification ERNiCrFe-7 (Alloy 152), will be used only as needed to repair indications in base materials prior to overlay initiation.

* The material supplier's weld wire designation may be either 52M or 52MS. The “S” designates the process route that converts the hot-rolled billet into finished cold-drawn wire. The material properties are not

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affected. For this reason, references herein to 52M are considered to encompass 52MS filler material as well.

As discussed herein, there is no comprehensive criterion for a licensee to apply a SWOL repair to a DMW that is constructed of Alloy 82/182 weld material and is believed to be susceptible to or contain PWSCC degradation. Although the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, 2001 Edition, through 2003 Addenda, IWA-4000, is used for the Byron Unit 1 and 2 Section XI Repair/Replacement Program, it does not contain the needed requirements for this type of weld overlay repair. Repair/replacement activities associated with weld overlays of this type are required to address the materials, welding parameters, personnel radiation exposure concerns, operational constraints, examination techniques and procedure requirements.

5.0 PROPOSED ALTERNATIVE AND BASIS FOR USE

EGC proposes using SWOL's designed in accordance with Code Cases N-504-2 (Reference 1) with the modifications proposed in Table 2. Code Case N-504-2, currently approved for use in RG 1.147 with additional requirements of ASME Section XI, 2005 Addenda Appendix Q being required, allows a flaw to be reduced to an acceptable size by deposition of weld reinforcement on the outside surface of the pipe without flaw removal. The SWOL's will extend around the full circumference of the applicable DMWs as required by Code Case N-504-2. The specific thickness and length will be determined according to the guidance provided in Code Case N-504-2. The overlay will completely cover the DMWs and the adjacent stainless steel safe-end to pipe welds with Alloy 52 or Alloy 52M material that is highly resistant to PWSCC. A typical SWOL configuration is shown in Figure 1.

The temper bead welding technique for the specified nozzles adjacent to DMWs will be implemented in accordance with ASME Code Case N-638-1 (Reference 2) with the modifications proposed in Table 3.

The ultrasonic examination (UT) of the completed SWOL will be accomplished in accordance with ASME Section XI, 1995 Edition with the 1996 Addenda, Appendix VIII Supplement 11 with the modifications described in Table 4. These modifications were developed by the EPRI Performance Demonstration Initiative (PDI) program to implement the requirements of Appendix VIII. These EPRI Supplement 11 modifications have previously been approved for use (see Reference 6).

6.0 DURATION OF THE PROPOSED ALTERNATIVE

This relief request will be implemented during the remainder of Byron Station, Units 1 and 2 third ten-year inservice inspection interval.

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7.0 PRECEDENT

Similar relief requests have been previously approved for AmerGen Energy Company for its Three Mile Island Nuclear Station, Unit 1 in July, 2004, at Constellation Energy's Calvert Cliffs Nuclear Power Plant, Unit 2 in July, 2005 and at Dominion Nuclear Connecticut's Millstone Power Station Unit 3 in October 2005. These requests were associated with welding over detected flaws outside the acceptance criteria of Section XI.

8.0 REFERENCES

1. ASME Code Case N-504-2, "Alternative Rules for Repair of Classes 1, 2, and 3 Austenitic Stainless Steel Piping," dated March 12, 1997.
2. ASME Code Case N-638-1, "Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique," dated February 13, 2003.
3. Letter from Richard Laufer, NRC to Christopher M. Crane, AmerGen, "Three Mile Island Nuclear Station, Unit 1 (TMI-1) Request for Relief From Flaw, Heat Treatment, and Nondestructive Examination Requirements for the Third 10 year Inservice Inspection (ISI) Interval (TAC No. MC101)," Accession Number ML041670510, dated July 21, 2004.
4. Letter from Richard J. Laufer, NRC to George Vanderheyden, Calvert Cliffs, "Calvert Cliffs Nuclear Power Plant, Unit No. 2 – Relief Request For Use Weld Overlay and Associated Alternative Inspection Techniques (TAC Nos. MC6219 and MC6220)," Accession Number ML051930316, dated July 20, 2005.
5. Letter from L. Raghavan, NRC to Mano K. Nazar, I&M, "Donald C. Cook Nuclear Plant, Unit 1 (DCCNP-1) – Alternatives Regarding Repair of Weld 1-PZR-23 on Pressurizer Nozzle to Valve Inlet Line (TAC No. MC6704)," Accession Number ML053220019, dated December 1, 2005.
6. Letter from L. Raghavan, NRC, to Mano K. Nazar, I&M, "Donald C. Cook Nuclear Plant, Unit 1 – Alternative to Repair Requirements of Section XI of the American Society of Mechanical Engineers Code (TAC No. MC06751)," Accession Number ML051720006, dated June 27, 2005.
7. Letter from Leslie N. Hartz, Dominion Nuclear Connecticut, to NRC Document Control Desk, "Dominion Nuclear Connecticut, Inc., Millstone Power Station Unit 3, Second 10-year Inservice Inspection Interval, Revision 1 to Relief Request IR-2-39, Use of Weld overlay and Associated Alternative Repair Techniques," Accession Number ML052930108, dated October 19, 2005.
8. Letter from Richard J. Laufer, NRC, to Bryce L. Shriver, PPL Susquehanna, "Susquehanna Steam Electric Station, Unit 1 – Relief from American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (ASME Code), Section XI Appendix VIII, Supplement 11, Requirements and Cases N-504-2 and N-638

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Requirements (TAC Nos. MC2450 and MC2594)," Accession Number ML051220568, dated June 22, 2005.

9.0 ATTACHMENTS

1. RRA 05-08, BC06-134, Technical Basis Paper N-638-x, Ambient Temperature Temperbead Welding: Begin 48 Hour Hold After 3rd Layer Completion, authored by Bruce Newton, PCI Energy Services.
2. RRM-02-05, BC04-1003, Develop New Code Case to Address Inconel Weld Overlay on Various Materials, SIR-05-030, Rev. 0, Effect of Chromium Content on Nickel-base Alloy SCC Resistance

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TABLE 1
COMPONENT IDENTIFICATION

For Unit 1 Pressurizer 1RY01S

SAFE-END	IDENTIFICATION	ITEM #	SIZE	PIPING WELD (Line, Weld)	CONFIGURATION	ITEM #
Surge	PN-01 F1	R1.11 R1.15	14”	1RY11AA-14”, J1A	Safe-end to Pipe	R1.11
Spray	PN-02 F2	R1.11 R1.15	4”	1RY01C-4”, J1	6”x4” Reducer to Safe-end	R1.11
Relief	PN-03 F3	R1.15	6”	1RY02A-6”, J1	Safe-end to Cut 45° Elbow	R1.20
Safety A	PN-04 F4	R1.15	6”	1RY03AA-6”, J1	Safe-end to Cut 90° Elbow	R1.20
Safety B	PN-05 F5	R1.15	6”	1RY03AB-6”, J1	Safe-end to Cut 90° Elbow	R1.20
Safety C	PN-06 F6	R1.15	6”	1RY03AC-6”, J1	Safe-end to Cut 90° Elbow	R1.20

For Unit 2 Pressurizer 2RY01S

SAFE-END	IDENTIFICATION	ITEM #	SIZE	PIPING WELD (Line, Weld)	CONFIGURATION	ITEM #
Surge	PN-01 F1	R1.11 R1.15	14”	2RY11AA-14”, J1	Safe-end to Pipe	R1.11
Spray	PN-02 F2	R1.11 R1.15	4”	2RY01C-4”, J1	6”x4” Reducer to Safe-end	R1.11
Relief	PN-03 F3	R1.15	6”	2RY02A-6”, J1	Safe-end to Cut 45° Elbow	R1.20
Safety A	PN-04 F4	R1.15	6”	2RY03AA-6”, J1	Safe-end to Cut 90° Elbow	R1.20
Safety B	PN-05 F5	R1.15	6”	2RY03AB-6”, J1	Safe-end to Cut 90° Elbow	R1.20
Safety C	PN-06 F6	R1.15	6”	2RY03AC-6”, J1	Safe-end to Cut 90° Elbow	R1.20

Note: Item numbers reflect Risk-Informed classification per ASME Code Case N-578-1.
R1.11: Elements Subject to Thermal Fatigue.
R1.15: Elements Subject to Primary Water Stress Corrosion Cracking.
R1.20: Elements not Subject to a Damage Mechanism.

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Figure 1
Typical SWOL Configuration

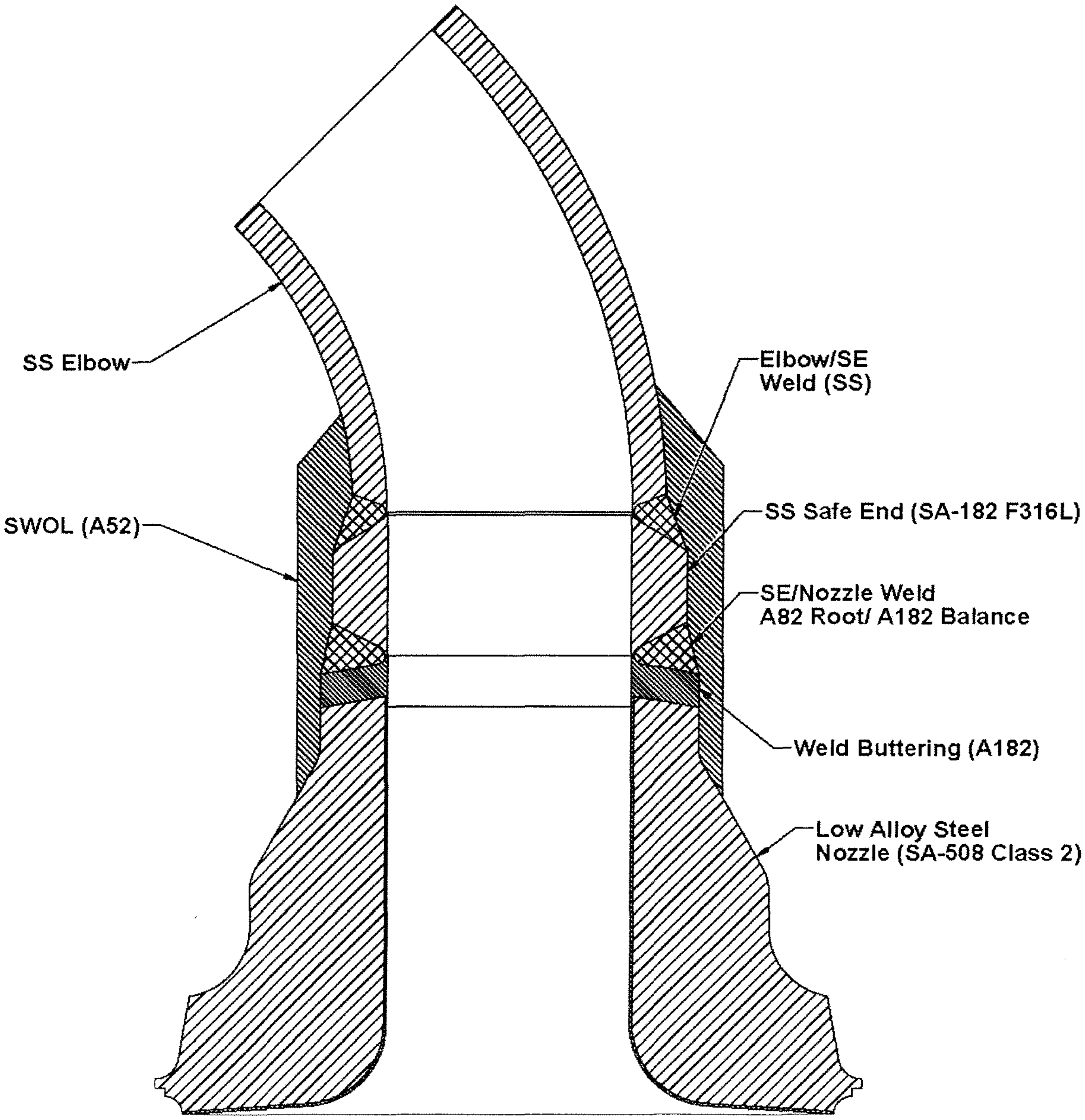

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TABLE 2
DESIGN / MATERIAL / NONDESTRUCTIVE EXAMINATION
Modifications to Code Case N-504-2 and ASME Section XI, Appendix Q

CODE CASE N-504-2 AND ASME SECTION XI APPENDIX Q	PROPOSED MODIFICATIONS
Reply: It is the opinion of the Committee that, in lieu of the requirements of IWA-4120 in Editions and Addenda up to and including the 1989 Edition with the 1990 Addenda, in IWA-4170(b) in the 1989 Edition with the 1991 Addenda up to and including the 1995 Edition, and in IWA-4410 in the 1995 Edition with the 1995 Addenda and later Editions and Addenda, defect in austenitic stainless steel piping may be reduced to a flaw of acceptable size in accordance with IWB-3640 from the 1983 Edition with the Winter 1985 Addenda, or later Editions and Addenda, by deposition of weld reinforcement (weld overlay) on the outside surface of the pipe, provided the following requirements are met.	*Modification:* Code Case N-504-2 and Appendix Q will be used for the weld overlay of the ferritic (P3) nozzle material, nickel alloy (F43/P43) weld material, and austenitic stainless steel base (P8, safe end and pipe) and weld materials. *Basis:* Code Case N-504-2 is accepted for use in the current NRC Regulatory Guide 1.147 Rev. 14, and has been used extensively in BWR primary system piping. More recently, N-504-2 has been applied to PWR applications, with modifications, for the weld overlay repair of dissimilar metal welds with known flaws. Industry operating experience in the area has shown that PWSCC in Alloy 82/182 will arrest at the interface with stainless steel base metal, ferritic base metal, or Alloy 52/52M/152 weld metal. The 360° full structural weld overlay will control growth in any PWSCC crack and maintain weld integrity. The weld overlay will also induce compressive stress in the weld, thus potentially impeding growth of any reasonably shallow cracks. Furthermore, the overlay will be sized to meet all structural requirements without considering the existing 82/182 weld.

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TABLE 2 DESIGN / MATERIAL / NONDESTRUCTIVE EXAMINATION Modifications to Code Case N-504-2 and ASME Section XI, Appendix Q	
CODE CASE N-504-2 AND ASME SECTION XI APPENDIX Q	**PROPOSED MODIFICATIONS**
b) Reinforcement weld metal shall be low carbon (0.035% maximum) austenitic stainless steel applied 360° around the circumference of the pipe, and shall be deposited in accordance with a qualified welding procedure specification identified in the Repair Program [essentially same as Q-2000(a)].	Modification: Weld overlay filler metal shall be an austenitic nickel alloy (28% Cr min.) applied 360° around the circumference of the item, and shall be deposited using a Welding Procedure Specification for groove welding, qualified in accordance with the Repair/Replacement Code and Owner's requirements and identified in the Repair /replacement Plan. Basis: Industry operational experience has shown that PWSCC in Alloy 82/182 will blunt at the interface with stainless steel base metal, ferritic base metal, or Alloy 52/52M/152 weld metal.
e) The weld reinforcement shall consist of a minimum of two weld layers having as deposited delta ferrite content of at least 7.5N. The first layer of weld metal with delta ferrite content of at least 7.5N shall constitute the first layer of the weld reinforcement design thickness. Alternatively, first layers of at least 5FN may be acceptable based on evaluation [essentially the same as Q2000(d) except if the deposited weld metal has a carbon content of <0.02% the first layers of at least 5FN are acceptable].	Modification: Delta ferrite measurements will not be performed for this overlay. The first two layers will be credited as part of the required weld overlay thickness and will not be considered as sacrificial layers. Basis: The deposited Alloy 52 or Alloy 52M is 100% austenitic and contains no delta ferrite due to the high nickel composition (approximately 60% nickel) The austenitic nickel alloy weld overlay shall consist of at least two weld layers deposited using a filler material with a Cr content of at least 28%. For applications addressed by this request, when welding over, a diluted first layer of at least 24% Cr is considered acceptable, provided the Cr content of the deposited weld metal is determined by chemical analysis of a representative coupon. (Refer to Attachment 1 for details).

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TABLE 2
DESIGN / MATERIAL / NONDESTRUCTIVE EXAMINATION
Modifications to Code Case N-504-2 and ASME Section XI, Appendix Q

CODE CASE N-504-2 AND ASME SECTION XI APPENDIX Q	PROPOSED MODIFICATIONS
h) The completed repair shall be pressure tested in accordance with IWA-5000. If the flaw penetrated the original pressure boundary prior to welding, or if any evidence of the flaw penetrating the pressure boundary is observed during welding operation, a system hydrostatic test shall be performed in accordance with IWA-5000. If the system pressure boundary has not been penetrated, a system leakage, inservice, or functional test shall be performed in accordance with IWA-5000.	Modification: In lieu of hydrostatic testing, a system leakage test and an ultrasonic examination (UT) of the weld overlay shall be performed in accordance with the Byron Station Third Interval ISI Program. Basis: Byron Station Third Interval ISI Program is to the ASME 2001Edition, through 2003 Addendum, which does not require a hydrostatic test. The combination of the system leakage test and the ultrasonic examination of the weld overlay are sufficient to demonstrate that the overlay is of adequate quality to ensure pressure boundary integrity.

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TABLE 3
AMBIENT TEMPERATURE TEMPER BEAD WELDING
Modifications to Code Case N-638-1

CODE CASE N-638-1	PROPOSED MODIFICATIONS
(a) The maximum area of an individual weld based on the finished surface shall be 100 sq. in., and the depth of the weld shall not be greater than one-half of the ferritic base metal thickness.	Modification: The maximum area of an individual weld based on the finished surface over the ferritic material will exceed 100 sq. in. and will be on the order of 300 sq. in. The one half base metal thickness limitation applies only to excavation and repair and is not applicable to this application. Basis: The SWOL will require welding on more than 100 sq. in. of surface on the low alloy steel base material. The SWOL will extend to the transition taper of the low alloy steel nozzle so that qualified UT of the required volume can be performed. There have been a number of temper bead WOL repairs applied to safe-end to nozzle welds in the nuclear industry, and a SWOL repair having a 300 sq. in. surface was recently approved for the Susquehanna Steam Electric Station (Reference 9). ASME Code Case N-432-1, which is approved for use in RG 1.147, allows temper bead welding on low alloy steel nozzles without limiting the temper bead weld surface area. The two additional conditions required by Code Case N-432-1 that are not required by Code Case N-638-1 are that temper bead welds have preheat applied and that the procedure qualification be performed on the same specification, type, grade and class of material. The elevated preheat would present a radiation exposure burden when performing the repair.

TABLE 3 AMBIENT TEMPERATURE TEMPER BEAD WELDING Modifications to Code Case N-638-1	
CODE CASE N-638-1	**PROPOSED MODIFICATIONS**
4.0 EXAMINATION	
(b) The final weld surface and the band around the area defined in para. 1.0(d) shall be examined using surface and ultrasonic methods when the completed weld has been at ambient temperature for at least 48 hours. The ultrasonic examination shall be in accordance with Appendix I.	Modification: For the SWOLs, full UT of the 1.5T band will not be performed. UT will be performed on the actual weld overlay, meeting the requirements of ASME Section XI, NMA Appendix Q-4100. When austenitic filler materials are used, the weld overlay will be examined using a surface and ultrasonic methods when the three tempering weld layers (i.e., layers 1, 2, and 3) are completed and have been in place for at least 48 hours. Basis: Later additions of the ASME Section XI code and the next revision to code case N-638(-2) removed the requirement for the 1.5T requirement. This is in line with the less restrictive requirements for UT of the ferritic nozzle due to hydrogen cracking that is not considered an issue in later additions of the ASME Section XI code and code case N-638. The code case applies to any type of welding where a temper bead technique is to be employed and is not specifically written for a SWOL repair. However, it is believed that for this type of repair, any major base material cracking would take place in the heat-affected zone directly below the weld overlay or in the underlying Alloy 82/182 weld deposit and not in the required band of material out beyond the overlay. Therefore, it is assumed that if this cracking were to occur, it would be identified by the UT of the SWOL. A white paper in support of a proposed revision to Code Case N-638-x, enabling 48 hour hold initiation after layer 3 installation is provided as Attachment 2.

TABLE 4 MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11	
Appendix VIII, Supplement 11	**PDI Modification**
1.0 SPECIMEN REQUIREMENTS	
(b) The specimen set shall consist of at least three specimens having different nominal pipe diameters and overlay thick nesses. They shall include the minimum and maximum nominal pipe diameters for which the examination procedure is applicable. Pipe diameters within a range of 0.9 to 1.5 times a nominal diameter shall be considered equivalent. If the procedure is applicable to pipe diameters of 24 inches or larger, the specimen set must include at least one specimen 24 inches or larger but need not include the maximum diameter. The specimen set must include at least one specimen with overlay thickness within –0.1 inches to +0.25 inches of the maximum nominal overlay thickness for which the procedure is applicable.	(b) The specimen set shall consist of at least three specimens having different nominal pipe diameters and overlay thick nesses. They shall include the minimum and maximum nominal pipe diameters for which the examination procedure is applicable. Pipe diameters within a range of 0.9 to 1.5 times a nominal diameter shall be considered equivalent. If the procedure is applicable to pipe diameters of 24inches or larger, the specimen set must include at least one specimen 24 inches or larger but need not include the maximum diameter. The specimen set shall include specimens with overlays not thicker than 0.1 inches more than the minimum thickness, nor thinner than 0.25 inches of the maximum nominal overlay thickness for which the procedure is applicable.
(d) Flaw Conditions	
(1) Base metal flaws. All flaws must be cracks in or near the butt weld heat-affected zone, open to the inside surface, and extending at least 75 percent through the base metal wall. Flaws may extend 100 percent through the base metal and the overlay; in this case, intentional overlay fabrication flaws shall not interfere with ultrasonic detection or characterization of the cracking. Specimens containing IGSCC (intergranular stress corrosion cracking) shall be used when available.	(1) Base metal flaws. All flaws must be cracks in or near the butt weld heat-affected zone, open to the inside surface, and extending at least 75 percent through the base metal wall. Intentional overlay fabrication flaws shall not interfere with ultrasonic detection or characterization of the base metal flaws. Specimens containing IGSCC shall be used when available. At least 70 percent of the flaws in the detection and sizing tests shall be cracks and the remainder shall be alternative flaws. Alternative flaw mechanisms, if used, shall provide crack-like reflective characteristics and shall be limited by the following: (a) The use of Alternative flaws shall be limited to when the implantation of cracks produces spurious reflectors that are uncharacteristic of actual flaws. (b) Flaws shall be semi elliptical with a tip width of less than or equal to 0.002 inches.

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TABLE 4
MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11

Appendix VIII, Supplement 11	PDI Modification
(e) Detection Specimens	
(1) At least 20 percent but less than 40 percent of the flaws shall be oriented within +/- 20 degrees of the pipe axial direction. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access. The rules of IWA-3300 shall be used to determine whether closely spaced flaws should be treated as single or multiple flaws.	(1) At least 20- percent but less than 40 percent of the base metal flaws shall be oriented within +/- 20 degrees of the pipe axial direction. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access.
(2) Specimens shall be divided into base and over-lay grading units. Each specimen shall contain one or both types of grading units.	(2) Specimens shall be divided into base metal and overlay fabrication grading units. Each specimen shall contain one or both types of grading units. Flaws shall not interfere with ultrasonic detection or characterization of other flaws.
(a)(1) A base grading unit shall include at least 3 inches of the length of the overlaid weld. The base grading unit includes the outer 25 percent of the overlaid weld and base metal on both sides. The base grading unit shall not include the inner 75 percent of the overlaid weld and base metal overlay material, or base metal-to-overlay interface.	(a)(1) A base metal grading unit includes the overlay material and outer 25 percent of the original overlaid weld. The base metal grading unit shall extend circumferentially for at least 1 inch and shall start at the centerline and be wide enough in the axial direction to encompass one half of the original weld crown and a minimum of 0.50 inch of the adjacent base material.
(a)(2) When base metal cracking penetrates into the overlay material, the base grading unit shall include the overlay metal within 1 inch of the crack location. This portion of the overlay material shall not be used as part of any overlay grading unit.	(a)(2) When base metal flaws penetrate into the overlay material, the base metal grading unit shall not be used as part of any overlay fabrication grading unit.
(a)(3) When a base grading unit is designed to be unflawed, at least 1 inch of unflawed overlaid weld and base metal shall exist on either side of the base grading unit. The segment of weld length used in one base grading unit shall not be used in another base grading unit. Base grading units need not be uniformly spaced around the specimen.	(a)(3) Sufficient unflawed overlaid weld and base shall exist on all sides of the grading unit to preclude interfering reflections from adjacent flaws.

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TABLE 4
MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11

Appendix VIII, Supplement 11	PDI Modification
(b)(1) An overlay grading unit shall include the overlay material and the base metal-to-overlay interface of at least 6 square inches. The overlay grading unit shall be rectangular, with minimum dimensions of 2 inches.	(b)(1) An overlay fabrication grading unit shall include the overlay material and the base metal-to-overlay interface for a length of at least 1 inch.
(b)(2) An overlay grading unit designed to be unflawed shall be surrounded by unflawed overlay material and unflawed base metal-to-overlay interface for at least 1 inch around its entire perimeter. The specific area used in one overlay grading unit shall not be used in another overlay grading unit. Overlay grading units need not be spaced uniformly about the specimen.	(b)(2) Overlay fabrication grading units designed to be unflawed shall be separated by unflawed overlay material and unflawed base metal-to-overlay interface for at least 1 inch at both ends. Sufficient unflawed overlaid weld and base metal shall exist on both sides of the overlay fabrication grading unit to prelude interfering reflections from adjacent flaws. The specific area used in one overlay fabrication grading unit shall not be used in another overlay fabrication grading unit. Overlay fabrication grading units need not be spaced uniformly about specimen.
(b)(3) Detection sets shall be selected from Table VIII-S2-1. The minimum detection sample set is five flawed base grading units, ten unflawed base grading units, five flawed overlay grading units and ten unflawed grading units. For each type of grading unit, the set shall contain at least twice as many unflawed as flawed grading units.	(b)(3) Detection sets shall be selected from Table VIII-S2-1. The minimum detection sample set is five flawed base metal grading units, ten unflawed base metal grading units, five flawed overlay fabrication grading units, and ten unflawed overlay fabrication grading units. For each type of grading unit, the set shall contain at least twice as many unflawed grading units. For initial procedure qualification, detection sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.

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TABLE 4 MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11	
Appendix VIII, Supplement 11	**PDI Modification**
(f) Sizing Specimen	
(1) The minimum number of flaws shall be ten. At least 30 percent of the flaws shall be overlay fabrication flaws. At least 40 percent of the flaws shall be cracks open to the inside surface.	(1) The minimum number of flaws shall be ten. At least 30 percent of the flaws shall be overlay fabrication flaws. At least 40 percent of the flaws shall be open to the inside surface. Sizing sets shall contain a distribution of flaw dimensions to assess sizing capabilities. For initial procedure qualification, sizing sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.
(3) Base metal cracking used for length sizing demonstrations shall be oriented circumferentially.	(3) Base metal flaws used for length sizing demonstrations shall be oriented circumferentially.
(4) Depth sizing specimen's sets shall include at least two distinct locations where cracking in the base metal extends into the overlay material by at least 0.1 inch in the through-wall direction.	(4) Depth sizing specimen sets shall include at least two distinct locations where a base metal flaw extends into the overlay material by at least 0.1 inch in the through-wall direction.
2.0 CONDUCT OF PERFORMANCE DEMONSTRATION	
The specimen inside surface and identification shall be concealed form the candidate. All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate review of unmasked specimens after the performance demonstration is prohibited.	The specimen inside surface and identification shall be concealed from the candidate. All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited. The overlay fabrication flaw test and the base metal flaw test may be performed separately.
2.1 Detection Test	
Flawed and unflawed grading units shall be randomly mixed. Although the boundaries of specific grading units shall not be revealed to the candidate, the candidate shall be made aware of the type or types of grading units (base or overlay) that are present for each specimen.	Flawed and unflawed grading units shall be randomly mixed. Although the boundaries of specific grading units shall not be revealed to the candidate, the candidate shall be made aware of the type or types of grading units (base metal or overlay fabrication) that are present for each specimen.

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TABLE 4
MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11

Appendix VIII, Supplement 11	PDI Modification
2.2 Length Sizing Test	
(d) For flaws in base grading units, the candidate shall estimate the length of that part of the flaw that is in the outer 25 percent of the base wall thickness.	(d) For flaws in base metal grading units, the candidate shall estimate the length of that part of the flaw that is in the outer 25 percent of the base metal wall thickness.
2.3 Depth Sizing Test	
For the depth sizing test, 80 percent of the flaws shall be sized at a specific location on the surface of the specimen identified to the candidate. For the remaining flaws, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	(a) The depth sizing test may be conducted separately or in conjunction with the detection test. (b) When the depth sizing test is conducted in conjunction with the detection test and the detected flaws do not satisfy the requirements of 1.1(f), additional specimens shall be provided to the candidate. The regions containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region. (c) For each separate depth sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.

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TABLE 4
MODIFICATIONS TO APPENDIX VIII, SUPPLEMENT 11

Appendix VIII, Supplement 11	PDI Modification
3.0 ACCEPTANCE CRITERIA	
3.1 Detection Acceptance Criteria	
Examination procedures, equipment, and personnel are qualified for detection when the results of the performance demonstration satisfy the acceptance criteria of Table VII-S2-1 for both detection and false calls. The criteria shall be satisfied separately by the demonstration results for base grading units and for overlay grading units.	a) Examination procedures are qualified for detection when; 1) All flaws within the scope of the procedure are detected and the results of the performance demonstration satisfy the acceptance criteria of Table VII-S2-1 for false calls. (a) At least one successful personnel demonstration has been performed meeting the acceptance criteria defined in (b). (b) Examination equipment and personnel are qualified for detection when the results of the performance satisfy the acceptance criteria of Table VII-S2-1 for both detection and false calls. (c) The criteria in (a), (b) shall be satisfied separately by the demonstration results for base metal grading units and for overlay fabrication grading units.
3.2 Sizing Acceptance Criteria	
(a) The RMS error of the flaw length measurements, as compared to the true flaw length, is less than or equal to 0.75 inch. The length of base metal cracking is measured at the 75 percent through-base-metal position.	(a) The RMS error of the flaw length measurements, as compared to the true flaw lengths, is less than or equal 0.75 inch. The length of base metal flaws is measured at the 75 percent through-base-metal position.
(b) All extensions of base metal cracking into the overlay material by at least 0.1 inch are reported as being intrusions into the overlay material.	This requirement is omitted.
(c) The RMS error of the flaw depth measurements, as compared to the true flaw depths, is less than or equal to 0.125 inch.	(c) The RMS error of the flaw depth measurements, as compared to the true flaw depths, is less than or equal to 0.125 inch

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RRM-02-05, BC04-1003, Develop New Code Case to Address Inconel Weld Overlay on Various Materials, SIR-05-030, Rev. 0, Effect of Chromium Content on Nickel-base Alloy SCC Resistance

Note: Attachment 1 is referenced on page 9, Table 2: Design / Material / Nondestructive Examination, Modifications to Code Case N-504-2 and ASME Section XI, Appendix Q.

1. Introduction

This evaluation provides a technical basis to establish a minimum chromium content for an overlay layer to be considered resistant to Inter Granular Stress Corrosion Cracking (IGSCC) in boiling water reactors (BWR) environment as well as resistant to Primary Water Stress Corrosion Cracking (PWSCC) in the pressurized water reactors (PWR) environment. Experimental work was performed in the 1980's to study crack initiation in BWR environments for creviced Alloy 600 and its filler alloys, 82 and 182. In addition, field experience on the use of this family of alloys has been good, absent a crevice, in BWR service. More recently work has been done by the Japanese to develop a stress corrosion resistivity index (SCRI) [8].

The only well established correlation between primary water stress corrosion cracking (PWSCC) propensities and nickel-based alloys and weld metal composition is the chromium content of the alloy [1]. However, there have been very few systematic studies to determine the minimum chromium content for PWSCC mitigation in either wrought materials or weld metals. Most studies have involved a straightforward comparison of Alloy 600 with 14-17% chromium and Alloy 690 with 28-31% chromium with no testing of custom nickel-chromium-iron alloys whose chromium content falls in between these two alloys. This absence creates a chromium composition gap between the susceptible Alloy 600/182/82 and very resistant Alloy 690/152/52.

Table 1-1 presents the nominal chemical compositions of nickel-base weld metals plus reference wrought Alloys 690 and 600 for each weld metal, i.e., Alloys 52, 152 and 72 for Alloy 690 and Alloys 82, 182, and 132 for Alloy 600 [2-5]. Based on chromium content, it would be anticipated that weld metals Alloys 52, 152 and 72 would be the most PWSCC resistant and this hypothesis has been verified by experiment. It is noted that Alloy 52M has the same chromium content as Alloy 52 and should be considered equivalent. Alloy 52M is a variant of Alloy 52 having increased Niobium (Nb) to improve weldability.

2. Discussion

2.1. Investigations of IGSCC in a BWR Environment

The relative susceptibilities of wrought Alloys 600 and 690 and weld metals Alloys 52 (R-127), 152 (R-135), 82 and 182 to IGSCC in pure or simulated resin intrusion BWR environments at 550° F have been investigated [6, 7]. Constant Extension Rate Test

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(CERTs) for IGSCC initiation evaluations were conducted in high purity water containing 200 ppb or 8 ppm dissolved oxygen for uncreviced specimens and 16 ppm dissolved oxygen for graphite wool/nickel foil creviced specimens. Uncreviced Alloys 600, 690, 82 and 182 demonstrated resistance to IGSCC in oxygenated environments (no cracking). Creviced Alloys 600 and 182 did suffer IGSCC and Inter Dendritic Stress Corrosion Cracking (IDSCC), respectively, while creviced Alloy 82 suffered Inter Granular Attack (IGA). Creviced Alloy 690 exhibited no susceptibility to IGSCC initiation in this CERT study. Types 316 NG and 308L stainless steel and Alloys 72, 52 (R-127) and 152 (R-135) were also found to resist IGSCC in this investigation.

Similar to the CERT studies described above, twenty constant load specimens of the same materials were tested at 1.25 and 1.5 times the 550 °F yield stress in high purity water containing 200 ppb or 8 ppm dissolved oxygen for uncreviced specimens and 16 ppm dissolved oxygen for graphite wool/nickel foil creviced specimens. Although no IGSCC was detected during the 8200-hour exposure, post-test examination of the specimens revealed "grooving" of machining marks on the specimen's surface. The grooves seemed to be the result of localized attack of machining marks and resembled linear crevices. A number of cracks <1 mil deep were associated with the grooving. Since the cracking was only identified with the grooves and not the smooth surface, it appeared that IGSCC susceptibility was related only to the presence of the crevice. Surface grooves accompanied by small cracks were present on all Alloy 600 or 182 specimens. No IGSCC of Alloy 690 or 82 was identified. Furthermore, neither cracks nor grooves were identified underneath the graphite crevice on the Alloy 690 specimens.

2.2. Stress Corrosion Resistivity Index (SCRI)

The SCRI was developed based on the results of creviced bent beam (CBB) tests where the beneficial effect of chromium content on IGSCC resistance is indeed factored into the materials resistance ranking [8]:

$$SCRI = \%Cr + 5[\%Nb] + 10[\%Ti] - 116.5[\%C]$$

Cr, Nb, Ti and C are individual weight percentages of these alloying elements.

To assure strong resistance to IGSCC in the BWR environment, a criterion of SCRI >34 is used.

If one calculates the SCRI for Alloy 82 and Alloy 182, the respective values are 32.85 versus 22.85. This is further evidence of the superior resistance to IGSCC for Alloy 82. Alloy 52 and Alloy 152 produce even higher values. The Alloy 52M variant of Alloy 52 has higher Nb with the same Cr level and thus results in even higher SCRI ranking.

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Chromium Content "Threshold" for PWSCC Resistance

To determine the "threshold" chromium content of a nickel-base weld metal to mitigate PWSCC, it is necessary to review the limited test results obtained in PWR environments and also examine the results from tests on wrought nickel alloys. Note that some information was obtained in oxygenated environments. However, these data are also largely characterized by Alloy 600 versus Alloy 690 investigations.

The PWSCC resistance of nickel-based weld metals with various chromium contents ranging from approximately 15% to 30% chromium has been evaluated [1,9]. Testing was performed on U-bend specimens exposed to impurity doped steam and primary water. Alloy 182, with approximately 14.5% chromium, was the most susceptible to PWSCC while Alloy 82 with 18–20% chromium took three or four times longer to initiate PWSCC. For example, PWSCC appeared in one of the Alloy 182 specimens at the first test interruption after 500 hours of exposure and the second specimen cracked after 1,500 hours. The first Alloy 82 specimen cracked after 2,000 hours and all were cracked at 6,500 hours. For chromium contents between 21 and 22%, no PWSCC initiation was observed for tests lasting between 18,000 and 27,000 hours. This was also the case for Alloys 52 and 152 that have approximately 30% chromium. These results indicated that weld metals having 30% chromium were very resistant to PWSCC. Thus a "threshold" for PWSCC resistance appears to exist somewhere between 21% and 30% chromium.

The above PWSCC behavior for nickel base alloys is consistent with test results on solution annealed wrought Ni-Cr-Fe base alloys (i.e., higher chromium content provides more PWSCC resistance) [1, 10]. Constant load tests were used to evaluate the effect of chromium content on the PWSCC susceptibility of wrought Ni-Cr-Fe alloys in 680°F (360°C) water. The constant load specimens were loaded at an applied stress 2.4 times the 0.2% proof stress. Figure 1-1 clearly demonstrates that the PWSCC initiation susceptibility decreased as the chromium content increased from approximately 1% to over 15% [1,10]. Unfortunately, this study did not evaluate higher chromium alloys (e.g., 18-22% Cr).

To possibly identify a chromium content "threshold" for PWSCC mitigation, it is necessary to discuss a more fundamental mechanistic experiment. Alloy 600 obtained from a vessel head penetration containing 16.05% chromium and Alloy 690 obtained from a steam generator tube plug containing 29.14% chromium were tested in simulated PWR primary water (1200 ppm B and 2 ppm Li) at 680 °F (360 °C) under electrochemical conditions corresponding to Ni/NiO equilibrium potential. The Ni/NiO equilibrium potential corresponds to a maximum susceptibility of Alloy 600 to the initiation of PWSCC [11]. The resulting oxidized structures (corrosion scale and underlying metal) were examined by

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transmission electron microscopy (TEM) using cross section specimens. The oxide on Alloy 600 consisted of small 50 nm Ni(Cr,Fe)2O4 and large 200 nm NiFe2O4 crystallite oxides, while the oxide on Alloy 690 consisted of small 30 nm Ni(Cr,Fe)2O4 and large 100 nm NiFe2O4 crystallite oxides. Alloy 690's oxide film was 50% thinner than Alloy 600's oxide film, which is characteristic of a more rupture resistant and protective oxide film.

For both alloys, energy dispersive X-ray spectroscopy (EDX) analysis revealed a chromium rich oxide layer where the underlying metal was chromium depleted. In both alloys a non-compact external oxide scale was identified, and a thin continuous inner layer rich in chromium was observed. Consequently, a chromium depleted zone just in the underlying alloy was observed. For Alloy 600, the particular importance of the depletion was found to be also associated with the presence of oxygen. Chromium oxide was even found in a triple grain boundary as far as 3 µm from the metal-oxide interface.

These test results tend to support the crack initiation mechanism induced by intergranular oxidation of the chromium-depleted zones [12]. Assuming that this mechanism is operative in these exposure conditions, it is then possible to explain, at least in terms of local reactivity, the effect of the carbide precipitation sites (transgranular- intergranular) on the crack initiation resistance of Alloy 600 exposed to PWR experimental conditions. Most importantly for this evaluation, when considering Alloy 690, despite its chromium depletion from 29% to 17% in the underlying alloy, the chromium content remains sufficiently high that an intergranular oxidation mechanism cannot be operative because the chromium content is greater than the 10% chromium needed to mitigate intergranular oxidation [13]. Thus, the excellent resistance of Alloy 690 to PWSCC can be explained. In contrast, Alloy 600 suffers PWSCC because its chromium content is also reduced by approximately 11 to 12% from a starting level of 16%. This reduces the chromium level to 5% - a level that is below the 10% chromium "threshold" for internal oxidation.

The oxide mechanistic study results suggest that a chromium depletion of 11 to 12% occurs in nickel-base wrought alloys exposed to PWR environments under environmental conditions that clearly support and promote PWSCC. Since the internal oxidation "threshold" for these alloys is approximately 10% chromium, then an additional 11 to 12% chromium should be present in the starting material to mitigate PWSCC. This suggests that an initial concentration of 21 to 22% chromium should be sufficient to mitigate PWSCC. This "threshold" value is consistent with the U-bend test results that indicated weld metals having 22 and 30% chromium were very resistant to PWSCC. The results from the above Alloy 82 studies suggest that 18 to 20% chromium is insufficient to mitigate cracking. However, since the required chromium content to mitigate cracking must exceed 22%, and

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the Alloy 82 specification permits up to 22% chromium [1], then the required chromium required to mitigate cracking must exceed 22%.

3. Conclusion

3.1. BWR Applications

Testing and field service has shown that Alloy 600, Alloy 82 and 182 are all reasonably resistant to IGSCC. In the creviced condition test results and field service have shown that Alloy 600 and Alloy 182 have cracked where Alloy 82 has remained uncracked. The SCRI has shown that Alloy 82 is more resistant than Alloy 182 or Alloy 600. To provide some IGSCC margin, it is recommended that a minimum of 20% chromium be present in the first overlay layer considered resistant to IGSCC.

3.2. PWR Applications

Considering the paucity of data and fragmentary nature of the available data on the effects of chromium on PWSCC, the relevant available test data plus a mechanistic analysis has been combined to suggest that the "threshold" chromium content for PWSCC mitigation will be somewhere greater than 22% chromium. Therefore a conservative estimate of the chromium threshold to mitigate PWSCC is 24%. This level of chromium would be considered as a minimum in the first overlay layer to be considered resistant to PWSCC.

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Table 1-1

Compositions of Nickel-base Alloys and Weld Metals

Alloying Element	Alloy 690 (Nuclear) [2]	Alloy 52 filler metal [3]	Alloy 152 electrode) [3]	Alloy 72 filler metal (nominal) [4]	Alloy 600 [5]	Alloy 82 filler metal [3}	Alloy 182 electrode [3]	Alloy 132 electrode [1-3]
Ni + Co	58.0 min.	Balance	Balance	55	72.0 min.	67.0 min.	59.0 min.	62.0 min
C	0.04 max.	0.04 max.	0.05 max.	0.05	0.15 max.	0.10 max.	0.10 max.	0.08 max
Mn	0.5 max.	1.0 max.	5.0 max.	0.1	1.00 max.	2.5-3.5	5.0-9.5	3.5 max
Fe	7.0-11.0	7.0-11.0	7.0-12.0	0.2	6.00-11.00	3.0 max.	10.0 max.	11.0 max
S	0.015 max.	0.015 max.	0.015 max.	0.008	0.015 max.	0.015 max.	0.015 max.	0.02 max
Si	0.50 max.	0.50 max.	0.75 max.	0.1	0.50 max.	0.50 max.	1.0 max.	0.75 max
Mo		0.50 max.	0.50 max.					
Cu	0.50 max.	0.30 max.	0.50 max.	0.20	0.50 max.	0.50 max.	0.50 max.	0.50 max
Cr	28.0-31.0	28.0-31.5	28.0-31.5	44.0	14.0-17.0	18.0-22.0	13.0-17.0	13.0-17.0
Ti		1.0 max.	0.50 max.	0.6		0.75 max.	1.0 max.	
Al		1.10 max.	0.50 max.					
P		0.020 max.	0.030 max.			0.030 max.	0.030 max.	0.03 max
Nb + Ta		0.10 max.	1.0-2.5			2.0-3.0	1.0-2.5	1.5-4.0
Al + Ti		1.5 max.						
Others		0.50 max.	0.50 max.			0.50 max.	0.50 max.	0.50 max

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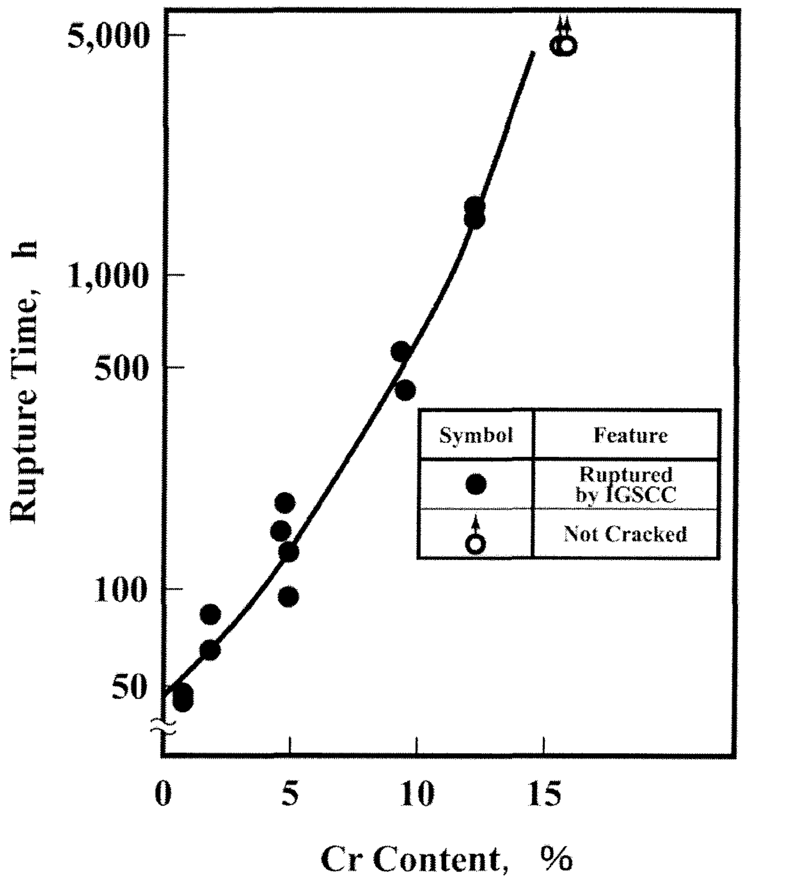

Figure 1-1. Effect of Chromium Content on the Stress Corrosion Cracking Resistance of Solution Annealed Ni-Cr-Fe Alloys [7]

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4. References

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ATTACHMENT 2

RRA 05-08, BC06-134 Technical Basis Paper

N-638-x, Ambient Temperature Temperbead Welding: Begin 48 Hour Hold After 3rd Layer Completion

Note: Attachment 2 is referenced on page 12, Table 3: Ambient Temperature Temp Bead Welding, Modifications to Code Case N-638-1

Background:

Ambient temperature temperbead welding eliminates elevated-temperature preheat and post-soak when conventional temperbead welding is impractical. Extensive nuclear industry experience continues to demonstrate its viability, safety, and effectiveness.

Historically, temperbead welding rules impose a 48 hour delay between welding completion and final Non-Destructive Examination (NED). The 48 hour delay serves solely to provide time for delayed hydrogen cracking before final NDE is performed. Early temperbead welding employed welding processes that were primarily flux-based and were, therefore, known to be susceptible to hydrogen pick-up. The 48 hour delay provided an effective measure of weld safety; necessary because of the moisture inherent in welding fluxes.

N-638 retains the conventional 48 hour NDE delay. N-638, however, excludes flux-based processes; it relies solely on the Gas Tungsten Arc Welding (GTAW) machine welding process. This process has been proven, through extensive laboratory testing, to consistently deliver low-hydrogen weld deposits. Testing includes welds deposited in fog chambers (≈95% humidity) using high-moisture argon shield gas, wherein deposits consistently meet "very low" hydrogen criteria (i.e., <1.0 ml/100g H_2). These 'worst case' conditions are far more severe than will be encountered in field applications. Still, test samples demonstrated that the most severe environments achievable yielded hydrogen levels too low to support delayed hydrogen cracking (Ref. EPRI Report GC-111050). Filler wire is another potential hydrogen source; however, the solid bare wire used for GTAW is not considered susceptible to moisture absorption. Test results prove, therefore, that the GTAW environment is essentially impervious to hydrogen from both internal and external sources. The inherently low hydrogen contents of GTAW machine weld deposits, coupled with extensive crack-free industry experience in their application, enables limited relaxation of the mandatory 48 hour NDE delay period.

Description of Change:

This action retains the 48 hour NDE hold, but revises the time at which the 48 hour hold time is initiated. Current rules require hold initiation after weld completion, and after the weldment has cooled to ambient temperature. The proposed change revises hold initiation time such that the 48 hour hold begins immediately after completion of the third weld layer.

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Justification for Change:

Industry experts generally accept the inherent low-hydrogen characteristics of GTAW machine welding. These inherently low hydrogen characteristics enable consistently low-hydrogen deposits even when external sources of hydrogen are present during welding. Still, external contaminants may be present during welding, and laboratory conditions cannot effectively simulate every potential hydrogen source. The 48 hour NDE hold is a conservative means of hydrogen assessment, since it evaluates hydrogen's effects, rather than its presence. In so doing, the 48 hour NDE hold evaluates hydrogen introduced through any number of sources, including surface oxides, residues, and other base metal contaminants.

While the potential for external contaminants during temperbead welding cannot be completely ruled out, the extent of these contaminants can be minimized. Regarding surface cleanliness prior to welding, N-638 requires a liquid penetrant examination before weld initiation. As a result, the weld area and adjacent base materials are cleaned to bright, shiny metal. This cleaning removes potential hydrogen sources, and demonstrates substrate soundness, which ensures that external sources of hydrogen are effectively minimized. N-638 further minimizes HAZ exposure to external contaminants by stipulating that only the first weld layer contacts the base material(s). The initial weld layer, therefore, constitutes the only weld layer in which unknown surface contaminants may be encountered. All subsequent layers contact only clean, newly deposited weld material. Since the initial weld layer constitutes the primary opportunity for hydrogen ingress to the crack-susceptible coarse-grained heat affected zone, it is reasonable to tie initiation of the 48 hour hold to completion of this layer, instead of to overall weld completion.

Contaminant exposure is one concern; another is welding's proximity to the HAZ. Only welding performed in contact with, or in close proximity to the HAZ has the potential to introduce hydrogen into the hardened HAZ. In temperbead welding, each successive layer provides a progressively decreasing opportunity for HAZ hydrogen introduction, because of each successive layers' decreasing proximity to the HAZ. Only the first weld layer contacts base material, and the second and third layers extend along the full length of this first layer. When these three layers are installed, the HAZ is considered to be effectively tempered. Existing N-638 methodology, therefore, identifies these three layers as an effective, protective barrier between subsequent weld layers and the HAZ. This protective barrier not only insulates the HAZ from additional tempering, but also effectively protects the HAZ from additional hydrogen introduction.

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N-638-x, Ambient Temperature Temperbead Welding: Begin 48 Hour Hold After 3rd Layer Completion

Test data clearly demonstrates that GTAW machine welds installed using N-638 methodology are likely to free of damaging levels of hydrogen be completely free of hydrogen. Nevertheless, let us assume that some external contaminant was not removed from the base metal surface and serves as a hydrogen source. Further, let us assume that the GTAW processes' inherent propensity to protect the weld pool from free hydrogen somehow fails, and hydrogen is introduced into the weld deposit. In this situation, HAZ hydrogen exposure would occur during installation of the first weld layer. This layer, because it is the only layer in direct contact with the base metal contaminants and since it is the only layer that directly contacts the HAZ, is considered to have the greatest potential contribution to hydrogen cracking. For the second and third (tempering) weld layers, the likelihood of additional hydrogen introduction is negligible. For the fourth through final weld layers, the likelihood of introducing additional HAZ hydrogen is virtually nonexistent. Because the proposed change to N-638 is limited to austenitic filler materials, and because austenitic filler materials have a much greater affinity for hydrogen than carbon steel base metals, hydrogen can be assumed to move rapidly away from the HAZ through the austenitic material matrix, further reducing chances of HAZ cracking.

Weldment Temperatures During Ambient Temperature Temperbead Welding:

When conventional GTAW temperbead welding is employed, HAZ hydrogen is mitigated either by imposing a 48 hour NDE delay, or by performing a 450°F to 550 °F post-soak for two hours. Ambient temperature temperbead welding effectively simulates these alternatives during installation of the fourth and subsequent weld layers, as follows:

Water Backed Applications: Ambient temperature temperbead welding is often performed with water backing, wherein the base metal acts as an infinite heat sink during welding. This heat sink contributes to a moderate HAZ temperature, particularly as the fourth and subsequent weld layers are installed. This reduced HAZ temperature effectively enables 'time at ambient temperature' to occur while the fourth and subsequent weld layers are installed. The proposed change enables credit to be taken for this 'time at ambient temperature', even though it occurs while welding is in process.

Non-Water Backed Applications: As ambient temperature temperbead methodology has matured, changes in conventional temperbead welding have occurred. These changes recognize that an elevated temperature post-soak (typically 450°F to 550 °F for 2 hours) accelerates hydrogen dissipation. Current Code rules recognize, therefore, that an elevated temperature post-soak is an effective alternative to the 48 hour NDE delay period (Ref. IWA-4624, 2004 Edition). Ambient temperature temperbead welding may, in some instances, be performed without water backing. In these instances, the 350°F interpass

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temperature imposed by N-638, combined with the effective heat sink provided by the vessel or nozzle to be welded, typically contributes to low HAZ temperatures during welding. In some instances, however, smaller weldments may experience temperature increases. In these applications, moderate HAZ temperature increases serve to accelerate hydrogen dissipation, reducing the risk of delayed hydrogen cracking. Since hydrogen sources are essentially nonexistent for the second and subsequent layers, this accelerated dissipation effectively mitigates the risk of hydrogen cracking. Hydrogen dissipation is improved when austenitic filler materials are used, as is the case for all welding within the scope of this proposed Action. Hydrogen dissipates much more easily through the austenitic matrix of these filler materials, further reducing the propensity for high hydrogen levels in the hardened carbon steel HAZ.

Both with and without water backing, therefore, ambient temperature temperbead welding contains process controls that effectively moderate adverse hydrogen effects during weld installation. These factors, when considered in light of the inherent low-hydrogen characteristics of GTAW machine weld deposits, help to explain why not a single instance of delayed hydrogen cracking has been identified in any ambient temperature temperbead repair performed to date.

Summary:

This action recognizes that welding occurs in a variety of locations, and that sources of external contamination cannot always be completely quantified and/or eliminated. Acknowledging these variables, this action retains the existing 48 hour NDE hold, but enables it to start immediately upon completion of the third weld layer. The proposed change thereby provides an effective method that delays final NDE sufficiently to detect any delayed hydrogen cracking. Concurrently, this action acknowledges the inherently low susceptibility of ambient temperature temperbead welding to delayed hydrogen cracking. The result is an effective compromise that maintains safety, yet enables application of recognized science to reduce unwarranted costs and schedule delays associated with the existing 48 hour requirement.