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May 3, 2007

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Subject: Duke Power Company LLC d/b/a Duke Energy Carolinas, LLC (Duke)
McGuire Nuclear Station, Unit 1
Docket Numbers 50-369
Inspection and Mitigation of Alloy 82/182 Pressurizer Butt Welds

By letter dated March 22, 2007, the NRC issued Confirmatory Action Letter (CAL) confirming commitments made by Duke by letter dated February 27, 2007 regarding Alloy 82/182 butt welds in the pressurizer at McGuire Nuclear Station, Unit 1. As required by this CAL, Duke hereby notifies the NRC of the completion of these commitments.

1/ Duke completed this mitigation during 1EOC18 refueling outage.

2/ Duke submitted the UT results to the NRC by letter dated April 19, 2007.

3/ The attachment to this letter provides a summary of the results of the stress analyses demonstrating that the preemptive full structural weld overlay will not hinder the components from performing their design function, as committed by Duke's Relief Request 07-GO-001 dated January 24, 2007.

If you have any questions or require additional information, please contact P. T. Vu at (704) 875-4302.

Very truly yours,

Gary R. Peterson

Attachment

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xc:

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Attachment

Summary of Design and Analyses of Preemptive Weld Overlays for Pressurizer Nozzle Locations Containing Alloy 600 Materials

1.0 Introduction

Duke Energy has applied full structural weld overlays (WOLs) on dissimilar metal welds (DMWs) of four 6" pressurizer safety/relief nozzles, one 4" pressurizer spray line nozzle, and one 14" pressurizer surge line nozzle at the McGuire Nuclear Station, Unit 1. The purpose of these overlays is to eliminate dependence on the primary water stress corrosion cracking (PWSCC) susceptible Alloy 82/182 welds as pressure boundary welds and to mitigate any potential future PWSCC in these welds. The overlays were installed using a PWSCC resistant weld filler material, Alloy 52M [1].

The requirements for design of weld overlay repairs are defined in ASME Code Case N-504-2 [2], supplemented for this application by the Relief Request [3]. Weld overlay repairs are considered to be acceptable long-term repairs for PWSCC susceptible weldments if they meet a conservative set of design assumptions which qualify them as "full structural" weld overlays. The design basis flaw assumption for full structural weld overlays is a circumferentially oriented flaw that extends 360° around the component, completely through the original component wall. A combination of internal pressure, deadweight and seismic stresses is applied to the overlaid nozzles containing this assumed design basis flaw, and they must meet the requirements of ASME Code, Section XI, IWB 3641 [4].

ASME Section III stress and fatigue usage evaluations are also performed that supplement existing piping, safe end, and nozzle stress reports, to demonstrate that the overlaid components continue to meet ASME Code, Section III. The original construction Code for the pressurizer was ASME Section III, 1971 Edition through Summer and Winter 1971 Addenda. However, as allowed by ASME Section XI, Code Editions and Addenda later than the original construction Code may be used. ASME Section III, 2001 Edition with Addenda through 2003 [5] was used for these analyses.

In addition to providing structural reinforcement to the PWSCC susceptible locations with a resistant material, weld overlays have also been shown to produce beneficial residual stresses that mitigate PWSCC in the underlying DMWs. The weld overlay approach has been used to repair stress corrosion cracking in U.S. nuclear plants on hundreds of welds, and there have been no reports of subsequent crack extension after application of weld overlays. Thus, the compressive stresses caused by the weld overlay have been effective in mitigating new crack initiation and/or growth of existing cracks. In addition, the weld residual stresses from the overlays act as compressive mean stresses in fatigue crack growth assessments.

Finally, evaluations are performed, based on as-built measurements taken after the overlays are applied, to demonstrate that the overlays meet their design basis requirements, and that they will not have an adverse effect on the balance of the piping systems. These include comparison of overlay dimensions to design dimensions, evaluations of shrinkage stresses and added weight effects on the piping systems.

2.0 Analysis Summary and Results

2.1 Weld Overlay Structural Sizing Calculations

Detailed sizing calculations for weld overlay thickness were performed using the "Codes and Standards" module of the **pc-CRACK** computer program [6], which incorporates ASME Code, Section XI, IWB-3640 evaluation methodology. Loads and stress combinations were provided by Duke Energy. Both normal operating/upset (Level A/B) and emergency/faulted (Level C/D) load combinations were considered in this evaluation, and the design was based on the more limiting results. The resulting minimum required overlay thicknesses are summarized in Table 2-1. Because of weld metal dilution concerns over the low alloy steel nozzle, a dilution weld layer is specified, in addition to the thickness required for structural reinforcement, to allow for the possibility that the minimum required chromium content for PWSCC resistance (24%) may not be achieved in the first layer.

The weld overlay length must consider: (1) length required for structural reinforcement, (2) length required for access for preservice and inservice examinations of the overlaid weld, and (3) residual stress improvement. In accordance with ASME Code Case N-504-2, the minimum weld overlay length required for structural reinforcement was established by evaluating the axial-radial shear stress due to transfer of primary axial loads from the pipe into the overlay and back into the nozzle, on either side of the weld(s) being overlaid. Axial weld overlay lengths were established such that this stress is less than the ASME Section III limit for pure shear stress. The resulting minimum length requirements are summarized in Table 2-1.

The overlay length and profile must also be such that the required post-WOL examination volume can be inspected using Performance Demonstration Initiative (PDI) qualified nondestructive examination (NDE) techniques. This requirement can cause required overlay lengths to be longer than the minimums for structural reinforcement. A typical weld overlay design for the McGuire Unit 1 pressurizer nozzles is illustrated in Figure 2-1. Because of the relatively short lengths of the original safe-ends, it was necessary to extend the overlay over both the DMW and the adjacent stainless steel (SS) welds, to ensure sufficient overlay length for inspectability and residual stress improvement. The designs were reviewed by qualified NDE personnel to ensure that they meet inspectability requirements for both welds, and the overlays were designed to satisfy full structural requirements for both the DMWs and the SS welds.

Table 2-1: Weld Overlay Structural Thickness and Length Requirements

		Safety/Relief Nozzle	**Spray Nozzle**	**Surge Nozzle**
Minimum* Thickness (in.)	Nozzle Side	0.397	0.292	0.427
	Safe End Side	0.365	0.242	0.469
Minimum** Length (in.)	Nozzle Side	0.932	0.590	1.175
	Safe End Side	1.503	0.917	1.683

* - Weld dilution layer (0.08") must be added

** - Additional length requirements apply for inspectability

2.2 Section III Stress Analyses

Stress intensities for the weld overlaid Safety/Relief, Spray and Surge nozzles were determined from finite element analyses for the various specified load combinations and transients using the ANSYS software package [8]. Linearized stresses were evaluated at a total of nine stress locations - three paths as shown in Figure 2-2, each evaluated at the intrados, extrados and cheek locations for 3-dimensional models. (3-dimensional models were used for the safety/relief and spray nozzles because of the adjacent elbows. The surge nozzle was deemed to be adequately modeled by a 2-dimensional, axisymmetric model.) The stress intensities at these locations were evaluated in accordance with ASME Code, Section III, Sub-articles NB-3200 and NB-3600 [5], and compared to applicable Code limits. A summary of the stress and fatigue usage comparisons for the most limiting locations is provided in Table 2-2. The stresses and fatigue usage in the weld overlaid nozzles are within the applicable Code limits. Figure 2-2 illustrates a typical stress model and stress paths evaluated. In general, the limiting location for the Section III stress analyses was found to be the section of the original pipe at the end of the overlay (Path 1 in Figure 2-2).

Table 2-2: Limiting Stress Results for Weld Overlaid Nozzles

Nozzle	Load Combination	Type	Calculated	Allowable
Safety/ Relief	Level A/B	Eqn.10: Primary + Secondary (P +Q) (ksi)*	67.58**	47.88
		Eqn.12/13: Simplified Elastic-Plastic Analysis (P +Q) (ksi)	42.25**	47.88
	Fatigue	Cumulative Usage Factor	0.051	1.000
Spray	Level A/B	Eqn.10: Primary + Secondary (P +Q) (ksi)*	149.09**	48.53
		Eqn.12/13: Simplified Elastic-Plastic Analysis (P +Q) (ksi)	45.72**	48.53
	Fatigue	Cumulative Usage Factor	0.986	1.000
Surge	Level A/B	Eqn.10: Primary + Secondary (P +Q) (ksi)*	48.28	48.34
	Fatigue	Cumulative Usage Factor	0.994	1.000

* - Primary stress acceptance criteria are met via the sizing calculations discussed in Section 2.1.

** - Elastic analysis exceeds the allowable value of $3S_m$, however, criteria for simplified elastic-plastic analysis and thermal ratchet are met.

2.3 Residual Stress and Section XI Crack Growth Analyses

Weld residual stresses for the McGuire Unit 1 pressurizer nozzle weld overlays were determined by detailed elastic-plastic finite element analyses. The analysis approach has been previously documented to provide predictions of weld residual stresses that are in reasonable agreement with experimental measurements [7]. Two-dimensional, axisymmetric finite element models were developed for each of the nozzles. Modeling of weld nuggets used in the analysis to lump the combined effects of several weld beads is illustrated in Figure 2-3. The models simulated an inside surface (ID) repair at the DMW location with a depth of approximately 50% of the original wall thickness. 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. The models also simulated the SS pipe to safe-end weld.

The residual stress analysis approach consists of a thermal pass to determine the temperature response of the model to each individual lumped weld nugget as it is added in sequence, followed by an elastic-plastic stress pass to calculate the residual stress due to the temperature cycling from the application of each nugget. Since residual stress is a function of welding history, the stress passes for each nugget are performed sequentially, over the residual stress fields induced from all previously applied weld nuggets. The resulting residual stresses were evaluated on the inside surface of the original welds and safe-end components, as well as on several paths through the DMW and SS welds (Figures 2-4 and 2-5).

The residual stress calculations were then utilized, along with stresses due to applied loadings and thermal transients, to demonstrate that assumed cracks that could be missed by inspections will not exceed the overlay design basis during the ASME Section XI inservice inspection interval due to fatigue or PWSCC. In the fatigue crack growth analyses, 25% of the original 40 year design quantity of each applied transient was assumed to be applied in the 10 year interval. Initial flaw sizes for the crack growth assessments were assumed consistent with the post-overlay UT inspections performed. Fatigue crack growth results are summarized in Table 2-3 for initial flaw sizes of 25%, 50% and 75% of the original pipe wall thickness. In all cases, the maximum crack depth at the end of the ten-year inspection interval is less than the weld overlay design basis flaw (the original wall thickness plus dilution layer for the DMW or just the original wall thickness for the SS welds, since no dilution layer was specified). Since the exam volume for the PDI qualified post-overlay UT inspections includes the weld overlay plus the outer 25% of the original wall thickness, a 75% through wall crack is the largest flaw that could escape detection by this examination.

For crack growth due to PWSCC, the total sustained stress intensity factor during normal plant operation was determined as a function of assumed crack depth, considering internal pressure stresses, residual stresses, steady state thermal stresses, and stresses due to sustained piping loads (including deadweight). Zero PWSCC growth is predicted for assumed crack depths at which the combined stress intensity factor due to sustained steady state operating conditions is less than zero. For all nozzles, considering the worst case paths in the DMWs, the sustained stress intensity factors remained negative for crack depths up to and beyond 75% of the original wall thickness. Therefore, no crack propagation due to PWSCC is predicted in the overlaid nozzles.

Table 2-3: Limiting Fatigue Crack Growth Results for Weld Overlaid Nozzles

DMW	**Safety/Relief Nozzles**		**Spray Nozzle**		**Surge Nozzle**	
Initial Flaw Size (% of Orig. Thick.)	Flaw Size (in.)		Flaw Size (in.)		Flaw Size (in.)	
	Initial	Final*	Initial	Final*	Initial	Final*
Circumferential Flaws						
25%	0.2975	0.2986	0.2188	0.2196	0.377	0.487
50%	0.5950	0.5961	0.4375	0.4375	0.754	0.873
75%	0.8925	0.8946	0.6563	0.6563	1.131	1.183
Axial Flaws						
25%	0.2975	0.2975	0.2188	0.2191	0.377	0.378
50%	0.5950	0.5950	0.4375	0.4376	0.754	0.755
75%	0.8925	0.8927	0.6563	0.6574	1.131	1.132
Original thickness + dilution layer*		1.27		0.955		1.588

SS Welds	**Safety/Relief Nozzles**		**Spray Nozzle**		**Surge Nozzle**	
Initial Flaw Size (% of Orig. Thick.)	Flaw Size (in.)		Flaw Size (in.)		Flaw Size (in.)	
	Initial	Final*	Initial	Final*	Initial	Final*
Circumferential Flaws						
25%	0.1950	0.2038	0.1475	0.2230	0.360	0.434
50%	0.3900	0.4078	0.2951	0.3770	0.721	0.843
75%	0.5850	0.6105	0.4426	0.5139	1.081	1.404
Axial Flaws						
25%	0.1950	0.1992	0.1475	0.2140	0.360	0.452
50%	0.3900	0.4375	0.2951	0.4783	0.721	0.883
75%	0.5850	0.6528	0.4426	0.5728	1.081	1.224
Original thickness*		0.78		0.590		1.441

* - Allowable crack depth at end of ten year inspection interval.

2.4 As-Built Measurements and Reconciliations

The measured as-built thicknesses and lengths of the McGuire Unit 1 overlays, after final machining, were determined in order to demonstrate the adequacy of the installed repairs. For each critical dimension listed in Table 2-1, the as-built measurements exceeded the minimum required structural design dimension. Thus, the as-built configurations of the overlays satisfied all established design requirements.

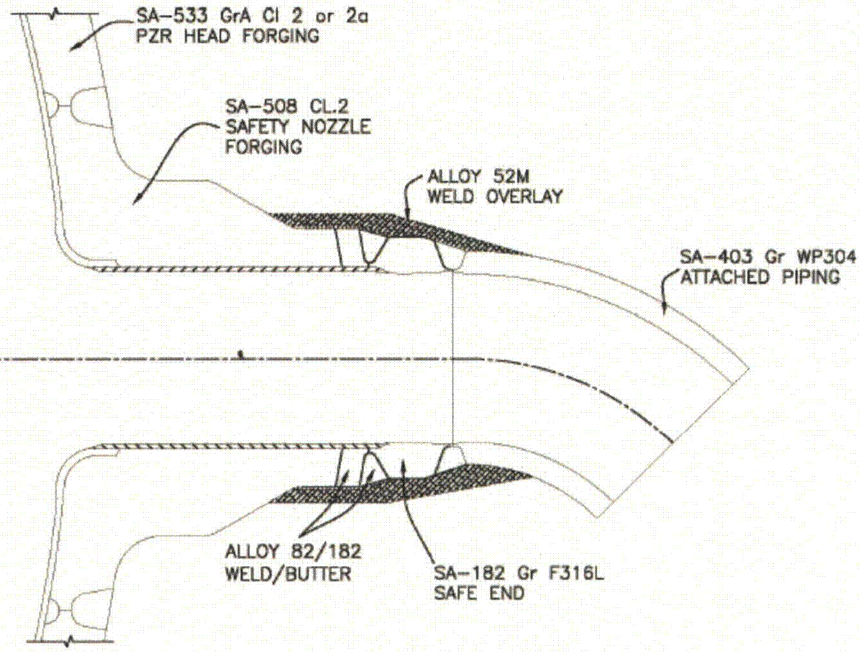


Figure 2-1: Illustration of Typical Weld Overlay Design for McGuire Unit 1 Pressurizer Nozzles

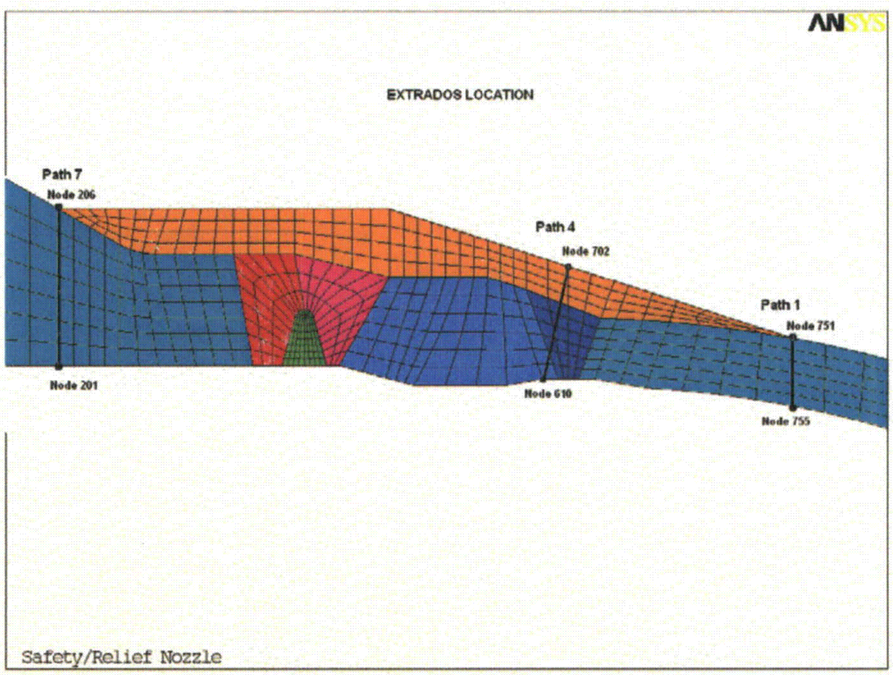


Figure 2-2: Typical Finite Element Model for Section III Stress Evaluation showing Stress Paths

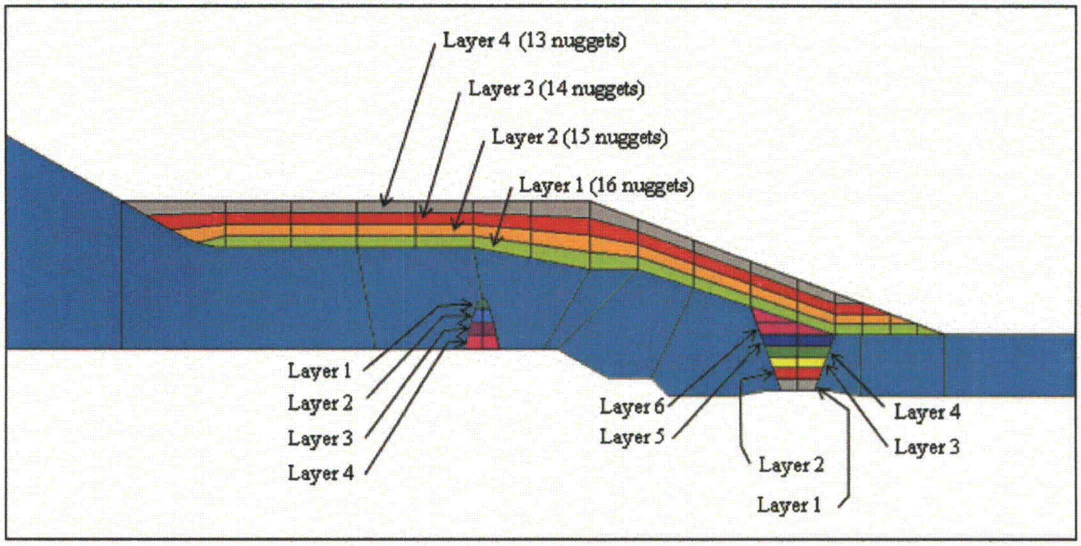


Figure 2-3: Typical Finite Element Model for Residual Stress Analysis showing Nuggets used for Welding Simulations

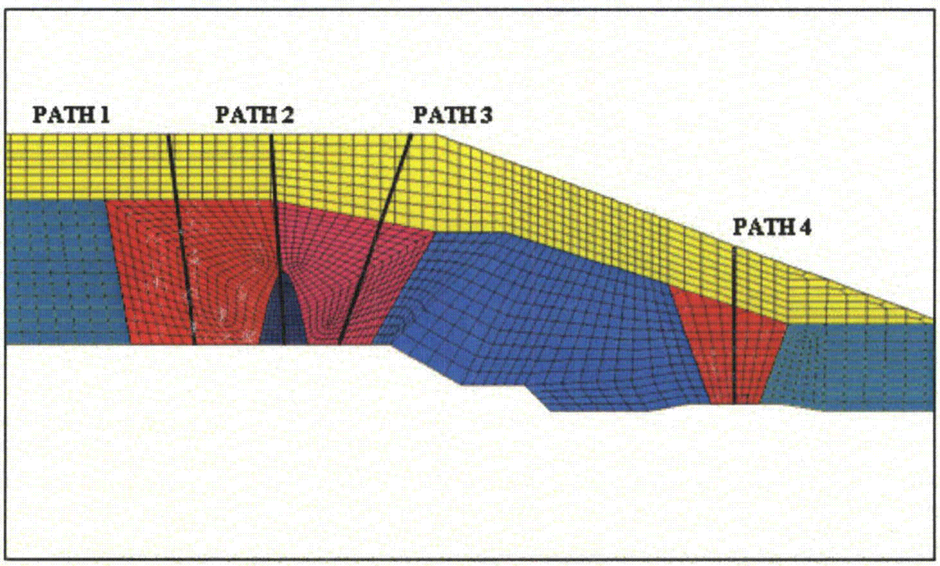
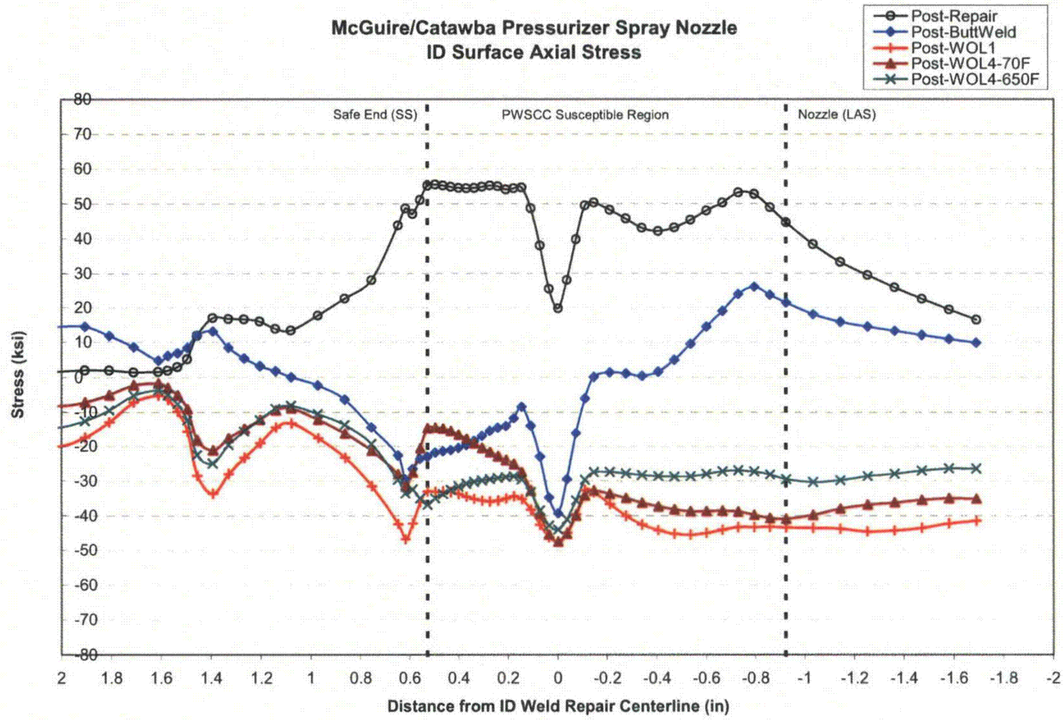


Figure 2-4: Finite Element Model for Residual Stress Analysis showing Paths used in Crack Growth Evaluations



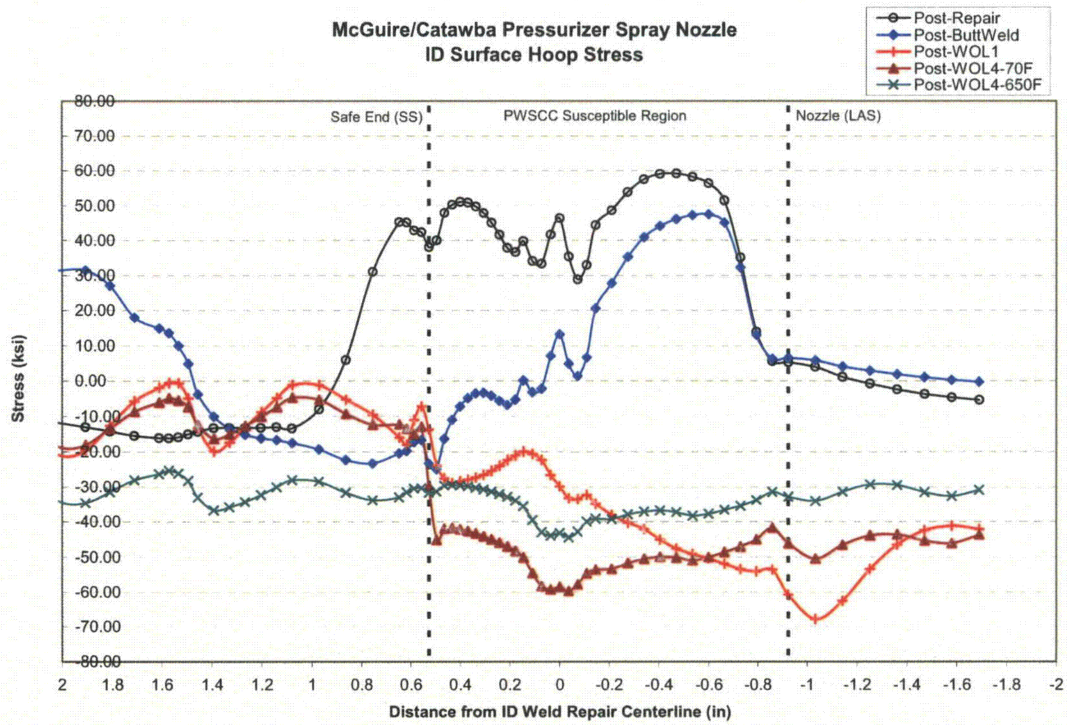


Figure 2-5: Typical Residual Stress Results along Inside Surface of Original Butt Welds and Safe-End

3.0 Conclusions

The design of the McGuire Unit 1 weld overlays was performed taking guidance from the requirements of ASME Code Case N-504-2 [2], amended in accordance with the Relief Request [3]. The weld overlays are demonstrated to be long-term mitigation of PWSCC in these welds based on the following:

- In accordance with ASME Code Case N-504-2, structural design of the overlays was performed to meet the requirements of ASME Section XI, IWB-3640 based on an assumed flaw 100% through and 360° around the original welds. The resulting full structural overlays thus restore the original safety margins of the nozzles, with no credit taken for the underlying, PWSCC-susceptible material.
- The weld metal used for the overlay is Alloy 52M, which has been shown to be resistant to PWSCC [1], thus providing a PWSCC resistant barrier. Therefore, no PWSCC crack growth is expected into the overlay.
- Because of the short safe-end lengths in the original nozzle designs, the overlays were extended to cover the adjacent stainless steel pipe to safe-end welds. Although not susceptible to PWSCC, covering them with the overlays was necessary to ensure inspectability and effective residual stress improvement of the DMWs. The overlays were also designed as full structural over the stainless steel welds, thereby providing additional structural margin.
- No credit was taken in the overlay designs for the first overlay layer, which could have been diluted by the base metal during the welding process.
- Application of the weld overlays was shown to not impact the conclusions of the existing nozzle Stress Reports. Following application of the overlay, 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. The post weld overlay residual stresses were shown to result in beneficial compressive stresses on the inside surface of the components, and well into the thickness of the original DMWs, assuring that future PWSCC initiation or crack growth into the overlay is highly unlikely.
- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the nozzles, assuming that cracks exist that are equal to or greater than the thresholds of the NDE techniques used on the nozzles. Both fatigue and PWSCC crack growth were considered, and found to be acceptable.
- Axial shrinkage was measured following the overlay applications and was found to be small or was accommodated by minor piping modifications. Therefore shrinkage induced stresses at other locations in the piping systems arising from the pressurizer nozzle weld overlays are not expected to have an adverse effect on the systems.
- All hanger set points and pipe whip restraint clearances were checked after the overlay repair, and were found to be within the design ranges.
- The total added weight on the piping systems due to any individual overlay is insignificant compared to the weight of the piping systems and therefore does not adversely impact the piping system stresses nor their dynamic characteristics.

- The as-built dimensions of the overlays exceeded the minimum design dimensions, thus demonstrating that the as-applied overlays satisfied the design requirements.

Based on the above observations and the fact that similar nozzle-to-safe end weld overlays have been applied to other plants since 1986 with no subsequent problems identified, it is concluded that the McGuire Nuclear Station Unit 1 pressurizer surge, safety/relief and spray nozzle dissimilar metal welds have received long term mitigation against PWSCC. Detailed calculations supporting the above conclusions are documented in the design report [9].

4.0 References

1. "Materials Reliability Program (MRP): Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52, and 152 in Pressurized Water Reactors (MRP-111)," EPRI, Palo Alto, CA: 2004. 1009801
2. ASME Code, Code Case N-504-2, "Alternative Rules for Repair of Classes 1, 2, and 3 Austenitic Stainless Steel Piping, Section XI, Division 1."
3. Request No. 07-GO-001, Duke Energy Corporation, McGuire Unit 1 and Catawba Nuclear Station Unit 2, Request for Alternative 07-GO-001.
4. ASME Boiler and Pressure Vessel Code, Section XI, 1998 Edition (with Addenda up to 2000).
5. ASME Boiler and Pressure Vessel Code, Section III, 2001 Edition through 2003 Addenda.
6. **pc-CRACK** for Windows, Version 3.1-98348, Structural Integrity Associates, 1998.
7. Materials Reliability Program (MRP-169), "Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs," September 2005.
8. ANSYS/Mechanical, Release 8.1 (w/Service Pack 1), ANSYS Inc., June 2004.
9. Report SIR-07-115, Revision 0, "Design Report for the Weld Overlay Repair of Pressurizer Locations Containing Alloy 600 Materials McGuire Nuclear Station, Unit 1", DUKE-42Q-408, May 2007.