ENCLOSURE 2

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EVALUATION AND REPAIR OF FLAW INDICATIONS IN THE FEEDWATER "A" SAFE-END TO EXTENSION WELD AT HATCH UNIT 2

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1.0 INTRODUCTION

During ISI as a part of the Spring 1991 refueling outage at the Georgia Power Company (GPCO) Hatch Unit 2, flaw indications were identified in the reactor vessel nozzle safe-end to extension piece butt weld on one feedwater line. The affected location is outboard of the safe-end, and so is remote from the nozzle and vessel. The weld material is Inconel 182, and the base metal on either side is Inconel 600. The identified flaws are axially oriented, and appear to be essentially limited to the weld material. Although the cause of the observed indications is not well defined, it is assumed that they are due to intergranular stress corrosion cracking (IGSCC), since propagation due to this mechanism is expected to conservatively bound that due to other possible mechanisms, such as thermal fatigue and crevice corrosion.

Structural Integrity Associates (SI) was contracted to evaluate the observed indications and to design a weld overlay repair for the affected location. The evaluation and repair were performed in accordance with the requirements of NUREG-0313, Revision 2 [1], with additional guidance in the area of IGSCC propagation in Inconel materials taken from work performed for the Electric Power Research Institute (EPRI) [2].

The evaluation determined that because of the observed depths of the indications, repair of some sort was necessary, even though the observed axially oriented flaws would not present a structural adequacy concern even if through the component wall. Although the NUREG allows a two-layer "leakage barrier" type repair for locations with axial flaws, discussions between GPCO and SI determined that a "standard" weld overlay design based upon an assumed 360° through-wall circumferential flaw would conservatively be applied. In addition, allowance for potential flaw propagation into the overlay material was included in the design as an additional conservatism.

This report summarizes the evaluation and repair design activities performed, and includes evaluation and acceptance of the as-built repair. An evaluation of the effects of the repair on other welds in the system due to weld shrinkage is also included.

2.0 FLAW DESCRIPTION

Weld 2B21-1FW-12AA-9 contains three identified flaws which are axially oriented and essentially confined to the Inconel 182 weld material [3]. The flaws are all contained in approximately 2 inches of circumference. The girth weld material is Inconel 182 weld metal, and the base material on either side of the weld in Inconel 600.

These flaws do not present a significant structural concern, even if through the original component wall, since they are axially oriented. However, repair was considered to be necessary based upon guidance in NUREG-0313, Revision 2 [1]. Paragraph 4.4.2 notes that axial flaws will generally require some form of repair. Further, because of the observed depth of the flaws (70-80% of wall), repair was prudent in any event, since they violated the allowable flaw depth defined in ASME Section XI, IWB-3641 [4].

The flaws were evaluated as if they resulted from IGSCC, since this conservatively bounds behavior due to other possible causes, such as thermal fatigue or fabrication.

3.0 MATERIALS AND GEOMETRY

The identified flaws are located in the safe-end to extension piece weld (weld 9 in Figure 1). This weld is remote from the feedwater nozzle, and joins two Inconel 600 components. The weld itself was fabricated with Inconel 182 material. No low alloy steel is affected by the repair. Figure 1 illustrates the geometry of the location.

The repair is not located in the region of the thermal sleeve annulus, but in the pipe safe-end region where the inside surface is in contact with normal feedwater flow.

4.0 WELD OVERLAY REPAIR DESIGN

4.1 Design Basis

The design basis for this repair is the NUREG-0313, Revision 2 "Standard Weld Overlay" which is based upon an assumed 360° through-wall circumferential flaw [1]. This assumption is very conservative for the observed flaws. The weld overlay repair design is presented in Figure 2.

The design contains several features which are unique to the particular location being evaluated. These include:

1. The flaws are located on the feedwater inlet piping, upstream of the thermal sleeve annulus. This distinguishes the location from other feedwater flaws that have recently been detected in the industry. The inside surface is exposed to feedwater flow so it is unlikely that a crevice chemistry will be established in the bulk environment to drive the flaws.

2. The butt weld material is Inconel 182, which has been shown to be susceptible to IGSCC. The base metal on either side is Inconel 600 material. The repair is made using ASME ERNiCr-3 metal (a material with the same chemical composition as that of Inconel 82) deposited by the GTAW process.

3. The flaws appear to be largely confined to the weld metal.

4. Because of the flaw location, the repair did not impact any carbon steel material, and neither temper bead processes nor post weld heat treatment was required.

The SI computer program pc-CRACK [5] was used to determine the required weld overlay repair thickness necessary to meet the

NUREG-0313 design basis. The pc-CRACK results are summarized in Table 1. The analysis used the following input stress data:

$$P_m = 6869 \text{ psi}$$
$$P_b = 0 \text{ psi}$$
$$S_m = 23300 \text{ psi}$$
$$t_{wall} = 1.2 \text{ inches}$$

The use of P_m and P_b above conservatively bound the calculated hoop membrane stress and the calculated axial membrane plus bending stresses (which were determined from force/moment data provided in Reference 6). The above S_m is appropriate since all materials in this location (base metal, girth weld metal, overlay metal) are Inconel-type materials.

The design thickness for the weld overlay repair is 0.4 inches for structural adequacy. This thickness is adequate to provide a standard weld overlay repair for a 360° through-wall circumferentially oriented flaw. In addition, allowance was included to account for the worst case assumption of continued flaw growth into the repair. The allowance was determined by assuming continued growth at the rate defined by:

$$da/dt = 1.078 \times 10^{-8} K^{2.26}$$

from Reference 2. For the purpose of this flaw growth analysis, no benefit due to residual stress improvement as a result of the repair was assumed. In other words, a residual stress distribution of zero was assumed. We believe that this assumption is conservative. However, future inspections of this location will determine whether growth continues subsequent to the repair.

4.2 Allowance for Continued Flaw Growth

As noted above, the design was based upon the NUREG-0313 "Standard Weld Overlay". In addition, the design includes an allowance for continued crack growth into the weld overlay. There is some possibility of IGSCC propagation in Inconel 82-type material in sulfur bearing environments. Such environments are not anticipated at this location in the feedwater system, due to the high normal feedwater flow and excellent water quality in the plant. However, for additional conservatism in the present design, crack growth in worst case environments is considered in the repair design and analysis. It should be noted that NUREG-0313 considers Inconel 82 material to be resistant to IGSCC, so the design basis for the present repair is conservative with respect to NUREG-0313 requirements.

The design thickness required to meet the Standard Weld Overlay requirements for this location is 0.4 inches. The allowance for continued flaw growth is 0.2 inches. This allowance may be considered to be sacrificial material to guarantee that the structural portion of the repair (0.4 inches) is not degraded in the unlikely event that the observed flaws continue to propagate into the applied weld material.

For the purpose of post repair inspection of the weld overlay, it is only necessary to demonstrate that the structural portion of the repair (0.4 inches) is intact.

4.3 Overlay Repair Length

The overlay length is blended into the safe-end taper on that side of the repair as noted in Figure 2. On the pup piece side, the overlay is designed to extend to a full thickness length of at least 2.5 inches from the butt weld centerline. This length is determined based upon a calculation of $0.75\sqrt{Rt}$.

4.4 Welding Sequence

Because of the thermal sleeve junction on the inside surface and because of the flaws themselves, the welding was sequenced such that all passes began at the safe-end taper, and proceeded toward the feedwater piping end of the repair (in other words, the welding progressed upstream relative to feedwater flow). This sequence minimized the resulting stresses in the region of the thermal sleeve junction. On the safe-end side of the repair, the weld overlay was blended into the transition region, to minimize stress concentration in the region.

4.5 Comparison of Design and As-Built Data

Structural Integrity Associates has reviewed the as-built data [7] for the subject repair, and has determined that the design basis for the repair has been met by the repair. The required structural reinforcement thickness of 0.4 inches is met at all measured locations. The allowance for continued flaw propagation (0.2 inches) is met in the vicinity of the observed flaws in particular, and the average of all thickness measurements exceeds the design thickness of 0.6 inches (which includes both structural material of 0.4 inches and growth allowance of 0.2 inches). Two locations have reported thicknesses of slightly less than the 0.6 inches value (0.57 inches and 0.58 inches), but this is not significant and in no way invalidates the repair. These locations are remote from the observed flaw location.

5.0 EFFECTS ON NEARBY WELDS

Weld overlay repairs have the potential for producing steady state secondary stresses at other welds in the piping system, due to the shrinkage which the repair experiences upon cooling. In such repairs applied to recirculation systems, the highest of these stresses occur in 12 inch pipe locations where the component wall thickness is generally 0.6 inches to 0.75 inches. Overlay repairs applied to such 12 inch piping generally exhibit axial shrinkage in the vicinity of 0.25 inches. In larger pipe (e.g., 28 inch OD with 1.25 inches or greater wall thickness), measured axial shrinkage in an applied weld overlay repair is generally of the order of 0.1 inches or less.

5.1 Axial Shrinkage Effects

The location to which the weld overlay was applied in the Hatch Unit 2 feedwater line has a measured wall thickness of 1.2 inches prior to overlay, and therefore would be expected to produce a measured shrinkage in line with the large pipe values experienced on the recirculation system. This turns out to be the case.

The reported axial shrinkage due to the repair is an average of 0.078 inches. The only welds potentially affected by this shrinkage are in-line with the repair, so any imposed stress on these welds will be axial rather than bending. (The bending stresses are dominant in the recirculation system repairs.) Most of the minor shrinkage experienced during the feedwater repair will be accommodated by flexure of the relatively flexible feedwater riser piping, so no significant stress is expected in any of the Inconel or Inconel to carbon steel welds adjacent to the repair location.

A simple finite element piping analysis of the feedwater riser and safe-end region was performed to confirm this conclusion. The finite element model is shown in Figure 3. The resulting stresses at each of the Inconel weld joints in this line are shown in Table 2. These stresses are not expected to have a significant effect on these welds.

5.2 Radial Shrinkage Effects

Because of the concern regarding potential effects of radial shrinkage on the thermal sleeve to safe-end junction near the repair location, radial shrinkage due to the application of the repair was also measured by GPCO. The measured radial shrinkage was 0.002 inches to 0.004 inches, which is not significant. No radial shrinkage related stress is anticipated at the repair location, or at the thermal sleeve to safe-end junction.

6.0 CONCLUSIONS

The weld overlay design presented here conservatively repairs the observed flaws in weld 2B21-1FW-12AA-9 and meets the requirements of the NUREG-0313, Revision 2 "Standard Weld Overlay Repair". The conservatisms inherent in this design are:

1. The design thickness of 0.6 inches is based upon maintaining a structural overlay thickness of 0.4 inches at the end of two operating cycles, assuming worst case continued propagation by IGSCC. Postulated IGSCC propagation is expected to bound possible propagation by other recognized mechanisms. The 0.4 inches thickness is sufficient to meet the requirements of the NUREG-0313 standard weld overlay. Actual continued flaw growth if any will be monitored during future inspections.

2. The observed flaws are axially oriented and appear to be confined to the weld metal. These flaws present no structural concern, even if they were through the original component wall. The design basis flaw was taken as a through-wall, 360° circumferential flaw.

The shrinkage observed during the application of the repair is minimal in both the axial and radial directions. The repair is expected to have insignificant effect on adjacent and nearby welds in the feedwater system. In particular, no affect at the nozzle to safe-end joint is anticipated.

7.0 REFERENCES

1. Generic Letter 88-01, NUREG-0313, Revision 2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping", January, 1988.
2. EPRI NP-7085-D "Inconel Weld-Overlay Repair for Low Alloy Steel Nozzle to Safe-End Joint", January, 1991.
3. Southern Nuclear Operating Company Indication Notification (INF) I91H2040, April 12, 1991 and GPCO DCR2H91-072.
4. ASME Boiler & Pressure Vessel Code, Section XI, 1986 Edition.
5. SI Program pc-CRACK, Version 2.0, August 1989.
6. Stress Data provided by Georgia Power Company.
7. As-built Data provided by Georgia Power Company.

Table 1

Structural Reinforcement Design for Hatch Unit 2 Feedwater Safe-End

WALL THICKNESS = 1.2000 INCHES
MEMBRANE STRESS = 6869.0000 PSI (HOOP)
BENDING STRESS = 0.0000
STRESS RATIO = 0.2948
ALLOWABLE STRESS = 23300.0000 PSI

	L/CIRCUMFERENCE					
	0.00	0.10	0.20	0.30	0.40	0.50
FINAL A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
REINFORCEMENT THICK.	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000

Table 2

Shrinkage Stresses at Unrepaired Inconel Welds

Weld	Stress (psi)
7	292
8	341
10	325
11	335

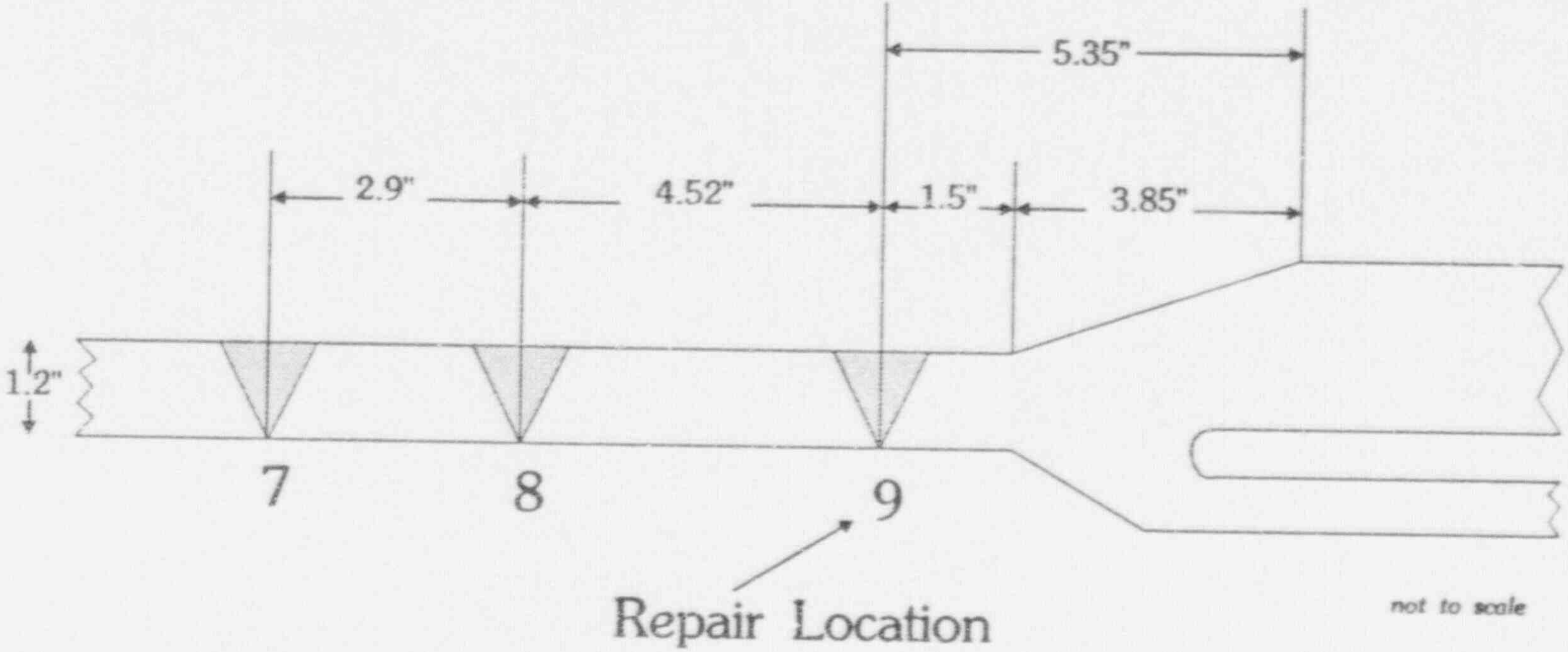
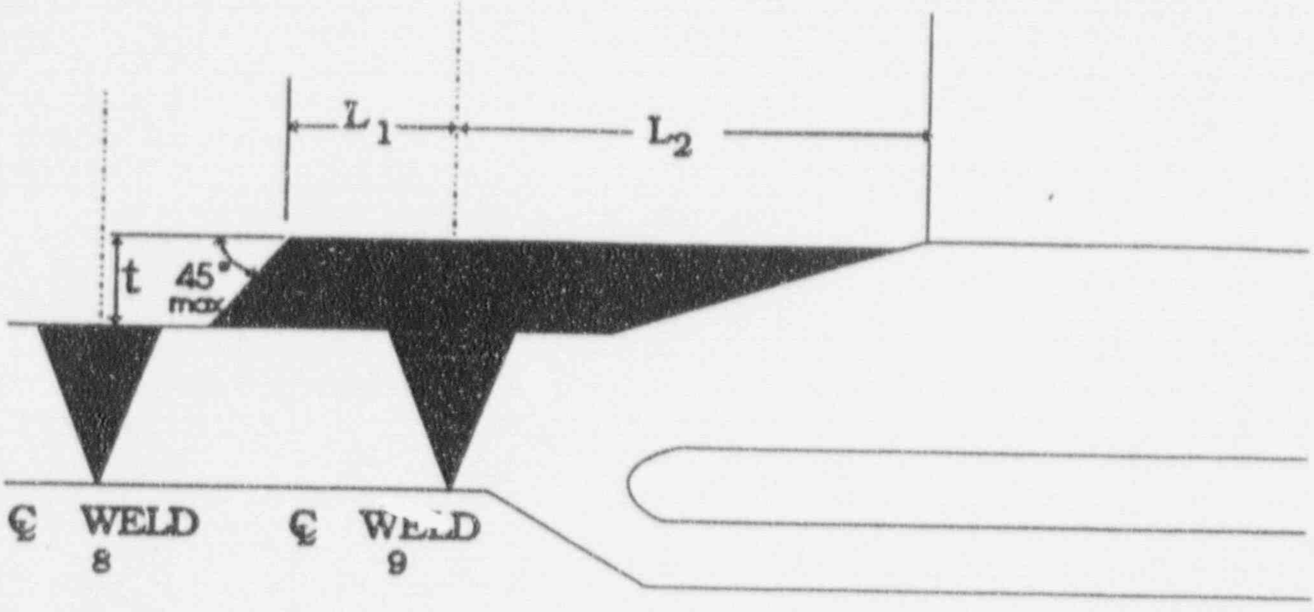


Figure 1. Geometry of Repair Location

Figure 2 Weld Overlay Repair Design



NOT TO SCALE

WELD NUMBER	FLAW CHARACTERIZATION	DESIGN DIMENSIONS			COMMENTS
		t	L_1	L_2	
2B21-1FW-12AA-9	3 Axial Flaws	.6"	2.5"	See Note 7	See Notes on Page 2

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Revision	Prepared by/ Date	Checked by/ Date	Approved by/ Date	COMMENTS

Job No: GPCO-19Q

File No: GPCO-19Q-301

Drawing No: GPCO-19Q-001

Plant/Unit Hatch Unit 2

STRUCTURAL INTEGRITY ASSOCIATES, INC.

Title: Weld Overlay Repair: Feedwater Safe End to Pup Piece Weld

Sheet 1 of 2

Figure 2 (continued)

NOTES

1. Prior to welding, a set of punchmarks is to be established approximately 1 inch beyond the anticipated ends of the repair, for use in measuring weld overlay shrinkage. A second set of punchmarks is to be applied approximately 3 inches upstream of the pup piece to feedwater pipe weld (weld #7), to be used in the event that the repair is extended at a later date. Measurements between all sets of punchmarks shall be performed prior to welding.

2. All punchmarks are to be made in accordance with GPCO procedures.

3. The base metal surface shall be examined prior to welding by the dye penetrant method. If relevant indications are noted, these must be repaired prior to continuing with overlay application. Design thickness is determined outboard of any completed repairs.

4. If a blow through occurs during welding, it must be repaired prior to continuing with overlay application. Design thickness is determined outboard of any complete repairs.

5. Delta ferrite determination of the first welded layer is not required, since this is not pertinent to ERNi-Cr-3 weld material.

6. Weld overlay application shall be by the automated GTAW process, using ERNi-Cr-3 weld wire.

7. On the downstream (vessel) side of the repair, the repair shall be blended smoothly into the safe-end taper.

8. Welding of all passes shall begin at the vessel (safe end) end of the repair, and passes shall progress outward (upstream) to minimize constraint stresses.

9. Indicated design thickness reflects thickness following surface finishing operations.

10. Prior to welding, the outside diameter of the component shall be measured at the centerline of Weld 9, and at locations near both ends of the planned repair. These measurements shall be repeated following repair, as a measurement of radial shrinkage.

Job No: GPCO-19Q	Plant/Unit Hatch Unit 2	STRUCTURAL INTEGRITY ASSOCIATES, INC.
File No: GPCO-19Q-301		
Drawing No: GPCO-19Q-001	Title: Weld Overlay Repair: Feedwater Safe End to Pup Piece Weld	Sheet 2 of 2

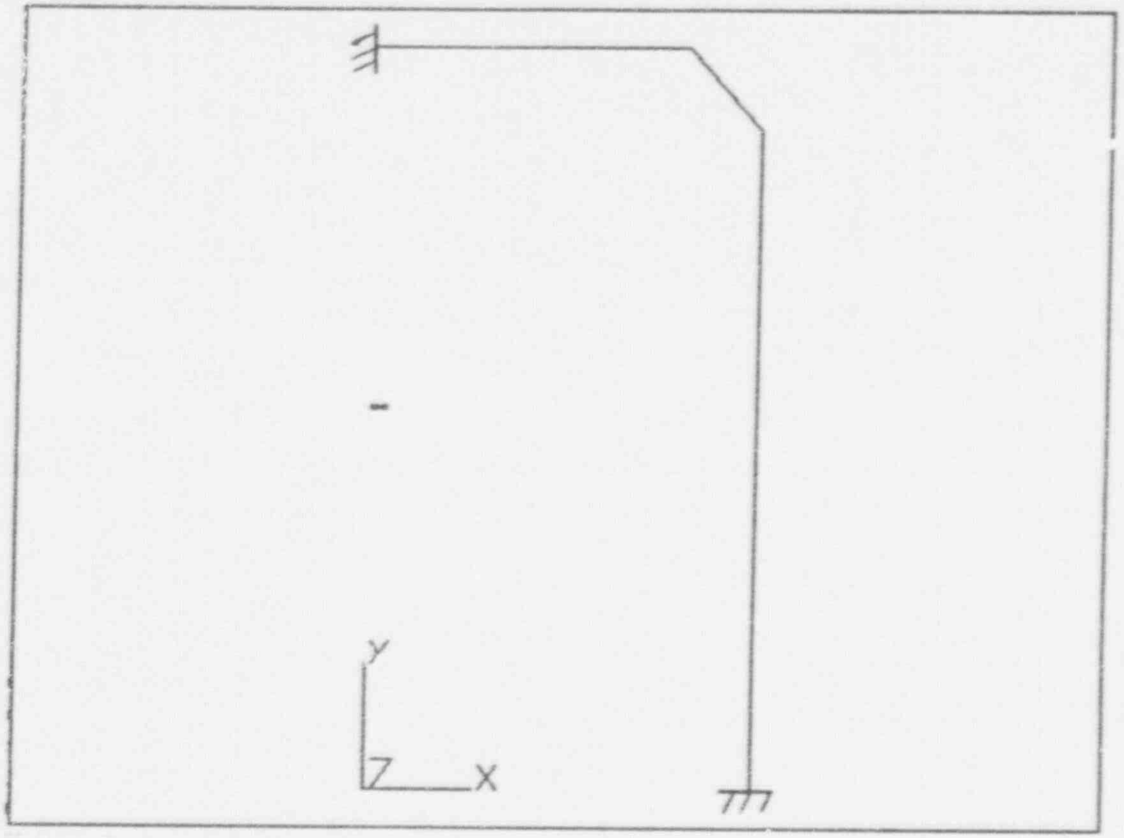

Figure 3. Finite Element Piping Model for Evaluation of Shrinkage Stresses