Report No. 0800024.407
Revision No.: 0
Project No.: 0800024
January 2009

Summary Report of the Design Analysis and Non-Destructive Examination Results for St. Lucie Unit 1 Hot Leg Nozzle Weld Overlay Repairs

Prepared for:

Welding Services Inc.
(Contract No. 47323)

Prepared by:

Structural Integrity Associates, Inc.
San Jose, CA

REVISION CONTROL SHEET

Title: Summary Report of the Design Analysis and Non-Destructive Examination Results for St. Lucie Unit 1 Hot Leg Nozzle Weld Overlay Repairs

SI Project Number: 0800024

Sections	Pages	Revision	Date	Comments
1.0	1-1	0	1/12/09	Initial Issue
2.0	2-1 – 2-9			
3.0	3-1 – 3-2			
4.0	4-1 – 4-5			
5.0	5-1 – 5-2			

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

Florida Power and Light (FPL) has applied full structural weld overlays (WOLs) on dissimilar metal butt welds (DMW) on the St. Lucie, Unit 1 Reactor Coolant System Hot Leg Surge Nozzle and two Shutdown Cooling Nozzles Alloy 82/182 welds as new pressure boundary welds, to mitigate any potential primary water stress corrosion cracking (PWSCC) in these welds in the future.

This report summarizes the design analysis and non-destructive examination (NDE) results of the WOLs on these hot leg nozzles. This summary report is in compliance with the 60 day reporting requirement of the submitted relief request (RR) and the Nuclear Regulatory Commission (NRC) Safety Evaluation Report (SER) for these WOLs.

Section 2.0 of this report discusses the design analyses that have been applied to demonstrate compliance with the FPL RR No. 2 and NRC SER dated November 3, 2008 (TAC No.-MD9256) to ensure that the structural integrity of the system is maintained by an alternate design.

Sections 3.0 and 4.0 discuss the non-destructive examinations (NDE) that had been performed during the implementation of the WOLs. This section addresses both the liquid penetrant examinations (PT) as well as the ultrasonic (UT) examinations.

Section 5.0 contains conclusions regarding the alternate method of repair to meet the structural integrity requirements of the subject nozzles and the examination requirements of the repair in accordance with the FPL RR No. 2 and the NRC SER dated November 3, 2008 (TAC No. MD9256).

2.0 DESIGN ANALYSIS SUMMARY

2.1 Background

The requirements for design of the weld overlay repairs are defined in the FPL RR. The analytical bases for the design of the repairs are in accordance with the requirements of ASME Code, Section XI, 2001 Edition with Addenda through 2003, IWB-3641.

Weld overlay repairs are considered to be acceptable long-term repairs for PWSCC-flawed weldments if they meet a conservative set of design assumptions which qualify them as "full structural" weld overlays. The principal design requirements that qualify a weld overlay as "full structural" are:

1. The design basis for the repair is a circumferentially oriented flaw that extends 360° around the component, and is through the original component wall. This conservative assumption eliminates concerns about PWSCC susceptibility of the original Alloy 82/182 dissimilar metal weld (DMW). In addition, potential concerns about the integrity of the original butt weld material are not applicable, since no credit is taken in the design process for the load carrying capability of this weld.

2. As required by ASME Code, Section XI, IWB-3641, a combination of internal pressure, deadweight, seismic, and other dynamic stresses is used in the design of weld overlay repairs.

2.2 Weld Overlay Structural Sizing Calculations

Design and sizing calculations for weld overlay thickness were performed using the methodology of the ASME Code, Section XI Appendix C. The following load combinations were used for the overlay design: Service Level A (Normal), Service Level B (Upset), Service Level C (Emergency), and Service Level D (Faulted), and the design is based on the more limiting results.

The weld overlays were installed using Alloy 52M filler metal, a material resistant to PWSCC. However, Alloy 52/52M has demonstrated sensitivity to certain impurities, such as sulfur, when deposited onto austenitic stainless steel base materials with high sulfur content. Therefore, a buffer (transitional) layer of ER308L austenitic stainless steel filler metal with low sulfur content was applied as a barrier across the austenitic stainless steel base material. The austenitic stainless steel buffer layer was not included in the calculated minimum required structural weld overlay thickness. However, the buffer layer thickness was included in the maximum WOL profile thickness design.

The weld overlay length has considered three requirements: (1) length required for structural reinforcement, (2) length required for access for preservice and inservice examinations of the overlaid weld, and (3) limitation on the area that can be overlaid on the carbon steel nozzle. Because of the short safe-end length on the overlaid nozzles, it is necessary to extend the overlay length over both the nozzle-to-safe-end dissimilar metal weld and the safe-end-to-elbow weld. In accordance with the RR, the weld overlay length required for structural reinforcement was established by evaluating the axial shear stress due to transfer of primary axial loads from the elbow into the overlay and back into the nozzle, on either side of the weld being overlaid. In addition, added length is typically necessary to allow for an effective UT exam.

Table 2-1 contains the calculated minimum required thicknesses and lengths for the Hot Leg Nozzle weld overlays. Figure 2-1 is a schematic of the Hot Leg Nozzles detailing the locations for the minimum weld overlay dimensions.

Table 2-1: Weld Overlay Structural Thickness and Length Requirements for the Hot Leg Nozzles

Nozzle	Weld	Location (1)	Design Minimum Thickness, in	Design Minimum Length(2), in
Hot Leg Shutdown Cooling Nozzle	Nozzle Side of DMW	1, A	0.503	0.974
	SE (3) Side of DMW	2	0.495	Not Applicable
	SE Side of SSW (4)	3	0.406	Not Applicable
	Elbow Side of SSW	4, B	0.406	1.0557
Hot Leg Surge Nozzle	Nozzle Side of DMW	1, A	0.587	1.083
	SE Side of DMW	2	0.579	Not Applicable
	SE Side of SSW	3	0.406	Not Applicable
	Elbow Side of SSW	4, B	0.406	1.106

1. See Figure 2-1 for locations.
2. Length shown is the minimum required for structural acceptance and does not include additional length necessary to meet inspectability requirements.
3. SE = Safe-end
4. SSW = Stainless Steel Weld

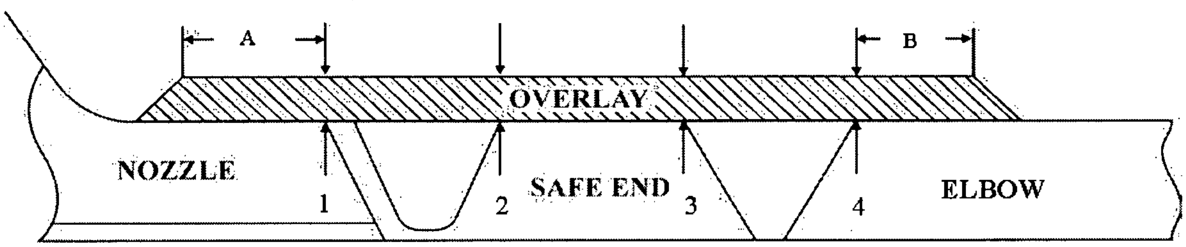

Figure 2-1: Hot Leg Nozzle Weld Overlay Geometry, Minimum Dimensions (Schematic Representation)

2.3 Residual Stress Analysis Results

In addition to providing structural reinforcement to the overlaid location to meet ASME Code safety margins, the weld overlay produces beneficial residual stresses that support the mitigation of PWSCC. The weld residual stresses for the Hot Leg Nozzle weld overlays were determined by detailed elastic-plastic finite element analyses. The residual stress calculations were based on the minimum design weld overlay profile dimensions.

Modeling of the welding progression in the overlays includes a simulated inside diameter (ID) repair at the DMW location with a depth of 50% of the original wall thickness for the full circumferential extent. This assumption is considered to conservatively bound any weld repairs that may have been performed during plant construction, from the standpoint of producing tensile residual stresses on the ID of the weld.

Figures 2-2 and 2-3 show the axial and hoop stress, respectively, for the Hot Leg Surge Nozzle (Hot Leg Shutdown Cooling Nozzle results are similar). As the figures indicate, the residual stress analysis demonstrates that the WOL results in beneficial ID compressive stresses within the DMW.

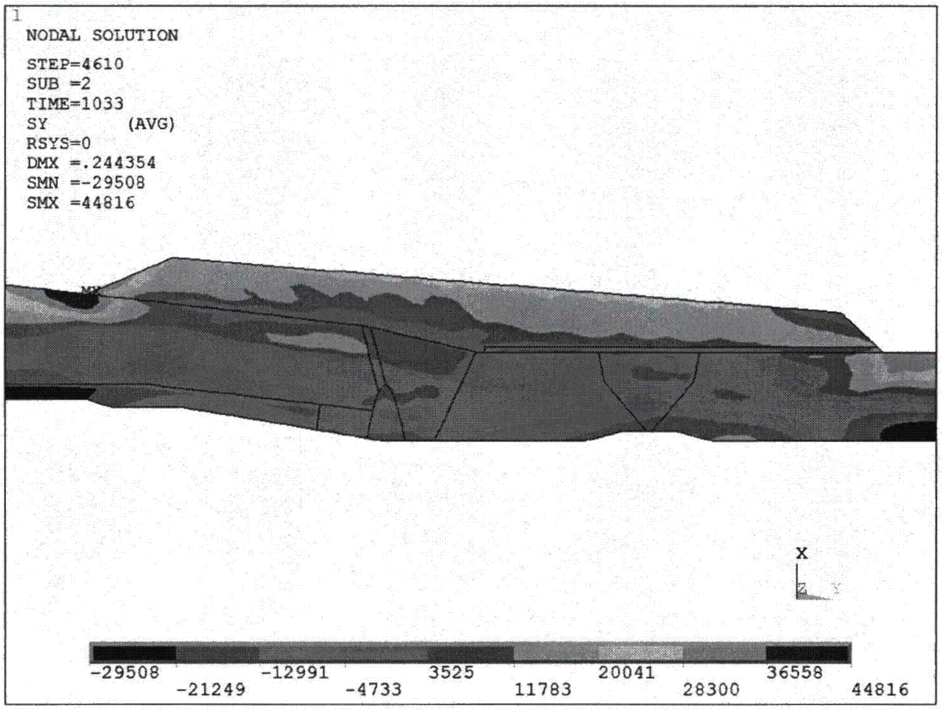

Figure 2-2: Hot Leg Surge Nozzle Post Weld Overlay Axial Stress at 604°F and 2235 psig

Note: The units of the color bar across the bottom of the figure are psi.

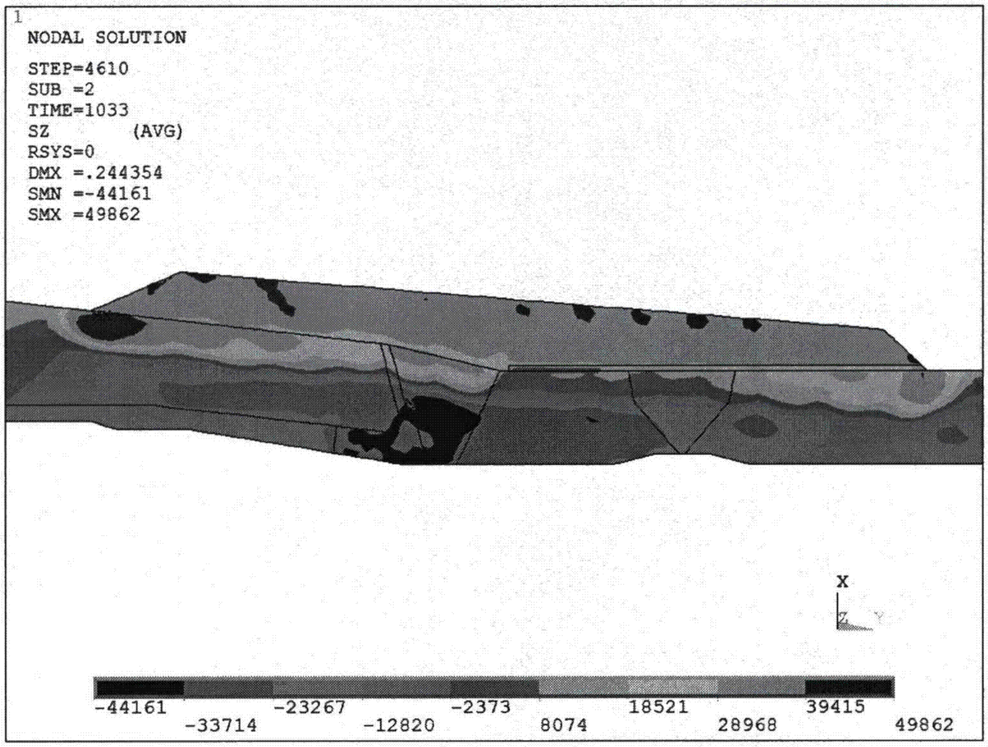

Figure 2-3: Hot Leg Surge Nozzle Post Weld Overlay Hoop Stress at 604°F and 2235 psig

Note: The units of the color bar across the bottom of the figure are psi.

2.4 Crack Growth Analyses

Flaw growth due to both fatigue (FCG) and PWSSC were considered for the DMW and SSW locations, as both locations are assumed to be 100% flawed leaving only the Alloy 52M overlay into which flaw growth may occur.

The crack growth results are shown in Table 2-2 for the combined FCG and PWSCC growth of postulated circumferential and axial flaws (100% of base metal) in the DMW and stainless steel weld (SSW) locations for the Hot Leg Surge Nozzle and Hot Leg Shutdown Cooling Nozzles. Note that PWSCC growth only applies to the DMWs.

At all of the weld locations, except the Hot Leg Surge Nozzle stainless steel weld (SSW) circumferential flaw, it takes greater than 40 years for an initial flaw of 100% of the original base metal thickness to reach the allowable depth without violating the calculated minimum overlay design thickness for both circumferential and axial flaws.

At the Hot Leg Surge Nozzle SSW location, a circumferential flaw, may only take 30 years to reach the minimum required WOL thickness as a result of crack growth. However, this period exceeds the plant licensed design life, including the present 20 year licensed extension period.

Table 2-2: Crack Growth Results

Flaw	Hot Leg Surge Nozzle	Hot Leg Shutdown Cooling Nozzle
Circumferential (DMW)	>40 years	>40 years
Axial (DMW)	> 40 years	>40 years
Circumferential (SSW)	30 years[1]	>40years
Axial (SSW)	> 40 years	>40 years

1. Exceeds balance of plant life, which extends through the approved license extension date of March, 2036.

2.5 ASME Code, Section III Stress Evaluation

This section presents a summary of the ASME Code, Section III, 2001 Edition with Addenda through 2003, Article NB-3000, Class 1 components stress evaluations performed for the nozzle WOLs.

Stress intensities for the weld overlaid Hot Leg Nozzles were determined from finite element analyses for the various specified load combinations. Linearized stresses were evaluated through several stress paths for these nozzles. The stress intensities along these paths were evaluated in accordance with ASME Code, Section III, Subarticle NB-3200 and compared to the applicable Code limits. A summary of the stress comparison for the most limiting locations is provided in Table 2-3 for the Hot Leg Surge Nozzle and Hot Leg Shutdown Cooling Nozzles. The resulting calculated stresses and the fatigue usage factors of these nozzle weld overlays are within the applicable ASME Code limits.

In conclusion, the WOL design for these hot leg nozzle welds satisfy the requirements of the ASME Code, and are qualified for the balance of plant life, which extends through the approved license extension date of March, 2036.

Table 2-3: Limiting Stress Results for Weld Overlaid Hot Leg Nozzles

Nozzle	Load Combination	Path and Type		Calculated Stress (ksi)	Allowable Stress (ksi)
Hot Leg Surge Nozzle	Level A/B	Path 4 (1)	Primary + Secondary (P + Q) (ksi) (3)	50.039	52.091
		Path 7 (1)	Simplified Elastic-Plastic Analysis (P + Q) (ksi) (2)	46.767	51.950
	Fatigue	Path 7 (1)	Cumulative Usage Factor	0.1034	1.0000
Hot Leg Shutdown Cooling Nozzle	Level A/B	Path 3 (1)	Primary + Secondary (P + Q) (ksi) (3)	30.424	49.908
	Fatigue	Path 7 (1)	Cumulative Usage Factor	0.00615	1.0000

1. Refers to locations in the WOL finite element model.
2. Elastic analysis exceeds the allowable value of $3S_m$; however, criteria for simplified elastic-plastic analysis are met.
3. Primary stress acceptance criteria are met via the sizing calculations discussed in Section 2.2.

2.6 Evaluation of As-Built Conditions

The RR-2 requires evaluation of the as-built weld overlays to determine the effects of any changes in applied loads, due to weld shrinkage from the entire overlay, on other items in the piping system. Calculations were performed based on the piping system design dimensions to confirm that the overlays would not affect critical piping components such as supports and restraints, and would not significantly affect the evaluated piping system stresses. Specifically, the predicted shrinkage effects on the piping system, based on design dimensions and conservative shrinkage assumptions, were evaluated and found to be acceptable. Actual measurements of the weld shrinkage were found to be less than the shrinkage values that had been used in the analysis of the piping and support system.

Also, the effect of the added weight of the overlays on the adjacent piping systems, based on maximum WOL design dimensions, was evaluated and found to be insignificant.

3.0 LIQUID PENETRANT EXAMINATION RESULTS

3.1 Liquid Penetrant Procedure

A liquid penetrant examination (PT) to detect any surface flaws that may exist was performed prior to the application of the WOL, as well as following the completion of the WOL. Additional PT exams were also performed during weld repairs of indications. Base metal PT indications were evaluated against a criteria of no indications greater than 1/16"and were found to be acceptable. The buffer layer and final weld overlay PT examinations were compared against the acceptance criteria of ASME Code, Section III, NB-5300, 2001 Edition with Addenda through 2003.

3.1.1 Liquid Penetrant Results

The following sections describe the results of the pre and post WOL Liquid Penetrant Examinations.

Table 3-1: Hot Leg Nozzle Weld Overlay PT Results

Weld Overlay PT Examinations			
Nozzle	PT of Base Metal	PT of Buffer Layer	Post WOL PT
"A" Shutdown Cooling	No Indications (See section 3.1.2 below)	Upon welding with Alloy 82, visual porosity was observed. Post excavation – No Indications. Final SS Buffer and Alloy 82 Seal Weld Surface - No Indications (See section 3.1.2 below.)	No Indications
"B" Shutdown Cooling	No Indications	No Indications	One rounded 3/32" indication - Acceptable
HL Surge	No Indications	No Indications	No Indications

3.1.2 Hot Leg Shutdown Cooling "A" Nozzle Repairs

An initial PT was completed of the base metal surface and no recordable indications were noted. A stainless steel buffer layer (ER308L) was deposited over the stainless steel safe-end and pipe elbow as a precaution to prevent hot cracking of the first layer of the Alloy 52M WOL. Following the ER308L buffer layer, an Alloy 82 bridge bead was applied to connect the stainless steel buffer layer to the DMW. During application of the initial Alloy 82 weld bead, visual porosity was observed. A repair of the areas of porosity by grinding and welding with Alloy 82 to seal the base material porosity was initiated. Initially, a 360 degree excavation was made to obtain a clean surface for continuing weld deposition. A PT examination was completed of the excavated surface and no recordable indications were noted.

Upon resumption of welding the excavation (with Alloy 82), a flaw was observed in the repair weld which was attributed to hot cracking possibly due to contaminants in the safe-end base material. A 360 degree excavation was completed again, to a depth ranging from 1/8"to 5/16" at an average depth of 3/16" and a width ranging from 1" to 1-1/4". A PT examination was completed of the excavated surface and no recordable indications were noted. The weld cavity was filled with Alloy 82 weld wire to the level of the adjacent buffer layer above the base material. A PT examination was completed of the entire stainless steel buffer layer and Alloy 82 seal weld surface and no recordable indications were noted. The full structural WOL with Alloy 52M weld wire was then applied. A final post WOL PT examination was completed and no recordable indications were noted.

4.0 ULTRASONIC EXAMINATION RESULTS

4.1 Ultrasonic Examination Procedure and Results Summary

SI-UT-126 Revision 3, Procedure for the Phased Array Ultrasonic Examination of Weld Overlaid Similar and Dissimilar Metal Welds, was used during the examinations. The SI-UT-126 procedure, and the examiners, are qualified through the EPRI Performance Demonstration Initiative (PDI) Program. Acceptance criteria for the examinations are provided in the FPL Relief Request, RR-2.

4.2 Hot Leg Surge Nozzle Weld Overlay Examination

Weld Identification: Nozzle-to-Safe End Weld: RC-6-509
Safe End-to-Pipe Elbow Weld: RC-108-FW-3
Weld Overlay: RC-108-FW-2002

Examination Date: November 10, 2008 Examination Time: 17:35 – 20:50

Examination Regions: 100% coverage of the preservice inspection (PSI) examination volume was obtained. The weld overlay material was applied over the carbon steel nozzle, alloy 82/182 weld, cast stainless steel safe end, stainless steel weld, and cast stainless steel elbow base materials. Ultrasonic examination of cast stainless steel base materials is currently not within the scope of ASME Section XI, Appendix VIII, Supplement 11. As a result, the Appendix VIII, Supplement 11, qualified inservice inspection (ISI) volume coverage was limited to a composite of 93.7% for the PSI weld plus base metal (WBM) volume for the nozzle to safe end weld (RC-6-509) and 90.4% for the PSI WBM volume for the safe-end to elbow weld (RC-108-FW-3). The cast safe end base material was interrogated with an ASME Section XI, Appendix III ultrasonic examination using the existing PDI qualified personnel and procedures as required by the FPL Fourth Ten-Year Interval Unit 1 Relief Request 2. The outer 25% of the safe end and attached elbow diameters (SA-351 CF8M cast stainless steel) were included in the intended examination volumes.

The examination angles were as follows:
Axial Examination Angles: 0° through 83° (in 1° Increments)
Circumferential Examination Angles: 0° through 70° (in 1° Increments)

Examination Summary: No suspected flaw indications were observed during the examinations.

The examination gain was adjusted to maintain the procedure-specified baseline noise level from 5% to 20% of full screen height. The lower range of examination angles detected responses from the inside surface of the component which were useful for monitoring search unit contact / coupling effectiveness during the examination.

4.3 Hot Leg Shutdown Cooling "A" Nozzle Weld Overlay Examination

Weld Identification: Nozzle-to-Safe End Weld: 10-509-B
Safe End-to-Pipe Elbow Weld: RC-162-FW-1
Weld Overlay: RC-162-FW-2000

Examination Date: November 11, 2008 Examination Time: 16:39 – 19:36

Examination Regions: 100% coverage of the PSI examination volume was obtained. The weld overlay material was applied over the carbon steel nozzle, alloy 82/182 weld, cast stainless steel safe-end, stainless steel weld, and 304 stainless steel elbow base materials. Ultrasonic examination of cast stainless steel base materials is currently not within the scope of ASME Section XI, Appendix VIII, Supplement 11. As a result, the Appendix VIII, Supplement 11, qualified ISI volume coverage was limited to a composite of 93.9% for the PSI WBM volume for the nozzle to safe-end weld (10-509-B) and 94.3% for the PSI WBM volume of the safe-end to pipe/elbow weld (RC-162-FW-1). The cast safe-end base material was interrogated with an ASME Section XI, Appendix III ultrasonic examination using the existing PDI qualified personnel and procedures as required by the FPL Fourth Ten-Year Interval Unit 1 Relief Request 2. The outer 25% of the safe end (SA-351 CF8M cast stainless steel) and attached elbow diameters were included in the intended examination volumes.

The examination angles were as follows:
Axial Examination Angles: 0° through 83° (in 1° Increments)
Circumferential Examination Angles: 0° through 70° (in 1° Increments)

Examination Summary: No suspected flaw indications were observed during the examinations of the WOL and the safe-end to elbow WBM. In an area that had undergone a base metal weld repair, at the safe-end side adjacent to the nozzle to safe-end DM weld, one laminar/lack of fusion subsurface indication (not within the overlay volume or adjacent overlay to weld repair fusion zone, that is below the thickness of the weld overlay) was observed. The flaw was characterized as approximately 1/4" wide for the full circumference with a 4" length being 1" wide (total area of the flaw is 14.5 sq. in.). The weld overlay is designed to account for a hypothetical 100% through wall defect assumed to be 360 degrees around the circumference of the original nozzle, in accordance with the requirements of ASME Code, Section XI IWB-3640. The indication position at the bottom of the last layer of the Alloy 82 seal weld used to seal base material porosity does not influence the functioning of the weld overlay and is acceptable as-is.

The examination gain was adjusted to maintain the procedure-specified baseline noise level from 5% to 20% of full screen height. The lower range of examination angles detected responses from the inside surface of the component which were useful for monitoring search unit contact / coupling effectiveness during the examination.

4.4 Hot Leg Shutdown Cooling "B" Nozzle Weld Overlay Examination

Weld Identification: Nozzle-to-Safe End Weld: 10-509-A

Safe End-to-Pipe Elbow Weld: RC-147-FW-1

Weld Overlay: RC-147-FW-2000

Examination Date: November 9, 2008 Examination Time: 11:37 – 13:10

Examination Regions: 100% coverage of the PSI examination volume was obtained.
The weld overlay material was applied over the carbon steel nozzle, alloy 82/182 weld, cast stainless steel safe-end, stainless steel weld, and 304 stainless steel elbow base materials. Ultrasonic examination of cast stainless steel base materials is currently not within the scope of ASME Section XI, Appendix VIII, and Supplement 11. As a result, the Appendix VIII, Supplement 11, qualified ISI volume coverage was limited to a composite of 93% for the PSI WBM volume for the nozzle to safe-end weld (10-509-A) and 93.4% for the PSI WBM volume for the safe-end to pipe weld (RC-147-FW-1). The cast safe end base material was interrogated with an ASME Section XI, Appendix III ultrasonic examination using the existing PDI qualified personnel and procedures as required by the FPL Fourth Ten-Year Interval Unit 1 Relief Request 2. The outer 25% of the safe end (SA-351 CF8M cast stainless steel) and attached elbow diameters were included in the intended examination volumes.

The examination angles were as follows:
Axial Examination Angles: 0° through 83° (in 1° Increments)
Circumferential Examination Angles: 0° through 70° (in 1° Increments)

Examination Summary: No suspected flaw indications were observed during the examinations.

The examination gain was adjusted to maintain the procedure-specified baseline noise level from 5% to 20% of full screen height. The lower range of examination angles detected responses from the inside surface of the component which were useful for monitoring search unit contact / coupling effectiveness during the examination.

5.0 SUMMARY AND CONCLUSIONS

The design of these weld overlays was performed in accordance with the requirements of the FPL Relief Request. The weld overlays are demonstrated to be long-term repairs and to provide long term mitigation of PWSCC in these welds, based on the following:

- In accordance with the Relief Request, structural design of the overlays was performed to meet the requirements of ASME Code, Section XI, IWB-3640 and Appendix C based on an assumed flaw 100% through wall and 360° around the original welds. The resulting full structural overlays thus restore the original safety margins of the original welds, with no credit taken for the underlying PWSCC-susceptible material.
- The weld metal used for the overlays is Alloy 52M, which has been shown to be resistant to PWSCC, thus providing a PWSCC resistant barrier.
- Application of the weld overlays was shown to not impact the conclusions of the existing Nozzle Stress Reports. Following application of the overlays, all ASME Code, Section III stress and fatigue criteria are met.
- Nozzle specific residual stress analyses were performed, after first simulating severe ID weld repairs in the nozzle-to-safe-end welds prior to applying the weld overlays. After application of the WOL, the stresses on the inside surface of the original DMW are compressive at normal operating temperature and pressure.
- Ultrasonic examinations of the completed overlays indicated there were no unacceptable flaws associated with the weld overlays.
- Liquid penetrant examinations were completed and no unacceptable indications were identified.
- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the nozzles based on the design basis cyclic loading. Both fatigue and PWSCC crack growth were considered, and the designs were found to be acceptable for the remaining licensed plant life, including the present 20 year license extension period.

- The impact of WOL shrinkage that may occur due to application of the weld overlays has been evaluated and the resulting stresses are well below allowables for the attached piping as well as supports and restraints. There is no significant impact on the piping loads and attached supports for the hot leg nozzle attached piping due to application of weld overlays to these nozzles. Actual measured shrinkage was less than the assumed values in the analysis.
- For the "A" SDC Nozzle, in an area that had undergone a base metal repair, at the safe-end side adjacent to the nozzle to safe-end DM weld, one laminar/lack of fusion subsurface indication (not within the overlay volume or adjacent overlay to weld repair fusion zone, that is below the thickness of the weld overlay) was observed. As the weld overlay is designed to account for a hypothetical 100% through wall defect, the position of the indication at the bottom of the last layer of the Alloy 82 seal weld used to seal base material porosity does not influence the functioning of the weld overlay and is acceptable as-is.

Based on the above, the St. Lucie, Unit 1 Hot Leg Surge Nozzle and Hot Leg Shutdown Cooling Nozzle dissimilar metal welds have received long term mitigation against PWSCC and are qualified for the balance of plant life, which extends through the approved license extension date of March, 2036.